POLITECHNIKA ŚLĄSKA BIBLIOTEKA GŁÓWNA Gliwice

To be Filled in by Head Office:

Class..... *Date of Election*..... *Branch allocated to*.....

INSTITUTE OF BRITISH FOUNDRYMEN.

Established 1904. *Incorporated by Royal Charter*, 1921.

Registered Office ..... 49, Wellington Street, Strand, London, W.C.2.

Secretary:
T. MAKEMSON.

General Office:
SAINT JOHN STREET CHAMBERS,
DEANSGATE, MANCHESTER, 3.

PROPOSAL AS *ORDINARY MEMBER, *ASSOCIATE MEMBER, OR *ASSOCIATE.

* Please cross out the words not required.

Name in full .....

Designation or Occupation.....

Qualification .....

Business Address .....

Private Address.....

being desirous of admission into the Institute of British Foundrymen, we, the undersigned, Proposer and Seconder, propose and recommend him as a proper person to belong to the Institute.

Witness our hands, this.....day of..... .....19.....

Two Members' or Associate Members' Signatures are required .....

Proposed from *personal knowledge* or by recommendation } by.....

Seconded from *personal knowledge* or by recommendation } by.....

I, the undersigned, do hereby apply to be admitted as an *Ordinary Member, *Associate Member, (or) an *Associate of the Institute of British Foundrymen, and I undertake, if admitted, to pay the Fees in connection with my membership, and also to abide and be bound by the Rules and Regulations of the Institute for the time being in force. Provided that if I signify in writing to the Secretary that I am desirous of withdrawing my name therefrom, I shall (after paying all arrears which may be due by me at that period) be free from this obligation.

Signature of Candidate.....

Nationality by { (*a*) *birth*..... (*b*) *parentage*.....

Passed by Branch Council..... *Date*.....

Branch President .....

Branch Secretary ..... *Subscription paid* .....

NOTE.—It is desirable to remit the first subscription with the Proposal Form to save correspondence and expense, and to facilitate the work of the Council. In the event of non-election the amount will be refunded in full.

SUBSCRIPTION: Members, £2 2s. 0d. Associate Members, £1 1s. 0d. per annum. Associates, 10s. 6d. per annum.

This Form may be torn out and used as a Proposal Form.

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Class..... *Date of Election*..... *Branch allocated to*.....

INSTITUTE OF BRITISH FOUNDRYMEN.

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T. MAKEMSON.

General Office:
SAINT JOHN STREET CHAMBERS,
DEANSGATE, MANCHESTER, 3.

PROPOSAL AS A SUBSCRIBING FIRM.

Name in full .....

Designation or Occupation .....

Qualification .....

Business Address .....

Representative .....

being desirous of admission into the Institute of British Foundrymen, we, the undersigned, Proposer and Seconder, propose and recommend them as proper persons to belong to the Institute.

Witness our hands, this..... day of..... 19.....

Two Members' or Associate Members' Signatures are required .....

Proposed from *personal knowledge* or by recommendation } by .....

Seconded from *personal knowledge* or by recommendation } by .....

I (or we), the undersigned, do hereby apply to be admitted as a Subscribing Firm of the Institute of British Foundrymen, and undertake, if admitted, to pay the fees in connection with my (or our) membership and also to abide and be bound by the Rules and Regulations of the Institute for the time being in force. Provided, that if I (or we) signify in writing to the Secretary that I am (or we are) desirous of withdrawing therefrom, I (or we) shall be free from this obligation.

Signature of Firm.....

Passed by Branch Council..... *Date*.....

Branch President .....

Branch Secretary ..... *Subscription paid* .....

Extract from Bye-Laws of the Institute of British Foundrymen.

Any Firm engaged in the Foundry or Allied Industries shall be eligible for enrolment as a Subscribing Firm at an Annual Fee of £5 5s., and in respect of such enrolment shall be entitled to receive the printed literature and volume of "Proceedings" of the Institute, and to representation at any of the meetings of the Institute.

Each Subscribing Firm may nominate a representative of the firm for recommendation to the Council for election as an ordinary member of the Institute.

POLITECHNIKA ŚLĄSKA BIBLIOTEKA GŁÓWNA

POLITECHNIKA ŚLĄSKA
BIBLIOTEKA
GŁÓWNA
w Gliwicach

Mr. W. B. Lake, J.P.
President, 1939-40.

Mr. W. B. Lake, who is Chairman and Governing Director of Lake & Elliot, Ltd., of Braintree, Essex, was educated at Witham and Greifswald, Germany.

He served his apprenticeship as a pattern maker at Barnard & Lake's foundry at Rayne.

In 1896 he started the business which later became Lake & Elliot, Ltd. This company made the first mild steel castings by the crucible process in Great Britain, and in 1910 installed the first electric furnace for their production.

In 1914 Mr. Lake established the National Steel Foundry (1914) Ltd., of Leven, Fife, and was Managing Director of this company and Lake & Elliot, Ltd., for the duration of the last war.

He joined the Institute in 1922 and was President of the London Branch in the years 1927 to 1929, and Treasurer of the Institute from 1930 to 1937.

PROCEEDINGS
OF THE
INSTITUTE OF BRITISH FOUNDRYMEN

BIBLIOTEKA POLITECHNIKI ŚLĄSKIEJ

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VOLUME XXXII. 1938-1939

Containing the Report of the International Foundry Congress and Thirty-Sixth Annual Conference of the Institute, held in London, June 12th to June 17th, 1939; also Papers and Discussions presented at Branch Meetings held during the Session 1938-1939.

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POLITECHNIKA ŚLĄSKA
BIBLIOTEKA GŁÓWNA
w Gliwicach
P. 151/32

The Institute of British Foundrymen

Founded 1904. *Incorporated by Royal Charter*, 1921.

Officers, 1939-40

PRESIDENT.

W. B. Lake, J.P., Albion Works, Braintree, Essex.

VICE-PRESIDENTS:

Major R. Miles, M.Eng., Teesdale Ironworks, Thornaby-on-Tees.
D. H. Wood, 65, Middleton Hall Road, King's Norton, Birmingham.

PAST PRESIDENTS:

(*Surviving Past-Presidents are ex-officio members of the Council.*)

R. Buchanan. (Deceased, 1924.) 1904–1905.
H. Pilkington. (Deceased.) 1906–1907.
F. J. Cook, M.I.Mech.E., 31, Poplar Avenue, Edgbaston, Birmingham, 17. 1908–1909.
P. Longmuir, M.B.E., D.Met., 2, Queen's Road, Sheffield. 1910–1911.
C. Jones. (Deceased, 1923.) 1912.
S. A. Gimson, J.P. (Deceased, 1938.) 1913–1914.
W. Mayer. (Deceased, 1923.) 1915.
J. Ellis. (Deceased, 1930.) 1916–1917.
T. H. Firth. (Deceased, 1925.) 1918.
John Little, M.I.Mech.E. (Deceased, 1932.) 1919.
Matthew Riddell. 1920.
Oliver Stubbs. (Deceased, 1932.) 1921.
H. L. Reason. 1922.
Oliver Stubbs. 1923.
R. O. Patterson, Pioneer Works, Blaydon-on-Tyne. 1924.
J. Cameron, J.P., Cameron & Roberton, Ltd., Kirkintilloch, Scotland. 1925.
V. C. Faulkner, F.R.S.A., 3, Amersham Road, High Wycombe, Bucks. 1926.
J. T. Goodwin, M.B.E., M.I.Mech.E., Sheepbridge Coal & Iron Co., Ltd., Chesterfield. 1927.
S. H. Russell, Bath Lane, Leicester. 1928.
Wesley Lambert, C.B.E., "Greyfriars," Sea Drive, Westgate-on-Sea. 1929.
F. P. Wilson, J.P., "Parkhurst," Middlesbrough. 1930.
A. Harley, The Daimler Co., Ltd., Coventry. 1931.
Victor Stobie, M.I.E.E., The Stobie Steel Co., Ltd., Dunston House, Harrogate. 1932.
C. E. Williams, J.P., "Coniston," Cefn-Coed Road, Roath Park, Cardiff. 1933.
Roy Stubbs, 36, Broadway, Cheadle, Cheshire. 1934.
J. E. Hurst, D.Met., "Ashleigh," Trent Valley Road, Lichfield, Staffs. 1935.
H. Winterton, Moorlands, Milngavie, Dumbartonshire. 1936.
C. W. Bigg, "Selworthy," Burley Lane, Quarndon, Near Derby. 1937.
J. Hepworth, J.P., M.P., Ingle Nook, Bolton Road, Bradford, Yorks. 1938.

HON. TREASURER:

S. H. Russell, Bath Lane, Leicester.

SECRETARY AND EDITOR AND GENERAL OFFICE:

T. Makemson, Assoc.M.C.T., St. John Street Chambers, Deansgate, Manchester, 3.

Registered Office: 49, *Wellington Street, Strand, London, W.C.*2.

ASSISTANT SECRETARY:

J. Bolton.

AUDITORS:

Messrs. J. & A. W. Sully & Co., 19/21, Queen Victoria Street, London, E.C.4.

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V. Delport, 7, Kenton Gardens, Kenton, Harrow, Middlesex.

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F. K. Neath, B.Sc., Hollywell House, Armley, Leeds, 12.

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P. A. Russell, B.Sc., Bath Lane, Leicester.

A. W. Walker, " Ailsa Craig," 113, Dalton Green Lane, Huddersfield.

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(*Branch represented shown in brackets.*)

N. C. Blythe, 24, Bagnell Road, King's Heath, Birmingham, 14. (Birmingham.)

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H. V. Grundy, 359, Washway Road, Sale, Cheshire. (Lancashire.)

A. Hares, 648, Stapleton Road, Bristol, 5. (Wales and Monmouthshire.)

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A. S. Worcester, Toria House, 162, Victoria Road, Lockwood, Huddersfield. (W. Riding of Yorkshire.)

J. G. Pearce, M.Sc., M.I.E.E., M.I.Mech.E., F.Inst.P., 21, St. Paul's Square, Birmingham, 3.

Branch Presidents and Honorary Branch Secretaries

(Ex-officio members of the Council.)

BIRMINGHAM.

A. Tipper, M.Sc. (Eng.), The Fordath Engineering Co., Ltd., Hamblet Works, West Bromwich, Staffs.
A. A. Timmins, A.I.C., 21, St. Paul's Square, Birmingham, 3.

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R. H. Buckland, "Foremark," 28, Grange Avenue, Normanton, Derby.
B. Gale, "Parkdale," Boulton Lane, Alvaston, Derby.

LANCASHIRE.

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A. Boyes, "Roseville," 7, Kirkstall Road, Davyhulme, Manchester.

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Barrington Hooper, C.B.E., 3, Amersham Road, High Wycombe, Bucks.
H. W. Lockwood, Stewarts & Lloyds, Ltd., Winchester House, Old Broad Street, London, E.C.2. (*Vice-President and Acting Secretary.*)

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D. K. Barclay, 8, Aske Road, Redcar, Yorks.
J. K. Smithson, The North Eastern Iron Refining Co., Ltd., Stillington, Stockton-on-Tees. (*Acting Secretary.*)

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C. Lashly, M.C., Sir W. G. Armstrong Whitworth & Co. (Ironfounders), Ltd., Close Works, Gateshead-on-Tyne.

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J. Bell, 60, St. Enoch Square, Glasgow, C.1.

SHEFFIELD.

M. Brown, 14, Oakholme Road, Sheffield, 10.
T. R. Walker, M.A., 11, Broomgrove Crescent, Sheffield, 10.

SOUTH AFRICAN.

Dr. H. J. van Eck, The Dunswart Iron & Steel Works, Ltd., 8th Floor, Anglovaal House, 71, Fox Street, Johannesburg, South Africa.
F. C. Williams, Mutual Buildings (Third Floor), Corner Harrison and Commissioner Streets, Johannesburg, South Africa.

WALES AND MONMOUTH.

S. Protheroe, 65, Bangor Street, Cardiff.
J. J. McClelland, 12, Clifton Place, Newport, Mon.

WEST RIDING OF YORKSHIRE.

S. Carter, "Essendyne," 63, Bank End Lane, Almondbury, Huddersfield.
S. W. Wise, 110, Pullan Avenue, Eccleshill, Bradford, Yorks.

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These Sections are part of the Branches with which they are associated. The Presidents and Secretaries of Sections receive invitations to attend meetings of the Council.

EAST MIDLANDS—LINCOLN SECTION.

E. C. Carrott, Chestnut House, 48, Western Avenue, Lincoln.
E. R. Walter, M.Sc., The Technical College, Lincoln.

LANCASHIRE—BURNLEY SECTION.

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(*President and Acting Secretary.*)

LONDON—EAST ANGLIAN SECTION.

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J. L. Francis, Ranelagh Works, Ipswich, Suffolk.

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T. R. Goodwin, "Viewfield," Bonnybridge, Stirlingshire.

WALES AND MONMOUTH—BRISTOL SECTION.

M. Wayman, J. Jefferies & Sons, Ltd., Hotwells Foundry, Bristol.
A. Hares, 648, Stapleton Road, Bristol 5.

Honorary Corresponding Members of Council

AUSTRALIA.

W. T. Main, T. Main & Sons (Proprietary), Ltd., 29, George Street, East Melbourne, Victoria, Australia.

ITALY.

Dott. Ing. Guido Vanzetti, 73, Corso Venezia, Milan, Italy.

SOUTH AFRICA.

A. H. Moore, Standard Brass Foundry, Benoni, Transvaal.

AWARDS 1938-39

THE "OLIVER STUBBS" GOLD MEDAL

1939 Award to Mr. J. G. PEARCE, M.Sc., M.I.E.E., M.I.Mech.E., F.Inst.P., "in recognition of the many Papers which he has presented to the Institute, and for the work he has done in promoting the aims and objects thereof."

The Oliver Stubbs Medal has been awarded as follows :—

1922.—F. J. Cook, M.I.Mech.E.
1923.—W. H. Sherburn.
1924.—John Shaw.
1925.—A. Campion, F.I.C.
1926.—A. R. Bartlett.
1927.—Professor Emeritus Thomas Turner, M.Sc.
1928.—J. W. Donaldson, D.Sc.
1929.—Wesley Lambert, C.B.E.
1930.—James Ellis.
1931.—John Cameron, J.P.
1932.—J. E. Hurst, D.Met.
1933.—J. W. Gardom.
1934.—V. C. Faulkner.
1935.—No Award.
1936.—F. Hudson, E. Longden } Two Awards.
1937.—P. A. Russell, B.Sc.
1938.—S. E. Dawson, F.I.C.
1939.—J. G. Pearce, M.Sc., M.I.E.E., M.I.Mech.E., F.Inst.P.

THE MERITORIOUS SERVICES MEDAL

The 1939 Award was made to Mr. J. E. COOKE in recognition of his valuable services to the Institute, and particularly to the Lancashire Branch, of which he had until lately been Hon. Secretary.

The Meritorious Services Medal has been awarded as follows :—

1933.—F. W. Finch.
1934.—J. J. McClelland.
1935.—H. Bunting.
1936.—J. Smith.
1937.—No Award.
1938.—No Award.
1939.—J. E. Cooke.

THE "E. J. FOX" GOLD MEDAL

1939 Award was made to Dr. HARRY A. SCHWARTZ of Cleveland, Ohio, U.S.A., in recognition of the outstanding services which he has rendered to the development of malleable iron castings.

The E. J. Fox Gold Medal has been awarded as follows :—

1937.—Professor Emeritus Thomas Turn M.Sc.
1938.—J. E. Hurst, D.Met.
1939.—Dr. Harry A. Schwartz.

DIPLOMAS OF THE INSTITUTE

were awarded to :—

Mr. W. W. BRAIDWOOD, for his Paper on " Melting Practice in a large Engineering Iron Foundry," presented to the Scottish Branch.

Mr. S. CARTER and Mr. A. W. WALKER, for their joint Paper on " Moulding Sands with Special Reference to Blind Scabs," presented to the West Riding of Yorkshire Branch.

Mr. R. D. LAWRIE, for his Paper on " Examples of Loam Moulding," presented to the Lancashire Branch.

Mr. W. WEST and Mr. C. C. HODGSON, for their joint Paper on " Porosity and Sinking in Cast Iron," presented to the Lancashire Branch.

Mr. J. DEARDEN, for his Paper on " The Effect of Moisture on the Principal Properties of Moulding Sands," presented to the Scottish Branch.

Diplomas for Papers presented to the International Foundry Congress were Awarded to :—

Mr. J. J. SHEEHAN, for his Paper on "Core Shop Control."

Mr. A. J. MURPHY, for his Paper presented jointly with Messrs. S. A. E. Wells and R. J. M. Payne, on "The Effect of Melting Conditions on Light Alloys."

Mr. G. L. BAILEY, for his Paper on "The Effect of Melting Conditions on Gas Unsoundness in Metals."

Mr. G. R. SHOTTON, for his Paper on "Some Notes on the Design and Operation of the Open Hearth Furnace for Melting Malleable Cast Iron."

Mr. F. A. MELMOTH, for his Paper on "The Renaissance of the Steel Casting and the Rôle of the Metallurgist."

Mr. A. H. GUY, for his Paper on "Industrial Legislation in South Africa."

The "Edward Williams" Lecture

The following Lectures have now been delivered :—

1935.—" Man and Metal " (delivered at Sheffield).—Sir WILLIAM J. LARKE, K.B.E.

1936.—" Cast Iron and the Engineer " (delivered at Glasgow).—Prof. A. L. MELLANBY, LL.D., D.Sc.

1937.—" Factors in the Casting of Metals " (delivered at Derby).—C. H. DESCH, D.Sc., Ph.D., F.R.S.

1938.—Not delivered.

1939.—" The Atomic Pattern of Metals " (delivered in London).—Prof. W. L. BRAGG, O.B.E., M.C., D.Sc., M.A., F.R.S.

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The Institute of British Foundrymen

ANNUAL GENERAL MEETING

The thirty-sixth Annual General Meeting of the Institute was held at the Dorchester Hotel, Park Lane, London, on Monday, June 12. Mr. J. Hepworth, J.P., M.P. (retiring President) presided.

The minutes of the preceding Annual General Meeting, held in June, 1938, at Bradford, were taken as read, and the minutes of the adjourned Annual General Meeting, held in Manchester on October 15, 1938, to confirm the alterations to the Bye-laws that were approved in June, were read. They were confirmed and signed.

Arising out of the minutes of the October meeting, the SECRETARY (Mr. T. Makemson) said that active steps were being taken to secure a supplementary Charter; it was hoped to obtain it shortly, and that the new Bye-laws would come into force on January 1, 1940.

Council's Report and Accounts

On the motion of the PRESIDENT, seconded by MR. C. W. BIGG (Past-President), the Annual Report of the Council for the year 1938-39 was unanimously adopted, without discussion.

The Report is printed on pages 2 to 9.

MR. S. H. RUSSELL (Past-President and Honorary Treasurer), proposing the adoption of the balance sheet and accounts for the year ended December 31, 1938, commented that the income had exceeded expenditure by the comparatively small amount of £122; if the South African Branch had not been in existence, that surplus would have disappeared entirely.

The motion for the adoption of the balance sheet and accounts was seconded by MR. V. C. FAULKNER (Past-President) and carried.

Report of Technical Committee

MR. J. W. GARDOM (Convener of the Institute's Technical Committee, proposed the adoption of the Committee's Report for the past session, and said that the work of the Committee since its inception in 1931 would be reviewed in a Paper before the Congress. He took the opportunity to thank the members of the Technical Committee for their help.

The motion was seconded by MR. C. H. KAIN, and the Report (see page 9) was adopted.

Awards

It was reported that medals and diplomas had been awarded as follows:—

Oliver Stubbs Gold Medal, 1939, to Mr. J. G. Pearce (Director and Secretary, British Cast Iron Research Association).

Meritorious Services Medal (which had not been awarded for some years) was awarded for 1939 to Mr. J. E. Cooke, who until recently was Secretary of the Lancashire Branch, and was still carrying on a great deal of work on behalf of that Branch.

The E. J. Fox Gold Medal.—The Council have accepted the recommendation of the two assessors (Sir William Larke and Sir Harold C. Carpenter) and had awarded the Medal to Dr. Harry A. Schwartz, of Cleveland, Ohio, U.S.A.

Diplomas were awarded to the following:—Mr. W. W. Braidwood, for a Paper on "Melting Practice in a Large Engineering Iron Foundry," presented to the Scottish Branch; Mr. S. Carter and Mr. A. W. Walker, for their Paper on "Moulding Sand, with special reference to Blind Scabs," read before the West Riding of Yorkshire Branch; Mr. R. D. Lawrie, for a Paper on "Some Examples of Loam Moulding"; Mr. J. Dearden, for a Paper on "Moisture in Moulding Sand," and Mr. Walter West and Mr. C. C. Hodgson, for a Paper on "Porosity and Sinking in Cast Iron."

Election of Officers

The following officers were elected for 1939-40:—

President—Mr. W. B. Lake, J.P. (director, Lake & Elliott, Limited, Braintree).

Senior Vice-President—Major R. Miles, M.Eng. (Director, Head, Wrightson & Company, Limited, Thornaby-on-Tees).

Junior Vice-President—Mr. D. H. Wood (Constructional Engineering Company, Limited, Birmingham).

The election of Mr. Lake was proposed by the retiring PRESIDENT, who expressed the confidence which Mr. Lake enjoyed among the whole membership. MR. C. C. BOOTH, J.P. (President of the London Branch), who seconded, spoke from

practical experience of Mr. Lake's valuable work for the Institute for many years, and the encouragement he had given to members of his staff to assist the organisation. The members of his family also had given him great support.

In his response, Mr. Lake confessed that he had been a little nervous about accepting the office; his health had not been too good recently. Yet he had so many friends in the Institute and had received so many offers of help that he was able to accept the office with a good heart. He thanked the members very sincerely for the honour.

The election of Major Miles was proposed by Mr. Lake, who commended his admirable work as Junior Vice-President during the past year, and said that the more the members saw of him, the more they liked him. The resolution was seconded by Mr. F. J. Cook (Past-President). Major Miles briefly responded.

Proposing the election of Mr. Wood to the Junior Vice-Presidency, Mr. F. J. Cook said it was unnecessary, in a company of foundrymen, to extol his virtues. He was well known as a hard worker for the Institute for very many years, and would have the support of the whole of the Birmingham Branch particularly when, in due course, he filled the Presidential Chair. Mr. J. Cameron (a Past-President), as an old personal friend of Mr. Wood, claimed the pleasure of seconding. He referred to Mr. Wood as one of his most valued friends, and commended his great work as President of the Birmingham Branch. Mr. Wood expressed his appreciation of his election, first as an honour to the Birmingham Branch, and secondly, as an honour to himself.

Votes of Thanks

Mr. W. B. Lake, proposing a hearty vote of thanks to Mr. Hepworth for his services as President during the past year, recalled the wonderful success of the Bradford Conference last year, and the great work Mr. Hepworth had done to ensure its success. Throughout the year he had rendered great service, in spite of the calls which his Parliamentary and other duties made upon his time, and the members were deeply indebted to him.

No seconder was needed for so popular a proposal, and the vote of thanks was accorded with enthusiasm.

Mr. Hepworth, in his response, assured the members that he was honoured to have served as President; and he paid tribute to the officers and members of the West Riding Branch for their support, and particularly for the noble manner in which they had worked to ensure the success of the Bradford conference. He was all the better for having made the acquaintance of so many members, and hoped that the acquaintance would ripen into friendship as the years passed.

Professor T. Turner, proposing a hearty vote of thanks to the officers and Council for their services during the past year, said that the Annual Report indicated the work that had been done and the progress which the Institute had made during the past successful year. An institute, he said, did not make progress if left to itself; if it were allowed to drift, it would drift downwards. The Institute's rising importance and increasing work was a great testimony to the work of its officers.

The resolution was seconded by Mr. E. Brown, and carried with acclamation.

Auditors

On the motion of Mr. V. Stobie (Past-President), seconded by Mr. J. W. Gardom, Messrs. J. & A. W. Sully & Company (chartered accountants) were re-appointed auditors for the ensuing year.

Election of Members of Council

The following five nominees for election to the five vacancies on the Council were declared elected for two years:—Mr. V. Delport; Mr. E. Longden; Mr. H. J. Roe, Mr. P. A. Russell, and Mr. A. W. Walker.

The Annual General Meeting closed.

ANNUAL REPORT

This Report covers the period May 1, 1938, to April 30, 1939, and the accounts are for the year ended December 31, 1938.

Another increase in the membership of the Institute is shown in Tables I and II, whilst the balance sheet and statement of accounts show that the finances of the Institute have been maintained in a sound condition, although during the past year considerably increased expenditure has been borne. The Council is also pleased to assure members that all phases of the Institute's work have made progress, and that the industry continues to recognise the value of this work.

Deaths

The Council regrets to report the deaths of seventeen members. Particular mention is made of the following who were widely known throughout the industry, and whose work on behalf of the Institute has undoubtedly assisted in the past to bring about the happy position in which the Institute now finds itself.

Mr. S. A. Gimson, J.P., East Midlands Branch, was one of the oldest members of the Institute, which he joined in 1906, and of which he was President from 1913 to 1915.

Mr. W. J. Molineux contributed several valuable Papers, for one of which he was awarded a diploma. At the time of his death he had been nominated as President of the Birmingham Branch, and had previously been a Vice-President of the Newcastle Branch.

Mr. E. V. Ronceray joined the Institute in 1909, and was elected an Honorary Member in 1922. He was a Past-President of the Association Technique de Fonderie. He had been decorated by the French and by foreign Governments, and had received honours from numerous technical institutions.

Mr. D. M. S. Parker, during his short membership of the London Branch of the Institute, became widely known, particularly to members of that Branch.

Mr. Kenneth Hill was also a comparatively new member of the London Branch, and was widely known, particularly to those members associated with the vitreous enamelling industry.

Mr. J. B. Corrie was a member of the London Branch who was well known throughout this country and on the Continent.

TABLE I.—*Changes of Membership*, 1938–39.

	Subscribing firms.	Members.	Associate Members.	Associates.	Associate students.	Total.
At April 30, 1938	73	926	1,053	137	31	2,220
Additions and transfers from other grades	2	85	116	17	4	224
	75	1,011	1,169	154	35	2,444
Losses and transfers to other grades ..	1	37	75	21	3	137
At April 30, 1939	74	974	1,094	133	32	2,307

TABLE II.—*Analysis of Membership, April* 30, 1939.

Branch.	Subscribing firms.	Members.	Associate members.	Associates.	Associates (students).	Total.
Birmingham ..	8 (8)	157 (151)	157 (156)	15 (17)	7 (7)	344 (339)
East Midlands ..	4 (4)	67 (64)	102 (87)	5 (4)	2 (1)	180 (160)
Lancashire	14 (14)	127 (115)	198 (210)	25 (32)	— —	364 (371)
London	10 (9)	203 (187)	125 (117)	5 (6)	— —	343 (319)
Middlesbrough ..	1 (1)	27 (23)	44 (34)	8 (9)	7 (7)	87 (74)
Newcastle	7 (7)	34 (34)	30 (29)	56 (49)	11 (10)	138 (129)
Scottish	7 (6)	99 (104)	185 (191)	6 (7)	2 (2)	299 (310)
Sheffield	6 (7)	97 (96)	69 (67)	2 (2)	1 (1)	175 (173)
South African ..	10 (10)	41 (36)	27 (17)	7 (7)	— —	85 (70)
Wales & Mon. ..	2 (2)	44 (44)	51 (50)	— —	2 (3)	99 (99)
W.R. of Yorks. ..	5 (5)	55 (51)	89 (79)	3 (4)	— —	152 (139)
Unattached ..	— —	23 (21)	17 (16)	1 —	— —	41 (37)
	74 (73)	974 (926)	1,094 (1,053)	133 (137)	32 (31)	2,307 (2,220)

Mr. D. H. Wilkinson, a Past-President and former secretary of the Birmingham Branch, was also a diploma holder.

Mr. F. C. Edwards, a prominent member of the Birmingham Branch, will long be remembered for the valuable Papers on patternmaking which he presented to many Branches of the Institute.

Mr. J. R. Hyde, a Past-President of the Sheffield Branch, died in June, 1938, after twenty-seven years of membership of the Institute. For many years he was a member of the Council and was the first Convener of the Steel Castings Sub-Committee. He was the author of several Papers, for one of which he was awarded a diploma.

Mr. C. H. Smith, who was killed in a street accident last November, was a well-known member of the East Midlands Branch.

Mr. R. Potter was elected to membership in 1932, and was a valued member of the Scottish Branch.

Honours Conferred upon Members

Amongst those members who received honours during the twelve months covered by this report are the following:—

The Rt. Hon. Lord Weir of Eastwood, P.C., G.C.B., was created a Viscount at the time of His Majesty's birthday last June.

Sir Robert A. Hadfield, Bart., F.R.S., was honoured by the American Institute of Mining

and Metallurgical Engineers in recognition of his fifty years' membership. The honour carried with it a diploma and a gold pin, insignia of the Legion of Honour of the Institute.

Professor Sir Harold Carpenter, M.A., Ph.D., F.R.S., A.R.S.M., received the platinum medal of the Institute of Metals for the outstanding services which he has rendered to the development of non-ferrous metallurgy. Sir Harold has also been elected an Honorary Member of the American Institute of Mining and Metallurgical Engineers.

Professor-Emeritus T. Turner, M.Sc., F.I.C., F.C.S., A.R.S.M., was elected a Fellow of the Imperial College of Science and Technology.

Dr. T. Swinden was awarded the M.C. James Gold Medal by the Council of the North-East Coast Institution of Engineers and Shipbuilders.

Mr. J. E. Hurst, Past-President, was elected to the Presidency of the International Committee on Testing Cast Iron, and in July next will receive the honorary degree of Doctor of Metallurgy from the University of Sheffield.

Mr. V. Delport was awarded the Gold Medal of the Association Technique de Fonderie de France.

Mr. W. T. Griffiths, M.Sc., was awarded the degree of Doctor of Science by the University of Wales.

Mr. G. E. France was elected President of

BALANCE SHEET, 31st December, 1938

LIABILITIES.

	£ s. d.	£ s. d.
Subscriptions paid in advance		164 1 0
Sundry Creditors		450 4 5
Secretary's Policy Fund		18 8 8
The Oliver Stubbs Medal Fund :—		
Balance from last Account	210 13 1	
Interest to date	12 1 2	
	222 14 3	
Less : Cost of Medal	9 15 0	
		212 19 3
The Buchanan Medal Fund :—		
Balance from last Account	122 14 10	
Interest to date	4 12 7	
	127 7 5	
Less : Cost of Medals and Prizes	5 11 7	
		121 15 10
The E. J. Fox Medal Fund :—		
Balance from last Account	497 5 1	
Interest to date	13 17 7	
	511 2 8	
Less : Cost of Medal	15 0 0	
		496 2 8
Technical Development Fund :—		
Balance from last Account	500 0 0	
Interest to date	5 9 5	
		505 9 5
International Conference Fund :—		
Surplus (included in General Investments)		40 18 11
Accumulated Fund :—		
Balance 31st December, 1937	2,405 0 1	
Add : Excess of Income over Expenditure for the year ended 31st December, 1938	122 11 10	
		2,527 11 11
		£4,537 12 1

ASSETS.

	£ s. d.	£ s. d.
Cash in hands of Secretaries :—		
Lancashire Branch	4 9 6	
Birmingham Branch	34 7 7	
Scottish Branch	36 17 5	
Sheffield Branch	21 1 6	
London Branch	9 12 8	
East Midland Branch	18 19 0	
West Riding of Yorkshire Branch	18 1 9	
Wales and Monmouth Branch	13 7 11	
Newcastle Branch	8 14 0	
		165 11 4
Cash in Hand :—		
Secretary's Policy Fund		18 8 8
Head Office Petty Cash		2 11 7
Sundry Debtors :—		
Subscriptions due and subsequently received		74 3 6
Lloyds Bank Ltd.		486 9 7
The Oliver Stubbs Medal Fund :—		
£342 5s. 7d. Local Loans £3 per cent. Stock at Cost	200 0 0	
Balance at Lloyds Bank Ltd.	12 19 3	
		212 19 3
The Buchanan Medal Fund :—		
£125, £3 10s. 0d. per cent. Conversion Stock at 78¼	98 6 9	
Balance at Midland Bank	23 9 1	
		121 15 10
The E. J. Fox Medal Fund :—		
£462 19s. 3d., £3 10s. 0d. per cent. Conversion Loan at Cost	500 0 0	
Less : Overdraft at Lloyds Bank Ltd.	3 17 4	
		496 2 8
Technical Development Fund :—		
Balance at Manchester and Salford Savings Bank		505 9 5
Investments :—		
£650, 3½ per cent. War Loan at Cost	630 8 4	
£653 19s. 0d. Local Loans 3 per cent. Stock at Cost	451 13 8	
£964 5s. 1d. 3 per cent. Funding Loan at Cost	897 14 11	
£400 Leeds Corporation Mortgage	400 0 0	
		2,379 16 11
Furniture, Fittings, and Fixtures :—		
as per last Account	61 18 7	
Less : Depreciation 10 per cent.	6 3 10	
		55 14 9
Superannuation Insurance :—		
Unexpired premium		18 8 7
		£4,537 12 1

S. H. RUSSELL, *Hon. Treasurer.*
TOM MAKEMSON, *Secretary.*

19/21 Queen Victoria Street,
LONDON, E.C.4.
23rd March, 1939.

We have prepared and audited the above Balance Sheet with the Books and Vouchers of the Institute and certify same to be in accordance therewith.
J. & A. W. SULLY & Co., *Chartered Accountants, Auditors.*

the Foundry Trades' Equipment and Supplies Association.

Mr. Frank S. Russell was elected President of the Refractories Association of Great Britain in May, 1938.

Mr. W. T. Laverton was elected President of the Stoke-on-Trent Association of Engineers.

industry." The presentation of the medal was made at the Annual Conference in Bradford in June, 1938.

The Council has accepted the recommendation of the assessors to make the 1939 award to Dr. Harry A. Schwartz, of Cleveland, Ohio. It is expected that Dr. Schwartz will attend the International Foundry Congress, to be held in

Income and Expenditure Account for the year ended 31st December, 1938

EXPENDITURE.

	£	s.	d.	£	s.	d.
Postages				158	18	10
Printing and Stationery including printing of "Proceedings"				834	2	9
Council, Finance and Annual Meetings Expenses				153	2	8
Medal for Past President				3	0	0
Branch Expenses :—						
Lancashire	125	10	6			
Birmingham	86	5	0			
Scottish	76	15	8			
Sheffield	49	18	6			
London	89	7	4			
East Midlands	54	1	0			
Newcastle	35	6	2			
West Riding of Yorkshire	35	18	3			
Wales and Monmouth	34	16	4			
Middlesbrough	24	13	1			
South Africa	76	13	5			
				689	5	3
Audit Fee and Accountancy Charges				12	12	0
Incidental Expenses	146	10	5			
Subscription, Joint Committee on Materials and their Testing	5	5	0			
Subscription, British Foundry School	5	0	0			
Subscription, International Committee on C.I. Testing	3	0	0			
				159	15	5
Salaries—Secretary and Clerks				886	17	9
Superannuation Insurance (Secretary)				55	5	10
Rent, Rates, &c., of Office *less* Received				113	12	0
Subscription International Committee				5	0	0
Depreciation of Furniture				6	3	10
John Surtees Memorial Examination. Grants to Branches				10	4	0
				3,088	0	4
Excess of Income over Expenditure carried to Balance Sheet				122	11	10
				£3,210	12	2

INCOME.

	£	s.	d.	£	s.	d.
Subscriptions received :—						
Lancashire Branch				443	2	0
Birmingham Branch				457	16	6
Scottish Branch				401	12	6
Sheffield Branch				261	19	6
London Branch				490	17	6
East Midlands Branch				243	12	0
Newcastle Branch				129	0	0
West Riding of Yorkshire Branch				168	10	6
Wales and Monmouth Branch				136	15	0
Middlesbrough Branch				87	12	6
Unattached Members				43	9	1
South African Branch				154	7	0
				3,018	14	1
Add : Subscriptions in advance, 1937	223	19	0			
Subscriptions due 1938	74	3	6			
				298	2	6
				3,316	16	7
Less : Subscriptions in advance, 1938	164	1	0			
Subscriptions due 1937	82	2	0			
				246	3	0
				3,070	13	7
Conference Registration Fees				29	12	6
Polish Conference Surplus				0	10	10
Sale of "Proceedings," etc.				16	4	0
Interest on Investments and Cash on deposits				85	6	1
John Surtees Memorial Examination Surplus				6	0	8
Profit on sale of Badges				2	4	6
				£3,210	12	2

Mr. R. C. Tucker, M.A., was elected President of the Sheffield Metallurgical Association.

Finances

The increase in membership, and the increasingly active part which the Institute is taking in affairs connected with the industry, have both contributed directly and indirectly to the additional expenditure which has been incurred during the past year. Nevertheless, the excess of income over expenditure at December 31, 1938, amounted to the sum of £122 11s. 10d.

Awards

E. J. Fox Gold Medal.—On the recommendation of the assessors, Sir William J. Larke and Professor Sir Harold Carpenter, the Council decided to award the E. J. Fox Gold Medal for 1938 to Mr. J. E. Hurst, "in recognition of his work on the metallurgy of cast iron and the application of the results of his research to the

June, when the presentation will be made to him.

Oliver Stubbs Gold Medal.—At their meeting held in Bradford, on June 14, 1938, the Council decided to accept the recommendation of the Literary and Awards Committee to award the Oliver Stubbs Gold Medal for 1938 to Mr. S. E. Dawson, F.I.C., "in recognition of the many valuable Papers which he has presented to almost all the Branches of the Institute." The presentation of the medal was made at the Annual Conference on the following day.

Diplomas.—At the Bradford Conference last June it was announced that diplomas for 1938 had been awarded to the following gentlemen. The Branches to which they presented the Paper for which they were awarded a diploma are also shown :—

A. Tipper ... ... Lancashire Branch
A. Phillips ... Lancashire Branch

P. Fassotte	...	London Branch
B. MacDougall	...	Scottish Branch
J. Cameron, jun.	...	Scottish Branch

Buchanan Medals and Prizes.—The names of the recipients of the medals and prizes are given under the heading "Educational Work" which appears later in the Report. The Buchanan Medals and Prizes are awarded as the result of examinations organised by the City and Guilds of London Institute on Foundry Practice and Patternmaking.

Branch Activities

The system of presenting a Paper to more than one Branch has been continued during the past year in respect of several important Papers. Several Papers by new authors were also presented to the Branches, and the quality of such Papers was found to be of a very high order. Another pleasing feature of the programmes was the large number of Branches which included the Cast Iron Sub-Committee's report in their programmes. In all, nine Branches or Sections discussed this report, and in this way expressed their appreciation of the work which the Technical Committee and its Sub-Committees are undertaking.

The system of joint meetings between Branches has been extended this year. The Branches at Newcastle and Middlesbrough enjoyed joint works visits, while the Sheffield and London Branches held a two-days' joint meeting in London, when Papers were discussed and works visited. Among other new features included in the Branch Programmes were the Apprentice Patternmakers' Competition, organised by the Sheffield Branch, and the "Mock Trial" of "Castings *versus* Welded Structures," arranged by the London Branch.

The South African Branch continues to make steady progress, and the Council had an opportunity of welcoming to its January Meeting Mr. T. Nimmo Dewar, the first President of the Branch.

Kindred Institutions

The happy relations which have always existed between the Institute and other similar bodies have been continued during the year under review. Several joint meetings have been held between local Branches of this Institute and of the Institute of Metals and The Institute of Vitreous Enamellers.

The Council takes this opportunity of extending to the newly-formed Institute of Australian Foundrymen its best wishes for the success of this new venture, which will be officially represented at the forthcoming International Foundry Congress.

In order that there should be a closer working between the Institute and the British Cast Iron Research Association, a Liaison Committee was formed in 1937. Several meetings have been held during the last year and a useful measure of co-operation has been found possible.

The Council tenders its thanks to the Iron and Steel Institute for the opportunity which members had of participating in the discussion of the Third Report of the Steel Castings Research Committee, when it was presented to a Joint Meeting of the two Institutes in the Autumn of last year.

The members of the Institute were also invited to attend a meeting of the Institution of Mechanical Engineers in December last, when the First Report of the Institution's Research Committee on High-Duty Cast Irons for General Engineering Purposes was presented by Mr. J. G. Pearce. Many members of the Institute availed themselves of this opportunity, and on their behalf the Council thanks the Institution and expresses the hope that such meetings may be continued in the future.

International Relations

Through the International Committee of Foundry Technical Associations, the Institute has been able to maintain its happy relations with foundry technical institutions overseas. A meeting of the Committee was held at the International Foundry Congress in Warsaw last September. The Institute was represented by Mr. J. Cameron, Senr., and the Secretary was also present as Secretary of the Committee. Over a dozen members of the Institute and their ladies were able to attend the Congress. The thanks of the Institute are extended to the Stowarzyszenie Techniczne Odlewnikow Polskich, who organised the Congress, and to Mr. K. Gierdziejewski, President of the Congress, for their hospitality.

In preparation for the next International Foundry Congress, to be held in London next June, contact has been made with thirty foundry and engineering technical associations in twenty countries. It is hoped that this Congress will afford a favourable opportunity for further strengthening the relations of the Institute with overseas foundry groups.

At a meeting of the International Committee for Testing Cast Iron held in Warsaw last September, Mr. J. E. Hurst, was elected Active President of the Committee. The Institute congratulates Mr. Hurst, and confidently hopes that under his Presidency the Committee will continue its useful rôle, and that through him, the Institute's participation in the Committee's work will be extended.

Mr. Hurst will attend the 43rd Annual Convention of the American Foundrymen's Association at Cincinnati and will extend to the American Foundrymen the good wishes of the Institute. He will also present the Institute's official Exchange Paper which has been prepared by Mr. F. Whitehouse.

The authors of other Papers presented on behalf of the Institute to overseas conferences were as follows:—

American Foundrymen's Association's Convention, 1938, Cleveland, Mr. W. J. Rees, M.Sc.

International Foundry Congress, 1938, Warsaw, Mr. B. B. Kent.

Association Technique de Fonderie, 1938, Lyons, Mr. T. R. Walker, M.A.

Papers were presented at the Bradford Conference on behalf of the American, French and German foundry associations. Official Exchange Papers from the following associations are expected to be presented at the forthcoming International Foundry Congress.

Nederlandsche Vereeniging van Gieterij-Technici.

Ceskoslovensky Odborny Spolek Slevarensky.

Stowarzyszenie Techniczne Odlewnikow Polskich.

Technischer Hauptausschuss für Giessereiwesen.

Magyar Ontodei Szakemberek Egyesulete.

Association Technique de Fonderie de Belgique.

Association Technique de Fonderie de France.

American Foundrymen's Association.

Federazione Nazionale Fascista degli Industriali Meccanici d'Italia.

Federazione Nazionali Fascista degli Industriali Metallurgici d'Italia.

Bye-Laws

Certain alterations to the Bye-Laws necessary to give effect to the re-organisation of the qualifications for membership were submitted to the Annual General Meeting at Bradford, on June 14, and passed at an adjourned General Meeting held in Manchester on October 15.

The Council is of the opinion that the alterations and additions which were made to the Bye-Laws will enable the Institute greatly to improve its status, and will benefit, both directly and indirectly, the individual member, who in return is called upon to pay an increased annual subscription. The new Bye-Laws will require intending members to show that they are fully qualified for the grade of membership to which they seek election, whereas at present such election depends solely upon the position which the intending member holds in industry. Membership will thus constitute a qualification. Additional advantages which the new Bye-Laws will facilitate were enumerated in a circular which was sent to all members prior to the adjourned Annual General Meeting.

Steps are being taken to ensure that the necessary supplementary Charter is obtained with the least possible delay, and it is expected that the new Bye-Laws will come into effect on January 1, 1940.

Publications

The Board of Development, on the Council's instructions, has reviewed the whole subject of the Institute's publications, and methods of publication, and has recommended to the Council that certain alterations be made in the publication of the "Proceedings," in order to give better service to members. The Council has accepted these proposals which will be put into effect at an early date.

Educational Work

The Institute has continued to collaborate with the City and Guilds of London Institute in organising examinations in foundry practice and science and in patternmaking. The following are the results of the examinations which were held in April and May, 1938.

Patternmaking—Intermediate Grade.

Number of candidates.	Pass 1st class.	Pass 2nd class.	Percentage of passes.
32	11	10	65.6
Final Grade			
20	7	7	70.0
Foundry Practice and Science.			
80	28	29	71.25

Prizes were awarded to:—

PATTERNMAKING—*Intermediate Grade.*

William Charles Marshall, Derby Technical College. Bronze Medal of the City and Guilds of London Institute.

PATTERNMAKING—*Final Grade.*

Stephen Moorhouse, Huddersfield Technical College. City and Guilds of London Institute's Silver Medal, and Buchanan Book Prizes of the Institute of British Foundrymen.

Edward Kenneth Greenwell, Constantine Technical College, Middlesbrough, Buchanan Silver Medal of the Institute of British Foundrymen.

Tom Draper, Keighley Technical College, Buchanan Book Prizes of the Institute of British Foundrymen.

FOUNDRY PRACTICE AND SCIENCE.

Jesse Reginald Simpson, South-East London Technical Institute. City and Guilds of London Institute's Bronze Medal and Buchanan Book Prize of the Institute of British Foundrymen.

Alfred Ronald Oldershaw, Nottingham University College. Buchanan Silver Medal of the Institute of British Foundrymen.

William Alan Backhouse, Central Technical College, Birmingham. Buchanan Book Prize of the Institute of British Foundrymen.

National Certificates in Mechanical Engineering issued by the Board of Education and the Institution of Mechanical Engineers, are endorsed by the President of the Institute in respect of those candidates who have been successful in special foundry subjects. Twenty-one National Certificates have been so endorsed during the last year, making a total of 176 since the scheme was commenced.

The degree course in foundry metallurgy at the University of Sheffield has now been in operation for nearly four years, and the first students who have completed the course have now entered industry. The establishment of the course has been fully justified.

The British Foundry School has also nearly completed its fourth year. The careers, subsequent to leaving, of those students who have taken the course show that it has achieved the object for which it was intended.

The Worshipful Company of Founders has during the past year established two scholarships whereby selected graduates of Universities may receive facilities for advanced education either in research, or a period in works, or foreign experience. The Council has accepted an invitation from the Master, Wardens and Court of Assistants of the Worshipful Company to co-operate with them in the scheme.

Annual Conference, Bradford

A very successful Annual Conference was held in Bradford from June 14 to 17. On June 14 the Annual General Meeting was held, and was followed by a civic reception at the Municipal Art Gallery. The Wednesday and Thursday were devoted to technical sessions and works visits, whilst on Friday, June 17, an excursion through the Yorkshire Dales was enjoyed. There was a large attendance at the Congress, and several members and visitors from overseas were present.

Mr. W. B. Lake, J.P., and Major R. Miles, M.Eng., were elected Senior and Junior Vice-Presidents respectively.

The thanks of the Institute are extended to the Rt. Hon. the Lord Mayor of Bradford (Alderman Henry Hudson, J.P.), the Lady Mayoress, and to the Corporation of the City of Bradford for the valuable assistance which they so willingly gave both to the organisers of the Conference and to the delegates, and also for the civic reception which will long be remembered by all those who were able to participate. The Council extends its thanks to the firms whose works were visited; to the authors of Papers; to the subscribers to the Conference Fund; and to all those who assisted in making the Bradford Conference so successful. Particular mention should be made of the work done by the West Riding of Yorkshire Branch officials, notably Mr. A. S. Worcester, Branch-President; Mr. H. Forrest, Chairman of the Conference Committee; Mr. W. G. Thornton, Honorary Conference Treasurer; and Mr. S. W. Wise, Honorary Branch Secretary.

British Cast Iron Research Association

The year 1938-39 has been one of steady activity and progress. Research Reports issued to member firms are being circulated at a rate of over one report each month and the Bulletin is now issued six times a year. In June, 1939, the current five-year period for grant from the Department of Scientific and Industrial Research terminates and the Department has agreed to continue the same grant for the next five-year period, subject to the industrial subscriptions being increased by £1,000. The support of all eligible foundries is therefore earnestly desired by the Council.

In the event of a national emergency arising, arrangements have been made by the Department of Scientific and Industrial Research for the Association to continue work for the benefit of the industry, and members may therefore rely on the continuation of the services to which they have become accustomed. Co-operation is being exercised with a number of Government departments on defence matters.

National Service

The Institute has accepted the invitation of the Ministry of Labour to co-operate in the compilation of the National Register of persons with scientific, technical, professional and higher administrative qualifications. The Secretary of the Institute has accepted the invitation of the Ministry of Labour to serve on the Mechanical Engineering Sub-Committee of the Central Register Advisory Committee.

Council

During the year, four meetings of the Council and more than twenty meetings of special and standing Committees have been held in addition to those of the Technical Committee and its Sub-Commitees. These meetings have been held in Sheffield, Bradford, London, Manchester, Birmingham and Glasgow.

Ten members of the Council are elected by ballot for a period of two years, five retiring each year. The five who so retire at the Annual General Meeting to be held on June 12 are:—Prof. J. H. Andrew, Mr. V. Delport, Mr. E. Longden, Mr. P. A. Russell, and Mr. D. H. Wood. All these gentlemen are eligible for re-election for a further period of two years, and with the exception of Prof. Andrew, offer themselves for re-election.

The thanks of the Council are tendered to the Convener of the Technical Committee, Mr. J. W. Gardom, for his devoted work in the leadership of the various activities of this Committee.

The Council also takes this opportunity to express its thanks to the International Foundry Congress (1939) Committee which during the past year has worked so energetically in arranging the International Foundry Congress.

International Foundry Congress

His Majesty's Government has graciously granted recognition to the International Foundry Congress, to be held in London from June 11 to 17, and has invited delegates to attend a Reception on Tuesday, June 13. The Congress will be opened by the Rt. Hon. the Lord Mayor of London, Sir Frank Bowater, on Tuesday, June 13, when Mr. W. B. Lake, J.P., will be installed as President.

Professor W. L. Bragg, O.B.E., M.C., D.Sc., M.A., F.R.S., will present the Fourth Edward Williams Lecture entitled "The Atomic Pattern of Metals." Ample time has been allowed for works visits and technical sessions, and there will also be a joint meeting with the Iron and Steel Institute. The Annual Banquet will be held on June 14; a Reception will be given by Mr. and Mrs. W. B. Lake on June 15, and Mr. and Mrs. Barrington Hooper will entertain delegates to a garden party at their home on Sunday, June 11.

A tour of the principal foundry centres of Great Britain has been arranged from June 18 to 30, during which time twenty-six foundries have consented to receive delegates. Hospitality will be extended to a considerable extent by various Branches of the Institute.

J. Hepworth,
President.

T. Makemson,
Secretary.

SEVENTH ANNUAL REPORT OF THE TECHNICAL COMMITTEE

During the past year the Technical Committee has actively pursued its policy of studying various developments which have been made in the foundry industry and in collaborating with other scientific bodies engaged in similar investigational work.

A general report of the work which it has done since its inception in 1931 will be presented to the International Foundry Congress in June, and from this Paper it will be seen that the Committee's activities are mainly connected with standardisation. It is because of the increasing amount of work which the Committee is undertaking in this sphere that it was decided to recommend to the Council that the Institute should become a member of the British Standards Institution, where, through members of the Technical Committee, the Institute is already well represented. The Council accepted this recommendation, and it is expected that this new development will enable the Institute, and particularly the Committee, to extend its useful work.

Relationships with overseas foundry associations have been maintained mainly through the International Committee on Testing Cast Iron, of which Mr. J. E. Hurst was elected President last September. It is hoped that the Technical Committee will be able to participate more fully in the programme of work arranged by the International Committee.

In the report of the Sub-Committee on Cast Iron, particular mention is made of the Special Report No. 1 ("Properties of Grey Cast Iron"), which has been published during the past year. This method of publication marks a new step in the service which the Institute renders to its members, and it is hoped that during the coming year and in the future more of these special reports will be published.

An important development in the co-operation between scientific institutions was the establishment of the Joint Committee on Foundry Sands. The Institute is represented on this new Committee by members of the Sands Sub-Committee.

During the past year the Costing Sub-Committee completed the work which resulted from the discussion of its report ("Recommendations Concerning the Establishment of Costing in the Grey Iron Foundry"). The Sub-Committee has, therefore, terminated its activities for the time being.

The Inquiry Bureau arranged by the Institute under the auspices of the Technical Committee has continued to provide members of the Institute with a useful service, which has been greatly appreciated.

The Technical Committee expresses the thanks of the Institute to those members who have given their time to the furtherance of the work which the Committee and its Sub-Committees have executed. Thanks are also extended to those firms which have so kindly provided facilities for members of their staffs to attend meetings; to those firms who have carried out research work and tests on behalf of the Institute, and to those firms who have co-operated with the Committee in connection with the questionnaires which have been circulated to industry during the past year.

J. W. Gardom,
Convener, Technical Committee.

Sub-Committee on Cast Iron

During the past year the Cast Iron Sub-Committee has continued to co-operate with the British Standards Institution in handling specifications directly or indirectly related to cast iron. In this connection assistance has been given in the preparation of a series of specifications dealing with precision tools for engineers, in which recommended compositions are included.

During the year the specification for cast iron gears has been issued; this includes grades of alloy iron with and without heat-treatment. The Sub-Committee actively participated in the preparation of this specification.

The principal work of the Committee during the year has been the preparation and publication of the Paper on the physical properties of cast iron, issued as Special Report No. 1. This Paper discusses all the work carried out by the Committee in connection with the preparation of the High-Duty Cast Iron Specification No. 786—1938, and in addition gives as far as possible information on the general physical characteristics of cast iron. It was presented before nine Branches of the Institute by members of the Sub-Committee, and was in each case given a full discussion. The discussions by the different Branches have been collected and classified and will be published together with the considered reply by the Sub-Committee.

Further consideration was given during the year to the possibility of issuing recommended methods of running and risering grey iron castings. As a result of a questionnaire to a number of foundries, however, it was found that it would be impossible to issue recommended methods in view of the very wide difference in practice as applied to the successful production of one and the same casting in different works. Similarly, it was agreed that the Sub-Committee was not in a position to make recommendations covering methods of preparing high-duty cast irons.

An investigation is now in hand to determine the relationship between the physical properties of cast irons as determined by normal methods and by tests conducted on small rings as developed in connection with piston rings. In order to correlate the results of tests carried out by these two methods it has been arranged to prepare standard test-bars and ring pots simultaneously from different grades of cast iron, and to carry out the necessary tests as a basis for comparison. The ultimate object of this work is to endeavour to find a suitable method of testing for the toughness of cast iron, and this will be studied from the point of view of such properties revealed by the tests as elasticity, energy required to break the test-pieces, impact resistance, etc.

P. A. Russell, B.Sc.,
Convener.

Sub-Committee on Malleable Cast Iron

During the past year the Malleable Cast Iron Sub-Committee has been almost exclusively engaged on work in connection with the revision of the British Standard Specifications for Blackheart and Whiteheart Malleable Cast Iron. A questionnaire upon this subject was circulated to the industry and this resulted in a 60 per cent. return. After tabulation of the data, the Sub-Committee was pleased to find that its own views were generally supported by the industry. After consideration of the replies, the Sub-Committee formulated tentative recommendations which it was subsequently found were not in complete agreement with those of the Committee of the British Cast Iron Research Association also engaged on this work. After preliminary correspondence had taken place a joint meeting between the two committees was arranged. This proved very successful and enabled recommendations to be tabled which received the support of both Committees. There are now only two items upon which further data are required before the British Standards Institution is requested to convene a meeting of the IS/35/3 Committee. These investigations concern the desirability of using a round bar or a flat bar with half-round edges for the bend test, and the choice of gauge length for the 0.357 in. dia. bar for whiteheart malleable. The work will be undertaken jointly by the two Committees.

A. E. Peace,
Convener.

Sub-Committee on Melting Furnaces

All sections of the report which the Sub-Committee has been preparing on Melting Furnaces for Grey Cast Iron are now complete, and the final draft has been approved. Publication will

be effected as soon as possible, and the report will be made available to all members of the Institute as Special Report No. 2.

L. W. Bolton, A.M.I.Mech.E.,
Convener.

Sub-Committee on Non-Ferrous Castings

Further progress has been made during the year with the Sub-Committee's work on the standardisation of non-ferrous casting alloys. As reported last year, a memorandum was submitted to the British Standards Institution covering the Sub-Committee's recommendation for standard specifications for two leaded gunmetals. This memorandum has received the consideration of the relevant committee of the British Standards Institution, and a further meeting will shortly be held after which it may be expected that a draft specification will be prepared and issued for comment.

The Sub-Committee was asked for certain recommendations on the revision of British Standard Specification 383 for 88-10-2 gunmetal castings and has submitted its views to the British Standards Institution.

Work on the three leaded bronze bearing alloys has now been completed and a report entitled "Recommendations for Three Leaded Bronze Bearing Alloys" has been prepared and is being presented at the International Foundry Congress in London. It is intended, after allowing for full discussion of this report by members of the Institute, to submit a similar memorandum to the British Standards Institution with a request for new specifications along the lines recommended.

It has been decided to proceed with the preparation of a report on the deoxidation and degasification of non-ferrous alloys.

L. B. Hunt, Ph.D.,
Convener.

Sub-Committee on Refractories

Practical tests on cupola ganisters have been made during the past year. It is hoped that these will provide the Sub-Committee with data on which it will be able to draw up a draft specification. The Sub-Committee is not yet in a position to make definite recommendations but hopes to complete this work in the near future.

W. J. Rees, M.Sc.,
Convener.

Sub-Committee on Sands

In May, 1938, the Joint Committee on Sands was formed, and with the co-operation of Sub-Committee members considerable progress has been made, and agreement reached on recommended methods of sand testing. The Sub-Committee's work on the subject of dry-sand and oil-sand testing is still proceeding, and a number of valuable reports on various types of laboratory drying ovens for dry strength tests have been made to the Sub-Committee. Other matters which have been considered during the past year are :—(1) The accuracy of test sieves; (2) Selection of a suitable standard silica sand for testing purposes; and (3) The comparison of various types of compression strength testing machines.

Future work of the Sub-Committee will include the investigation of deformation of sand under compression. The collection of data on casting defects related to sand condition is slowly progressing, but further typical examples are still required before attempting any publication.

J. J. Sheehan, B.Sc.,
Convener.

Sub-Committee on Steel Castings

The heat-treatment of carbon steel castings has formed the main subject of the Sub-Committee's deliberations during the past year. During the year under review considerable progress has been made in the analysis of the data obtained from replies to a questionnaire circulated to industry, and in the drafting of a report on this work.

As a result of investigations carried out by the Sub-Committee a considerable amount of data on Izod impact testing has been obtained, and this is now being analysed. It is hoped to issue a report on valve castings on which the Sub-Committee has completed some interesting tests. The conflicting nature of the results in connection with these latter investigations makes the compilation of comprehensive reports difficult.

Useful discussions on the Ruff fluidity test and its value as a measure of control in the steelfoundry have taken place. A considerable portion of the data collected has been published in Section II, part B of the Iron and Steel Institute's Third Report on Steel Castings which was discussed at a joint meeting of the two Institutes.

C. H. Kain,
Convener

The International Foundry Congress

and

THIRTY-SIXTH ANNUAL CONFERENCE OF THE INSTITUTE

The International Foundry Congress was opened on Tuesday morning, June 13, at the Dorchester Hotel, London, by the Rt. Hon. the Lord Mayor of London (Sir Frank Bowater, Kt.). The Lord Mayor was received by the retiring President (Mr. J. Hepworth, J.P., M.P.), who presided, and was accompanied on the platform by Mr. W. B. Lake, J.P. (President-Elect), Major R. Miles and Mr. D. H. Wood (Vice-Presidents), Dr. Guido Vanzetti, of Italy (President, International Committee of Foundry Technical Associations), Mr. C. W. Bigg (Past-President), and Mr. S. H. Russell (Past-President and Hon. Treasurer).

Civic Welcome

The Lord Mayor, opening the Congress, said it was devoted to the promotion of scientific development and the improvement of the technique of the foundry industry. It was surprising to him to learn, however, that in addition to some 400 foundrymen resident in this country, the Congress would be attended by probably 200 overseas delegates from several European countries, from the British Dominions and from the United States. He congratulated all concerned with the organisation of so vast a gathering.

In his business life, long since closed, he had realised all that he and his family had owed to the work of the founders, more especially the type founders, for their success and prosperity. Therefore, he was particularly happy to be associated with the gathering, and had great pleasure in declaring it open.

Reply on Behalf of Overseas Delegates

Dr. Guido Vanzetti, of Italy (President, International Committee of Foundry Technical Associations), expressed thanks on behalf of the overseas delegates for the warm hospitality and welcome extended to them.

People in the most progressive countries had realised that there could not be a large industry capable of reaching sure and practical results and adequate to the needs of our times, if it were not based on scientific knowledge and experience; industry and science had become so entwined that there was no industrial works which had not, as an indispensable branch, a research and routine laboratory.

But just because to-day industry and science were associated in a common work, both science and industry needed a constant exchange of ideas and information on their efforts and on their results. By means of periodical meetings it was exactly the intention to avoid the overlapping and waste due to individualism, which was a real calamity for science and industry.

Presentation of Medals

On behalf of the Institute of British Foundrymen, the Lord Mayor presented medals as follows:

The Oliver Stubbs Gold Medal was presented to Mr. J. G. Pearce (Director of the British Cast Iron Research Association).

Mr. Pearce, in his response, said he received the medal with pride and pleasure for many reasons, but for three in particular. First, it was associated with the name of Oliver Stubbs, whom he always recalled with affectionate regard and who was a great friend to the Institute and to the British Cast Iron Research Association. Secondly, the award he accepted as a tribute to the work of the Association during the past 15 years, and not so much to himself personally as to the staff, from whom he had had the most loyal help. Thirdly, it was a token and an earnest of the co-operation which should exist between the two bodies and which it would always be his earnest desire to forward as far as lay within his power.

The Meritorious Services Medal was presented to Mr. J. E. Cooke, who was Hon. Secretary of the Lancashire Branch for seven years.

Mr. Cooke, expressing thanks for the estimate which was placed on the value of his work, said that any work which had fallen to his lot had been rendered particularly easy by the fact that behind him in the Lancashire Branch he had always had an extremely loyal group of fellow workers.

The E. J. Fox Gold Medal was presented to Dr. H. A. Schwartz, of Cleveland, Ohio, U.S.A.

Dr. Schwartz, expressing his great appreciation, said that the Institute had established the

calibre of the E. J. Fox Medal when it had made the first award to Prof T. Turner; and he recalled that the first European name which appeared among the American Foundrymen's Association medallists was also that of Prof. Turner. Dr. Schwartz paid tribute to all concerned with the work with which his name was associated—the Corporation which had for 37 years financed the research work at considerable expense; his associates in the Research Department and those in the plants of the company who had attempted to utilise those things which the research workers tried to make available to them; and lastly, a considerable body of undergraduate and graduate students who had done a considerable amount of theoretical scientific exploration.

Vote of Thanks to the Lord Mayor

The President, proposing a vote of thanks to the Lord Mayor for having attended to open the Congress, said that his office as first citizen of the largest city in the world signified many things, the first and foremost being service—service to the City and to the State.

Mr. W. B. Lake, J.P. (President-Elect), seconding, recalled that ten years ago the Congress had received very great help from the City of London, and it was again greatly indebted to the Lord Mayor for his kindness in opening the 1939 Congress.

The vote of thanks was carried with enthusiasm.

The Lord Mayor, in his response, said he trusted that the Congress would be very happy and successful.

Induction of New President

Mr. Lake was inducted into the chair and was invested with the Presidential chain by Mr. Hepworth, who commented upon the distinction of being elected President at the time of the International Congress, and Mr. Lake's worthiness to uphold the traditions of the Institute. He wished both Mr. and Mrs. Lake happiness, health and prosperity during the coming year and for many years to come. Mr. Lake expressed his gratitude.

Presentation of Badges

A Past-President's badge was formally presented to Mr. Hepworth as a token of his Presidency and the services he had rendered during the past year. Mr. Lake expressed the hope that Mr. Hepworth would always retain happy memories of his year of office.

The collarette and badge worn by the President's wife was presented by Mrs. Hepworth to Mrs. Lake, the former confessing, amid laughter, that she was sorry to part with it. She wished Mrs. Lake health and happiness. Mrs. Lake responded.

Vice-Presidents' badges were presented to Major R. Miles (Middlesbrough Branch) and to Mr. D. H. Wood (Birmingham Branch), both of whom voiced their sense of privilege in being able to render service to the Institute.

A Loyal Message to Their Majesties

On the motion of the President, seconded by Mr. Hepworth, the meeting heartily agreed that a message of greeting and loyalty be sent to Their Majesties the King and Queen.

Welcome to Overseas Delegates

The President, extending a hearty welcome to friends from overseas who were attending the Congress, said he thanked them for coming; their British colleagues were delighted to see them, and would do everything possible to make their visit happy and profitable. He added the wish, which would be echoed by all British foundrymen, that all the nations of the world might come together with the same cordiality and friendliness as did the foundrymen of the various nations.

PRESIDENTIAL ADDRESS

The President then delivered his Presidential Address.

Mr. Hepworth, Ladies and Gentlemen,

I am deeply appreciative of the honour which you have accorded me in electing me your President at such an important juncture in the history of the Institute. I also regard my election as a recognition of the not unimportant part played by East Anglia in foundry developments. I hope that this International Congress will make a serious and lasting contribution to the cause of peace which foundrymen throughout the entire world so ardently desire.

A sincere welcome is being accorded to the visitors by distinguished representatives of the Government and by the civic authorities of this great city, and it is my first duty as President to add my own welcome and that of my colleagues in the Institute of British Foundrymen. My second duty is to address members upon a subject of my own choosing. My choice has been to compile a few notes on the subject of the history of steel castings, because steel castings have been one of the major interests of my career, and also because the subject shows how quickly the ironfoundry craftsmen developed the new steelmaking processes.

The History of Steel Castings

Although steel had been made in this country since 1609 mainly by the cementation process, it was not until about 1740 that the manufacture of steel castings became possible. Benjamin

Huntsman, a watchmaker of Doncaster, desiring to improve the quality of his watch springs, invented the crucible furnace. Huntsman was of German parentage but a native of Lincolnshire. Prior to his time it was customary to use shear steel or cemented bar. As at no time during its manufacture had it ever been liquid, it contained slag, and this obviously created difficulties in the manufacture of such thin-sectioned articles as watch and clock springs. By melting cemented bar in the crucible the slag was removed by the simple process of decantation.

There can be no doubt that from the very early days of crucible steel making attempts were made to make castings, but progress in those days was slow owing to the poorness of communication. For instance, there was a lapse of about 70 years before the process crossed the Atlantic. The first successful manufacturers of crucible steel in the United States were the brothers Garrard, who established themselves in business at Cincinatti in 1831, the family originating from Laxfield, Suffolk.

The earliest record of the production of steel castings in Germany is the manufacture of steel rolls using cast-iron moulds by Friedrich Krupp of Essen, as early as 1832. However, the first individual to make steel castings in non-metallic moulds by a process involving the use of wooden patterns was Jakob Mayer of Bochum. In his earlier days, his enterprise was confined to the manufacture of steel ingots for forging, and by 1850 ingots weighing up to 3 tons were being made. But from the very beginning Jakob Mayer was interested in producing finished steel articles by casting metal directly into sand or loam moulds. Success was achieved in 1851, and in the following year he exhibited some cast-steel bells in Düsseldorf. Several peals of bells were delivered to a number of churches in 1853.

The first steel castings in the U.S.A. were made by the William Butcher Steel Works, now the well-known Midvale Company, in the late 60's.

During the next fifty years there was an ever-increasing production of crucible-steel castings despite the inventions of Bessemer and Siemens, but the general run of material made for the British market was medium carbon steel.

In 1904 the late Mr. F. H. Crittall, of Braintree, founder of the metal window industry, received information that steel castings could be produced more cheaply than malleable iron castings for metal window-fittings. He therefore suggested that I should accompany his son, Mr. (now Sir) Valentine Crittall, to the Continent to investigate the matter. Together we visited a number of foundries in Holland and Germany, and discovered that this particular crucible process had its origin in a works at Bonn, operated by Monkemoeller & Company. An inspection showed it to be working very successfully, and large quantities of sound castings possessing very good physical properties were being produced. Unfortunately, they were quite unsuitable for Mr. Crittall's purpose, as the cost was too high and the finish too rough.

Because this process yielded *mild* steel castings, which in 1900 were still not produced in either Sheffield or Scotland, my company entered into an agreement with the Monkemoeller concern by which they undertook to supply the necessary furnaces and working details. A new foundry was built and production was started in September, 1906. The process consisted of melting Swedish wrought-iron scrap in plumbago crucibles, and the great secret was the addition of a small quantity of aluminium to the molten metal. The product was marketed as "Millennium wrought iron castings." These castings were well received by the engineering industry, and a constantly increasing demand was experienced, so much so that, after about four years, a search was made for a cheaper method of production whilst retaining the same high quality, a matter to which I will refer later.

The Bessemer Process

The Bessemer process became a practical proposition in 1858, when Robert Mushet provided the means of killing the steel by spiegeleisen or ferro-manganese additions. It should be realised that this process takes for granted the production of liquid cast iron, and this affords me an opportunity to interject an interesting American sidelight. It was in the year 1643 that the first iron foundry was established in the United States. It was situated at the village of Hammersmith, now called Lynn, about 10 miles from Boston. The second foundry was established three years later in the same area at Braintree, whilst the third was at Raynham.

It is interesting to observe that America had an iron-foundry industry almost one hundred years before Huntsman invented the crucible process, and, judging by the names of the villages, men from East Anglia were largely responsible for its initiation.

Whilst there is still some doubt as to whether the theoretical concept of the pneumatic process of steelmaking was due to Sir Henry Bessemer or Mr. William Kelly, it is generally agreed that its success was due to Bessemer's mechanical genius and Mushet's application of metallurgy. Unquestionably, the original Bessemer process was used for the production of steel castings. For instance, the Pittsburgh Steel Castings Company, a crucible-steel concern, in-

stalled in 1881 a 5-ton Bessemer converter for the express purpose of making steel castings. This date is prior to the appearance of the various modified tuyere systems introduced between 1880 and 1900. Moreover, it is interesting to note that varying angles of blast were envisaged by Sir Henry Bessemer in 1862. He arranged for horizontal blowing to take place in a converter mounted on axes which admitted the placing of the tuyeres at any depth below the surface of the metal or above it if desired.

In 1884 the Robert type of converter was put into practical operation for the purpose of making steel castings at the Stenay Works, Meuse, in France. Robert's early experiments at Stenay on the Franco-Belgian frontier were so successful that in 1887 M. Cambier-Dupret installed two converters of this type in his works at Marcenelle. M. Cambier has sent me, through M. Paul Fassotte, his impression of those early days. Conditions were invariably bordering on the hectic, and nothing was known as to the quality of the iron necessary to produce steel suitable for castings. Experience showed, however, that hematite imported from Middlesbrough gave the most reliable results. It is difficult to imagine the troubles that those early steelmakers must have encountered without a laboratory, or a knowledge of either blowing times or pressures. What would be described to-day as a reasonably good heat of steel was then an exception, and credence can be given to the story—for it was confirmed in English practice too—that a casting free from blowholes was looked upon with suspicion. The market at that time was the colliery industry situated around Charleroi, where the new steel castings at least gave results superior to those yielded by grey iron castings for rolling stock. As the quality improved, so new markets were found and steel castings achieved a recognised position as a material of construction. The early specifications were quite modest, and 26 to 28 tons per sq. in. tensile, associated with 12 to 13 per cent. elongation, was considered adequate. The making of steel was surrounded by a great deal of mystery and the blowers considered themselves as being endowed by Providence with magic knowledge. It was generally accepted that the blowers could detect by smell whether a heat of steel would be satisfactory or otherwise!

At that time it was considered essential for the pig-iron to carry a minimum of 2 per cent. silicon for the production of good steel, whilst a brick lining lasting more than ten heats was deemed to be of outstanding merit. Carburisation was carried out with coke and a high carbon content was normal, so that an annealing process lasting from eight to ten days was considered necessary to ensure adequate malleability.

Shortly after the installation of the Robert converter, a M. Léonard became a sub-contractor in the Stenay works. He bought the liquid steel, provided his own labour, and sold the castings. This portion of the works, which made quantities of steel axle boxes for the Compagnie du Nord was, and still is to-day, known as the "Congo"—the implication warranted in the early days being that the men worked and looked like niggers.

About the year 1889, a French engineer, M. Alexandre Tropenas, whilst he was managing the works of Société Industrielle de Fonderie de Bronze, induced his directorate to create a steel foundry based on the Robert steel-making process, but the tests, extending over six or eight months, were not deemed to be too reliable. However, he carried out a certain amount of experimental work that appeared to be very promising and when, in May, 1890, he met the late Mr. Alfred E. Wells, director in charge of Edgar Allen's steel foundry, discussion revealed that he was overcoming the very trouble that was being encountered in Sheffield. As a result, an arrangement was entered into for Mr. Tropenas to continue his experiments backed by the technical and financial resources of the English company. Success was finally achieved, and the system was extended to a good many foundries in the United Kingdom. Yet the true superiority of the Tropenas over the Robert is still a matter of speculation. A Robert converter was installed in the Atlas Works of John Brown & Company about 1890 and functioned with complete success. Moreover, about this time, there were fourteen Robert converters in the United States. Much of the later development of the Tropenas converter in the United Kingdom was due to the fact that it was manufactured and sold by Thwaites Brothers, of Bradford, whereas the Robert plant was not being "pushed."

It was not until 1897 that the Tropenas was installed in Germany, the first plant being ordered by the firm of C. Krautheim, of Chemnitz. The works manager of this concern, Herr Alexander Zenzes, a few years after set himself up in business as a manufacturer of small converter plants, having modified the design somewhat to suit German conditions, and in the course of time he installed a large number of these plants.

Stock Converter

There were no further inventions based on the original Bessemer system until 1906, when, at Darlington Forge, Mr. W. Stock started his experiments directed towards the melting by oil fuel and blowing in one and the same vessel. By

1908 he patented the process in all countries. The second installation was made at Thomas Summerson & Sons, of Darlington, and by 1913 the process had established itself not only in the United Kingdom, but also in France, Belgium and the United States.

The Siemens Process

It has been authoritatively stated that the Siemens regenerative gas-fired furnace was perfected prior to Bessemer's master patent of February, 1856, but though large-scale experiments were carried out both in England and in France, it was not until Dr. C. W. Siemens collaborated with Emile and Pierre Martin in 1864 that real success was achieved. The Martins contributed the steel-making process to the Siemens gas-fired furnace, and the process is known in English-speaking countries as the Siemens furnace and on the Continent as the Martin furnace. The process was introduced into America in 1868, at the works of the New Jersey Steel & Iron Company, of Trenton, New Jersey, but whether the plant was used for ingot-making or steel castings I have not been able to ascertain. In England, however, drawings were got out in 1862 by Dr. C. W. Siemens for Mr. Charles Atwood, the proprietor of Stanners Close Ironworks, Wolsingham, Co. Durham, for the manufacture of steel castings. This furnace was operated by Mr. William Shaw, founder of William Shaw & Company, Limited, of Middlesbrough, and it was here that the dredger buckets for the Suez Canal and some for the Panama Canal were made.

Though Krupps started to manufacture castings in 1863, they used no process other than the crucible until 1886, when they absorbed the Asthower works at Annen, this being the first concern to utilise the Siemens furnace for the manufacture of steel castings in Germany. Krupps certainly installed Siemens furnaces in 1871, and Bochum in 1873, and gradually other steel foundries used both the acid and basic open-hearth furnaces for making steel castings. Amongst the works employing the acid process was the Oeking works at Düsseldorf, the products of which became famous.

The Siemens furnace was introduced into the works of the Steel Company of Scotland in 1873, but it was not until 1880 that the process was used for making steel castings. The plant used initially was an 8-ton capacity furnace, for making general engineering castings. The capacity was increased from time to time until it attained two 40-ton furnaces.

Electric Furnaces

In the development of the electric furnace, Siemens certainly carried out some experiments and obtained patents. The Kjellin furnace was tried out in Sheffield about 1908 before the advent of the electrode furnaces. The Héroult, and the Stobie design of Electro-Metals furnace, were introduced into Sheffield in 1911, but these plants were not installed for the purpose of making steel castings, and historians credit my company in 1910 with the distinction of being the first foundry in the United Kingdom to install an electric furnace for the sole purpose of making steel castings. The crucible business having made good progress, there was a distinct incentive to search for a process capable of giving really mild easily-machinable castings at a lower cost and perhaps in larger quantity than the existing plant. Our friends, the Monkemoeller Company, of Berlin, were, in 1910, successfully making steel castings in the Stassano furnace, and they recommended me to make a similar installation. After visiting their works, I decided to study the potentialities of the Girod and Héroult furnaces installed in plants located in South-East France. I therefore visited these gentlemen, and on my return to England I decided to install a single-phase Héroult furnace. It was built by Campbell Gifford & Company and had a capacity of 2 tons. Current was applied through two round amorphous-carbon electrodes, and generated by an alternator driven by a Westinghouse gas engine. It produced good steel, but the refractory costs were very high owing to the electrodes being too near to the back wall, which involved rebuilding each week. The furnace worked regularly until 1916, when it was replaced by three larger furnaces of more modern design.

Unquestionably the United Kingdom lagged behind the Continent in the early development of the electric furnace. In 1905 Richard Lindenberg, of Remscheid, installed the first Héroult furnace, but this was for the manufacture of tool and special steels, the first installation for steel castings being made in 1908. About this time, A. Stotz, of Stuttgart, installed a Girod furnace.

In Italy, the pioneer work of the late Commendatore Vanzetti in both the field of electric furnaces and of steel castings is universally recognised. Whilst the British entered the field somewhat late, they made a serious contribution to design and wiring systems and some dozens of English-made furnaces were installed in France, Italy and Spain during and immediately after the war.

Although the U.S.A. were well to the fore in the development of the electric furnace, it was not until the same year that we started our electric furnace in Braintree that electric steel castings were made in America. Originally all the electric steel castings were made on basic

hearths, but during the war a change-over was made to acid hearths, and to-day we find that, with the exception of manganese steel, 90 per cent. of America's electric steel castings are made on acid hearths.

The first electric furnace in Switzerland was of the Héroult type. It was put into service in October, 1907, at the works of George Fischer of Schaffhausen—a firm now famous throughout the world. The founder, Johann Conrad Fischer, was a constant visitor to this country between the years 1790 and 1840, meeting most of the celebrities of the engineering world, including James Watt.

The first electric furnace was installed in Spain during 1917, at Bilbao, by my friend Mr. V. C. Faulkner, but it was not regularly used for steel castings manufacture.

High-Frequency Furnaces

At the present time the high-frequency furnace is used chiefly for the production of special tool steels. But in some instances it is used in the production of steel castings. In October, 1928, my company installed the first high-frequency furnace for the production of steel castings. It was employed in making magnetic letters, which are so small that in some cases as many as a score are required to weigh 1 oz.

Pulverised Fuel-Fired Rotary Furnaces

This process as adapted for steel making has scarcely emerged from the experimental stage. In 1930 a 5-ton Sesci type of pulverised fuel-fired rotary furnace was installed at Neufmanil in the French Ardennes. An experimental cast of steel was made and no insurmountable difficulties were encountered, and even though the product was somewhat wild, some of it was cast in moulds prepared to receive malleable iron. M. Georges Fosseprez, managing director of the Mons Foundry Company, was present on this occasion, and thereupon decided to install two small furnaces for making steel castings. Trouble was experienced initially in the direction of carbon control, but it was completely overcome by installing improved fuel-grinding machinery. About the same time as the Mons plant was started up, Mr. W. Scott, of Sir W. G. Armstrong Whitworth & Company, also started making steel castings in a Sesci furnace, but the plant was not used exclusively for this purpose. The first plant installed in Great Britain for the sole purpose of making steel castings was in the Crewe works of the London Midland & Scottish Railway Company, and it was officially put into commission in September, 1935.

The first steel castings were made in the Brackelsberg furnace in September, 1932, at Bofors, but systematic production can only be counted upon from June, 1933.

No address upon any phase of the history of steel castings can be complete without paying tribute to Sir Robert Hadfield's invention of manganese steel in 1888. For a long time this constituted the sole special steel made in the foundry, and gave to it an advertisement such as has never been equalled in any other branch of the industry.

The three major inventions from which the steel foundry has benefited were made by British subjects of foreign origin. Huntsman's parents were German, Bessemer's were French refugees, and the Siemens brothers were naturalised British subjects of German origin.

Finally, it is significant that only in very recent years has the steel foundry commanded the serious attention of research. But at the present time there are two research committees engaged on this important work, namely, the Steel Castings Research Committee of the Iron and Steel Institute and the Steel Castings Section of the Technical Committee of the Institute of British Foundrymen.

Acknowledgments

I wish to acknowledge with gratitude the help given me by the following gentlemen in the preparation of this address:—Mr. J. H. Cooper, M. Paul Fassotte, Mr. V. C. Faulkner, Dr. Th. Geilenkirchen, Mr. F. Nolan (Bofors), Mr. Thos. Nairn, Mr. H. A. Shaw, Mr. Chas. W. Townsend, Mr. N. F. Hindle, and the management of the George Fischer Company.

Following the Address, Mr. Hepworth voiced the thanks of the meeting to Mr. Lake, and endorsed his reference to the desire for peace.

The Edward Williams Lecture

Prof. W. L. Bragg, O.B.E., D.Sc., M.A., F.R.S., Nobel Laureate (Director, Cavendish Laboratory, University of Cambridge), then delivered the fourth Edward Williams Lecture entitled "The Atomic Patterns of Metals" (see page 25).

Mr. C. W. Bigg (Past-President), proposing a vote of thanks to Professor Bragg, assured him that there was no organisation in the country or in the world that was more anxious to strengthen the link between science and industry than was the Institute of British Foundrymen. The members were greatly appreciative of the honour Professor Bragg had done them in delivering the lecture, which alone was sufficient to mark the 1939 Congress as an event of very great importance in its contribution to the most advanced metallurgical knowledge.

Mr. V. Stobie (Past-President), seconding, expressed gratitude for the truly deep information which Professor Bragg had given in his lecture and for having honoured the Institute so early in a new series of lecture.

The vote of thanks was accorded enthusiastically, and the Congress then adjourned for luncheon.

After luncheon a technical session was held in the Ballroom of the Dorchester Hotel, when the following Papers were presented:—"Bonding Clays and the Properties of Synthetic Moulding Sands," by G. H. Piper, B.Sc., Ph.D. (presented on behalf of the British Cast Iron Research Association); "Core Shop Control," by J. J. Sheehan, B.Sc., A.R.C.Sc.I.; "The Selection and Testing of Cupola Refractories," by W. J. Rees, M.Sc.; "Gating with Special Reference to the Optimum Flow Conditions in the Molten Metal," by Dr. E. M. Lips (presented on behalf of the Nederlandsche Vereeniging van Gieterij-Technici); and "Some Iron Castings for Steelworks Plant," by J. Roxburgh.

Ladies were taken on a conducted tour of the Houses of Parliament and were entertained to tea on the terrace.

During the afternoon a meeting of the International Committee for Testing Cast Iron was held under the presidency of Mr. J. E. Hurst.

Government Reception

In the evening the delegates and their ladies were entertained by His Majesty's Government to a reception at Lancaster House, St. James's Park, London, W.1. The guests were received by the Lord President of the Council (the Right Honourable Viscount Runciman, P.C.) and Viscountess Runciman, and were entertained by light music by instrumentalists of H.M. Scots Guards. Refreshments were served and an interesting evening was spent examining some historic relics of London.

WEDNESDAY, JUNE 14

Two technical sessions were held simultaneously at the Dorchester Hotel during the morning. The following are the Papers which were presented:—Session A: "Developments in the Centrifugal Casting Process in Germany," by W. A. Geisler; "Specially Hard Alloy Cast Irons for Resistance to Wear," by M. M. Hallett, B.Sc., and Dr. A. B. Everest; "The Thermal Conductivities of High-Duty and Alloy Cast Irons," by J. W. Donaldson, D.Sc.; and "Defects in Electrically Melted Chilled Rolls," by Dr.-Ing. Franco Bondi (presented on behalf of the Federazione Nazionale Fascista degli Industriali Metallurgici). Session B: "The Effect of Melting Conditions on Light Alloys," by A. J. Murphy, M.Sc., S. A. E. Wells and R. J. M. Payne, B.Sc.; "The Effect of Melting Conditions on Gas Unsoundness in Metals," by G. L. Bailey, M.Sc.; "Pressure Die-Castings in Zinc and Aluminium Base Alloys, the Limitations and Possibilities of the Process," by A. G. Street, B.Sc., Ph.D.; "Light Alloy Melting Practice," by W. C. Devereux, F.R.Ae.S.; "The Influence of Repeated Remelting on the Properties of Light Alloys," by Dr. J. Koritta and Ing. M. Hajek, and "The Solution Heat-Treatment of Aluminium Casting Alloys," by Dr. R. Irmann.

A programme of alternative visits to either Messrs. J. Lyons & Company, Limited, Cadby Hall, Kensington, or the Wallace Collection, or the National Gallery, or the Tate Gallery, had been planned for the ladies, and good attendances were obtained at all the visits.

A buffet luncheon was taken by the delegates and ladies at the Dorchester Hotel, and afterwards the ladies visited Messrs. Derry & Toms, Limited, whilst the gentlemen inspected the following works: Messrs. J. & E. Hall, Limited, Dartford; Ealing Park Foundry, Limited, South Ealing; Sterling Manufacturing Company, Limited, Cubbitt Town; Messrs. R. & A. Main, Limited, Upper Edmonton; Messrs. Gillett & Johnston, Limited, Croydon; and Glacier Metal Company, Limited, Wembley.

ANNUAL BANQUET

In the evening of Wednesday, June 14, the Annual Banquet was held in the Ballroom of the Dorchester Hotel, where over five hundred delegates and ladies assembled to enjoy a brilliant evening.

Prior to the Banquet, the delegates and guests were received by the President and Mrs. Lake, and by Dr. Guido Vanzetti (President of the International Committee of Foundry Technical Associations) and Signora Vanzetti.

The President presided over the Banquet.

The Institute's principal guest was the Rt. Hon. Oliver Stanley, M.C., M.P. (President of the Board of Trade). Amongst other prominent guests were Sir William Larke, Mr. E. Bruce Ball, President of the Institution of Mechanical Engineers, and Mr. R. R. a-Ababrelton, Master of the Worshipful Company of Founders.

The Object of the Congress

The loyal toast having been honoured,

The Rt. Hon. Oliver Stanley, M.C., M.P. (President of the Board of Trade), proposing "The Foundry Industry and the Institute of British Foundrymen," first expressed his pleasure to be present and to join in the welcome to such a distinguished international gathering. In the world in which we lived, to-

day, he said, there were perhaps too few occasions of welcoming as many guests from overseas as were welcomed on that occasion; and it was a great satisfaction to feel that so many people had come from so many countries to join in a friendly, if to the layman wholly unintelligible, discussion on matters of common interest.

The history of the iron founding industry in this country—and no doubt its history has been very much the same in other countries—made it a matter of peculiar interest and of a considerable amount of pride to the outside industrial observer. It was a history unfortunately only too common with the passing of years, a history which must contain within itself a great many personal tragedies. It was an industry which for generations, and indeed, for centuries in this country was pre-eminent, until in the middle of the last century it had had an immense variety of uses and was, so far as this country was concerned, pre-eminent in the metallurgical world. But, just as the cotton industry, for example, was challenged by new textiles, and the railways and canals were challenged by new means of transport, so in the middle of the 19th century the iron industry was challenged by the growth of the steel industry, with new and cheaper methods. There would have been a great deal of excuse for people in those days, faced with a new and apparently overwhelming challenge, with the decay of the historic industry to which they belonged, with the decline of family businesses which for generations had enjoyed prosperity, if they had looked to the future with despondency and despair and with a spirit of surrender to the new forces.

Sphere of Research

It said a great deal for the industry and for the Institute that the challenge was not met in that way, but was met with courage, with enthusiasm and a determination to meet the new challenge with new methods. The success of the answer to that challenge had been due very largely to the Institute. To him the most interesting part of its work had been the emphasis it had placed upon and the assistance it had given to the work of research. In the first place, it had done a great deal in convincing individual units within the industry that the pooling of scientific information was not a loss to the individuals who gave it, but that it was the gain of the industry as a whole, and that the gain of the industry was the gain of every individual composing it. In the past, and in some industries even today, one found individual firms believing that they gained by keeping to themselves the scientific information which they might have acquired from the results of their own research. But how often had one seen that research reached its full value when it was pooled, that the value of the little bit one learned was doubled when placed alongside the little bit that somebody else had learned. In that respect the Institute and its propaganda had been a real lesson to the industries of this country.

That co-operation within the industry, however, had not been confined to this country. It had encouraged a similar co-operation between the units of the world, between foreign countries and ourselves. So we had in the industry people of all countries placing at the service of others the experience and knowledge they had gained. In doing so, they were helping the industry as a whole, they were helping their own countries, and were helping the world.

Perhaps just as important as the exchange of scientific knowledge was the exchange of knowledge of human beings; and not the least important part of the Congress was that each got to know, not only the problems of an industry, but the problems of each other. We all got to know thereby something of the other person's difficulties, something of his point of view, of his fears, his suspicions and his hopes; and so the first step was taken towards understanding each other. When we understood each other we had taken the first and perhaps the longest step to peace.

An Industrial Metamorphosis

The President, responding, thanked Mr. Stanley most sincerely, on behalf of the Institute and the foundry industry, for the good wishes expressed and for the felicitous way in which the toast was proposed. He was conscious, he said, that in responding to the toast on behalf of the industry, he had undertaken a responsibility of considerable magnitude. The foundry industry was proud that it represented one of the oldest crafts in the world—the art of casting metals. It was proud of its traditions; but sometimes those very traditions, by reason of their age and of the tenacity with which they were held, might prove to be a handicap to progress. The industry was endeavouring to free itself from any such handicap.

The establishment of the Institute of British Foundrymen, 35 years ago, was due to a desire to apply to its ancient craft the results of modern scientific investigation and to govern it in accordance with modern conditions. The ideals which were set in those days had been steadily pursued ever since, and to-day the industry as a whole was up-to-date in its methods, in the application of science to its processes and in its equipment. The progress made in the indus-

try during the last quarter of a century was remarkable, and that progress was continuing at an ever-increasing pace. Progress even during the last five years had been so extraordinary that it was almost impossible to keep pace with the many new departures which had come into being. He need only point to the developments in his own branch of the industry—steel foundry practice—to the very great developments in iron casting, and to the phenomenal growth of certain branches of non-ferrous foundry practice, particularly the founding of the light alloys.

The Institute of British Foundrymen stood for technical progress in the industry, and it was the technical or professional Institute of the industry. There were similar organisations in many other countries, which worked together very closely with the Institute. They all exchanged information annually, they held International Foundry Congresses, and they were the means of increasing the general level of all technical development; and, what was perhaps less easy to define, but even more important, they were the means of forming and maintaining close friendships between foundrymen of the different industrial countries of the world.

Ten years had elapsed since the International Foundry Congress was held in Great Britain, and at that time the President of the Congress was Mr. Wesley Lambert, whom they all welcomed on the present occasion (applause). The Congress was glad to be able to provide a platform for the interchange of ideas through the many technical Papers which were being presented; British foundrymen were glad to be able to show their overseas friends something of what was being done in the industry in this country, and they were delighted also to be able to reciprocate the hospitality and the friendly respects which many of them had enjoyed during their visits to the foundrymen of other countries.

Finally, the chairman again thanked Mr. Stanley for the interest he had shown in the Congress in many ways, for his presence at the Banquet, and for his very encouraging speech.

A Composite Toast

Mr. Barrington Hooper, C.B.E. (President of the London Branch of the Institute) proposed, in his usual witty manner, the toast of "The Ladies, Guests and Overseas Visitors."

Addressing his remarks first to the ladies, he welcomed them heartily—their charm, their grace and their beautiful dresses. The ladies of today, he was told, like the prophets of old, had little honour in their own country. After entertaining the gathering for a while with apt stories, he assured the ladies, in the name of the Institute of British Foundrymen, and that wider gathering, the International Congress, that the men were delighted to welcome them.

Coming to his second chapter, he said it was a delight to extend to the many guests of the Institute a cordial hospitality. In a special welcome to the Rt. Hon. Oliver Stanley, he said the Congress was honoured by the fact that he had found time to attend, in the midst of his multifarious duties. He was a very fine English gentleman, and the son of one of England's most beloved citizens. (Applause). Possibly no Department of the Government was so vital to the industry as was the Board of Trade. The industrialists present could manufacture everything the engineer required; and through the Board of Trade they received assistance in marketing those products in adequate quantities.

Extending a most cordial welcome to the wonderful array of representatives of many countries, he recalled the many happy memories which British foundrymen retained of their visits abroad to the various Congresses and to the marvellous hospitality extended to them there. The warmth of their greeting in those other countries lived in their memories always.

Mr. Barrington Hooper made special mention of some of the distinguished visitors from abroad, though not all, because the list would have been very lengthy. As he said, his list was not comprehensive, and each of them was greeted with loud and prolonged applause. They were:—Mr. R. Deprez and Mr. J. Léonard (Belgium); Dr. Mont. Fr. Pisek and Ingenieur A. Benda (Czecho-Slovakia); Mr. J. Lobstein and Professor A. Portevin (France); Prof. E. Piwowarsky and Dr. H. Jungbluth (Germany); Ing. F. W. E. Spies and Dr. K. J. van Nieukerken (Holland); Mr. R. Erdös (Hungary); Dr. M. Barigozzi and Dr. R. Dupuis (Italy); Mr. L. Brasseur and Mr. A. Henks (Luxembourg); Prof. C. Gierdziejewski and Ing. J. Lutoslowski (Poland); Dr. H. A. Schwartz and Mr. W. R. Bean (U.S.A.); and Begs. Y. Granström (Sweden). Finally, he paid tribute to Dr. Vanzetti, of Italy.

Reply to the Guests

Dr. Guido Vanzetti (President, International Committee of Foundry Technical Associations), replying on behalf of the guests, said that although the delegates from overseas were guests, they really felt at home. Some of them would remain in this country for more than three weeks, and they always received here a warm and charming reception. The Congress, when held in England, always proceeded so smoothly that one felt that the organisation of a world congress was the easiest thing to do, but his dear English friends—Mr. Lake, Mr. Hep-

worth, Mr. Barrington Hooper, Mr. Delport, Tom (Mr. Makemson) and others—those who had experience of the work knew that it was a difficult task. He paid a tribute to them, and expressed thanks also on behalf of the ladies for all that had been done to make their stay in this country delightful and interesting.

Looking forward to the International Congress to be held in Italy next year, he expressed the hope that as many as possible would give his fellow countrymen and himself the opportunity to reciprocate the hospitality extended to them in this country. In the name of the real friendship existing between them, he drank to the health of all his hosts, to their prosperity, to their industry, and to their country.

The Health of the President

Mr. J. Hepworth, J.P., M.P. (Past-President of the Institute), proposed the health of the President, Mr. Lake, at the same time congratulating the Institute and those responsible for his appointment, because the Institute could not have had a better man to grace that office.

(The toast was received with musical honours; and in the midst of the acclamation, an overseas delegate presented a bouquet to Mrs. Lake.)

The President, responding, thanked all who had contributed to the marked success of the Congress. In the first place he thanked the owners of works who, at considerable inconvenience, had thrown open their works to the delegates, and in the majority of cases had offered entertainment. He thanked also those who had contributed to the funds which had made the Congress possible, and all the members who had worked to that end. Though it was impossible to mention any number of them by name, he felt compelled to make one or two exceptions. Thus, he paid tribute to Mr. V. Delport (Secretary of the London Committee); to Mr. C. C. Booth (President of the London Branch); to Mr. Barrington Hooper, who had been responsible for most of the arrangements made for the entertainment of the delegates, and indeed, had been both the architect and the builder of the Congress; and to the wonderful organising ability of the General Secretary, Mr. Tom Makemson, and the splendid assistance of Mr. J. Bolton (Assistant Secretary) and their lady assistants. He thanked them all most heartily for their services to the Institute.

During the evening the President presented to Mrs. Hepworth, on behalf of the Past-Presidents of the Institute, a silver bowl as a memento of the past year, during which her husband had served the Institute as President.

The remainder of the evening was devoted to dancing.

THURSDAY, JUNE 15

For the gentlemen, the following visits to works were arranged for Thursday, June 15: (1) Whole day visit to the Ford Motor Company, Limited, Dagenham; (2) morning visit to Messrs. Bawshawe & Company, Limited, Dunstable, and afternoon in Whipsnade Zoo; (3) morning visit to Messrs. Crane, Limited, Ipswich, and afternoon visit to Messrs. E. R. & F. Turner & Company, Limited, Ipswich, and (4) morning visit to Messrs. Belling & Company, Limited, Enfield, and in the afternoon an inspection of the metallurgical section of the National Physical Laboratory. All of the visits were successful and enjoyable largely owing to the most generous hospitality which was extended in all cases by the managements of the works.

One party of ladies went by coach to Luton in the morning, and there were shown the hat factory of Messrs. Currant & Creak, Limited, before joining the group of gentlemen who had visited Messrs. Bagshawe's foundry. These ladies and gentlemen were the guests of Messrs. Bagshawe & Company, Limited, for luncheon, and spent the afternoon at Whipsnade Zoo. No arrangements were made for the remainder of the ladies during the morning, but in the afternoon a visit was made to the Hall of the Worshipful Company of Barbers.

Mr. and Mrs. Lake's Reception

In the evening of Thursday more than five hundred delegates and ladies were received by the President (Mr. W. B. Lake, J.P.) and Mrs. Lake at their Reception and Dance at the Dorchester Hotel. Refreshments were served during dancing, and a most enjoyable evening was appreciated by all those who were able to accept Mr. and Mrs. Lake's invitation to be present.

FRIDAY, JUNE 16

The Congress resumed at 9.30 a.m. at the Dorchester Hotel, where duplicate technical sessions were held. In Session A the following Papers were presented and discussed:—"Cutting Tools for Cast Iron," by H. Beeny, M.Met.; "Optimum Blast Volume for Cupola Practice," by Dr.-Ing. N. Czyzewski (presented on behalf of the Stowarzyszenie Techniczne Odlewnikow Polskich); "Some Notes on the Design and Operation of the Open Hearth Furnace for Melting Malleable Cast Iron," by G. R. Shotton; "Pitting Corrosion of Steel and Cast Iron Pipes," by Dr.-Ing. L. Olsansky; "Some Aspects of Malleable Cast Iron Pipe Fittings Manufacture," by C. Zehnder, and "Laws Governing Cupola Operation," by Dr.-Ing. Massimo Barigozzi (presented on behalf of the Federazioni

Nationale Fascista degli Industriali Meccanici). The following Papers were presented for discussion in Session B:—"Process of Crystallisation in Commercial Alloys," by Dipl.-Ing. W. Patterson (presented on behalf of the Technischer Hauptausschuss für Giessereiwesen); "The Progress of Inverse Segregation during Solidification," by Dr. J. A. Vero (presented on behalf of the Magyar Ontodei Szakemberek Egyesulete); "The Preparation of Alloys," by Prof. A. Portevin (presented on behalf of the Association Technique de Fonderie); "Controlled Solidification of Castings made Possible by Calculation," by Ing. N. Chvorinov (presented on behalf of the Ceskoslovensky Odborny Spolek Slevarensky); "Copper and Copper Alloys for Electrical and Thermal Conductivity Applications," by H. J. Miller, M.Sc.; and "The Compounding of Alloys," by the Technical Committee of the Association Technique de Fonderie de Belgique.

At 11 a.m. a meeting of the International Committee of Foundry Technical Associations was held under the chairmanship of Dr.-Ing. Guido Vanzetti, and afterwards the Committee, on behalf of the foundrymen of the world, laid a wreath on the Tomb of the Unknown Warrior in Westminster Abbey.

Many ladies participated in a sightseeing drive through the West End and City of London during the morning, and, after luncheon, another party left the Dorchester Hotel by coach for a visit to Hampton Court Palace and Kew Gardens.

Under the chairmanship of Mr. W. B. Lake, a joint meeting with the Iron and Steel Institute was held in the Ballroom of the Dorchester Hotel during the afternoon. Five Papers on steel foundry practice were presented and discussed. These were:—"Development and Organisation of Steel Foundry Research," by W. J. Dawson; "Radiography in Iron and Steel Founding," by F. W. Rowe, B.Sc.; "Notes on Dry Sand Practice for Steel Castings," by C. J. Dadswell, Ph.D., B.Sc., Ing.E.S.F., and T. R. Walker, M.A.; "The Renaissance of the Steel Casting and the Rôle of the Metallurgist," by F. A. Melmoth (presented on behalf of the American Foundrymen's Association); and "The Relationship Between the Quality of Iron and Steel Castings and the Nature of Materials of the Melt," by Dr.-Ing. P. Bardenheuer.

At 5.30 p.m. Mr. W. B. Lake in a short speech closed the Congress.

SATURDAY, JUNE 17

Soon after nine o'clock nearly two hundred delegates and ladies had assembled at Paddington Station to participate in the Excursion which had been arranged to Windsor Castle and on the River Thames. The journey to Windsor was made by rail, and after an inspection of the Castle, luncheon was taken at the Castle Hotel. In the afternoon the party boarded the steamer "Cliveden" for the journey up the River to Bourne End, from where a return train to London was taken.

ADDITIONAL CONGRESS PAPERS

Although not discussed at any of the technical sessions, the following Papers were also presented to the Congress:—"Foundry Education in Great Britain," by J. G. Pearce, M.Sc., M.I.E.E., F.Inst.P.; "The Work of the Technical Committee," by J. W. Gardom; "Recommendations on Three Leaded Bronze Bearing Alloys," by the Non-Ferrous Sub-Committee of the Technical Committee; and "Industrial Legislation in South Africa," by A. H. Guy (presented on behalf of the South African Branch of the Institute of British Foundrymen).

POST CONGRESS TOUR

The comprehensive tour of British foundries which had been arranged to follow the International Foundry Congress, started on Sunday, June 18, when almost one hundred members of the Congress, representing seventeen nationalities, left Paddington Station, London, by train for Banbury. Here the party detrained and proceeded on a sightseeing motor coach drive *via* Sulgrave Manor, Leamington, where luncheon was taken. Kenilworth, Warwick, and Stratford-on-Avon to Birmingham, which was reached about 7 p.m.

Birmingham

Mr. A. Tipper, Branch-President, welcomed the party on behalf of the Birmingham Branch of the Institute, representatives of which spent a happy and informal evening with their guests.

On Monday morning, June 19, the gentlemen visited the works of the Austin Motor Company, Limited, where they were kindly entertained to a luncheon presided over by the Rt. Hon. Lord Austin of Longbridge. Mr. R. Erdos (Hungary) and Mr. W. B. Lake proposed a vote of thanks to Lord Austin and the company. The

afternoon was spent in the Soho Foundry of Messrs. W. & T. Avery, Limited, who were thanked by Mr. W. Hanks, of Australia.

The ladies enjoyed a pleasant sightseeing drive into Worcestershire during the day, and in the evening joined the delegates as guests at a dinner given by the Birmingham, Coventry and West Midlands Branch. Mr. A. Tipper, who presided at the dinner, and Mrs. Tipper received the guests and expressed the pleasure of the Branch at being able to entertain so many overseas visitors. Replies on behalf of the guests were made by Mr. Lutoslawski (Poland), Mr. Amundsen (Norway), and Mr. Rauterkus (Germany). Dancing followed.

On the following morning, Tuesday, the works of the Midland Electric Manufacturing Company, Limited, were visited before the party entrained for Derby at 12.40 p.m.

Derby

Mr. and Mrs. C. W. Bigg and other representatives of the East Midlands Branch welcomed the visitors on arrival at Derby. Motor coaches were waiting and while the ladies were taken on a visit to the Royal Crown Derby porcelain factory and through the beautiful parks in the locality, the gentlemen were given the opportunity of inspecting the foundries of Ley's Malleable Castings Company, Limited, Rolls Royce, Limited, and Qualcast, Limited.

Accommodation for the night was provided at Matlock, where, in the evening, Mr. R. H. Buckland (Branch-President) presided over a dinner at which the East Midlands Branch acted as hosts. Mr. R. Erdos, the Mayor of Derby (Alderman D. S. Butler, J.P.), Dr. M. Barrigozzi (Italy) and Signor Mario Olivo (Italy) replied to the toast of "The Guests," which was proposed by the Branch-President.

On Wednesday, June 21, the delegates visited the works of Bamfords, Limited, Uttoxeter, the Stanton Ironworks Company, Limited, and International Combustion, Limited, and the ladies made an all-day excursion into Derbyshire, returning in time to join the gentlemen on an evening train to Sheffield.

Sheffield

Within an hour of arrival at Sheffield those on the tour were being entertained at a dinner as the guests of the Sheffield Branch, whose President, Mr. Malcolm Brown, and the Lord Mayor of Sheffield welcomed the party. Mr. Rousseau, of France, replied on behalf of the visitors who, after dinner, were taken on a short motor coach drive through the beautiful scenery in the neighbourhood of Sheffield.

Visits to Hadfields, Limited, and Firth-Vickers Stainless Steels, Limited, were made by the delegates during the morning of Thursday, June 22, and after luncheon the foundries of the English Steel Corporation, Limited, and Davy & United Engineering Company, Limited, were inspected.

Manchester

The ladies were entertained during the day by the ladies of the Sheffield Branch members. An early evening departure from Sheffield enabled the visitors to reach Manchester in time for an informal reception by the Lancashire Branch, on whose behalf Mr. A. L. Key (Branch President) and Mrs. Key, and Mr. H. V. Grundy (Chairman of the Reception Committee) and Mrs. Grundy welcomed the guests.

In the company of Lancashire ladies, the visiting ladies spent Friday, June 23, at Chester. The gentlemen made a morning visit to Mather & Platt, Limited, and after luncheon were shown the works of the Metropolitan Vickers Electrical Company, Limited.

The Lancashire Branch entertained the visitors to a dinner at the Midland Hotel in the evening, when Mr. R. Greenwood proposed the health of "Our Guests," and this was responded to by Mr. Y. Granstrom (Sweden), Mr. F. B. Bahker (Holland), and Mr. F. C. Krebs (Denmark). Sir Frederick J. West, C.B.E., J.P., proposed the toast of the Institute and the Lancashire Branch, to which Mr. W. B. Lake and Mr. A. L. Key replied.

The first part of the Post Congress Tour was brought to a close at mid-day on Saturday, when, after inspecting the works of Craven Bros. (Manchester), Limited, the Chairman (Mr. R. Greenwood) and the company entertained the delegates to a luncheon at the works.

About sixty members of the party departed from Manchester in the afternoon, while the remainder, including some additional members, started on the second portion of the Tour, by train to Windermere.

Scotland

Sunday, June 25th, was spent quietly in the Lake District, and in the evening the party proceeded by road from Windermere to Keswick and entrained for Glasgow. Monday, too, was a restful day, on which the party was taken by steamer down the Firth of Clyde as the guests of the Scottish Branch. On the trip Sir James Lithgow (Chairman of the Scottish Reception Committee) welcomed the delegates and their ladies, on whose behalf Mr. Polczarski and Mr. Harasowski (both of Poland) responded.

An informal reception was held in the evening, when Mr. J. Sissiner (Norway) explained

that the overseas delegates had learned that Mr. Lake would be leaving the Tour on the following Wednesday. On behalf of the overseas delegates and their ladies he then made a presentation to Mr. Lake, who briefly responded.

Tuesday, June 27, was given over to works visits in Glasgow. The morning programme allowed the gentlemen to visit either Harland & Wolff, Limited, Babcock & Wilcox, Limited, or G. & J. Weir, Limited. The ladies meanwhile enjoyed a motor drive around the "Three Lochs" and subsequently joined the gentlemen at a luncheon given by the Scottish Branch and presided over by Mr. Dan Sharpe (Convener of the Reception Committee).

The works of the Singer Manufacturing Company, Limited, the Carron Company, and Glenfield & Kennedy, Limited, were visited in the afternoon, and a most enjoyable day was brought to a close by the brilliant Civic Reception by the Lord Provost and Corporation of Glasgow in the City Chambers.

An early departure from Glasgow was made on Wednesday, June 28, and before luncheon there was a drive to the Forth Bridge. Sightseeing in Edinburgh occupied the afternoon, and the happy days in Scotland were brought to a conclusion by a dinner given by the Scottish Branch. Mr. W. Rottmann (Germany) proposed the toast of "The Institute of British Foundrymen," and Mr. T. Makemson, Secretary, who participated in the complete tour, responded. The health of the overseas guests was proposed by Mr. D. Sharpe. A reply was made by Mr. Pierre Denis, of Belgium, who particularly thanked Mr. J. Bell, Scottish Branch Secretary, for the most able way in which he had arranged the Scottish section of the tour. Mr. Bell briefly responded.

Newcastle

On Thursday morning the party travelled on by train to Newcastle-upon-Tyne, where Mr. E. B. Ellis (Branch-President) and other members of the Newcastle Branch welcomed them and entertained them, on behalf of the Branch, to a luncheon. There was a motor drive to the Roman Wall in the afternoon, and in the evening Mr. Ellis presided over a dinner given by the Branch. The toast of "The Guests," which he proposed, was responded to by Mr. Sissiner, whose remarks were supported by Mr. T. Fujita, of Japan, and Mr. Harasowski, who spoke in seven languages, including Japanese.

Mr. R. Erdos, on behalf of the overseas delegates, then paid a tribute to Mr. T. Makemson, Secretary of the Institute, for his work in connection with the Congress and Tour, and on behalf of the delegates he presented a silver cigarette box to Mr. Makemson, who briefly responded.

Friday, June 30, the last day of the tour, was spent in visiting the works of C. A. Parsons & Company, Limited, and Sir W. G. Armstrong Whitworth & Company (Ironfounders), Limited. Luncheon was again provided by the Newcastle Branch, who had also arranged for the ladies to be taken to Whitley Bay in the morning.

The Scandinavian members of the Tour remained in Newcastle, from whence they returned to their countries on the following day. The remaining members of the party returned to London by "The Coronation" in the evening

Paper No. 657

Atomic Patterns of Metals

By Professor W. L. BRAGG, O.B.E., M.C., D.Sc., M.A., F.R.S., Nobel Laureate
(The Cavendish Laboratory, Cambridge)

You are all familiar with the crystalline nature of metals. If a piece of metal is polished and etched with a suitable reagent, the crystals of which it is composed are revealed as a mosaic fitting together like the stones in crazy paving. The separate crystals stand out distinct from each other because the reagent etches the surface of each into minute parallel facets which reflect the light in a characteristic way. Further, this technique of polishing and etching has become extremely useful in the study of metals, because the mechanical properties of a metal are found to depend on the size and shape of the crystals of which it is composed. While in a pure metal the crystals are all of the same kind, though differently orientated, in the general case of an alloy, two or more types of crystal may be present, and changes in the shapes of the crystal blocks cause variations in mechanical properties which are so extreme that it is hard to believe one is dealing with essentially the same material.

One has merely to think of the range of properties exhibited by iron containing a little carbon to realise anew how remarkable this phenomenon is. The only constituents are nearly pure iron (ferrite), the carbide of iron (cementite), and in some cases graphite, yet depending on the way these crystals are interleaved with each other and on their relative amounts we get the whole gamut of properties of cast iron, wrought iron, mild steel, hard steel, and so forth, with many finer aspects of behaviour and character about which you know so very much more than I do. The heat-treatment and forging or cold-working which finally gives the metal the desired properties does this by moulding the crystals of the mosaic into certain shapes. By experience, the appearance of the etched specimen under the microscope has been correlated with its mechanical properties; hence the value of the microscope as a useful tool in the industrial laboratory.

X-Ray Analysis

My theme in this lecture is the new technique of X-ray analysis as applied to the structure of metals. The crystalline nature of metals implies that the atoms are arranged in patterns. By means of X-ray analysis, we can not only discover the pattern in any particular case, but can also get more detailed information about the size and shape of the regions of perfect pattern, the way in which atoms of more than one kind are incorporated into it in an alloy, internal strain, and so forth. The information yielded by X-rays can be summed up by saying that it is what we would obtain if we had a microscope so powerful that it enabled us to see the atoms in the metal. One may picture a specimen which has been polished and etched in the usual way. Ordinary microscopic examination shows the mosaic blocks, layers, needles, etc., which we have learnt to interpret as regards their influence on the properties of the metal. We now swing round a higher-powered objective on to the axis of the microscope (X-ray analysis), and as we move the specimen about beneath it we see all the atoms drawn up in the serried ranks of a crystal pattern. If it is an alloy of one metal with a small proportion of another, atoms here and there are different from the rest, and we can see how the structure embodies these foreign atoms, whether they are arranged at random, or regularly, or get into clusters or sheets. The interpretation of the X-ray results is not so straightforward and simple as my analogy would indicate, for it depends upon a rather profound and often difficult analysis of the diffraction of X-rays by the material, but in principle we have an X-ray microscope at our disposal.

It is clear that such an examination provides a wealth of information which we cannot afford to neglect, and that we must see how it can be used to improve technical methods. A new method such as this is developed first of all by scientists working in a University laboratory. They have little or no experience of the technical side, and when they describe the new knowledge they have obtained, their opposite numbers in industry are apt to say with perfect truth, " This is all very interesting, but it does not help us to understand why a certain alloy is good and another bad, why one heat-treatment gives the desired result while another is disastrous; in fact, it seems to have little bearing on the wealth of knowledge which we have acquired by experi-

ment and observation over many years." By degrees, however, the gap is bridged. Tentative experiments with the new X-ray methods show that the information about atomic structure they give can be correlated with desirable or undesirable properties, and a body of empirical knowledge is acquired. Further, in a way which is difficult to define but none the less important, a new method like X-ray analysis furnishes us with new ways of thinking. It helps to "explain" the properties of metals, and although the explanation may be at first a very dubious and lame one, yet any guiding idea is better than none. When trying new combinations of metals or treatments there are so many possible permutations and combinations that any clue which indicates likely lines of advance is better than mere trial and error methods.

Industrial Application of Science

X-ray analysis is just at this stage when its importance in industry is beginning to be recognised, and like others who have devoted themselves to its development, I am very keen that industry should take full advantage of its possibilities. As I see it, there are two ways in which as pure scientists we can further this end. In the first place, we should try to express the results of our researches in as clear and direct a way as possible, in order that the busy industrialist, who has no time to wade through the mass of detailed observations and analysis with which we must support our conclusions in scientific Papers, may appreciate what we have found out. I rank this as of the first importance, and think that as scientists we are often to blame for our neglect to do our duty in this respect. The trouble nowadays is not so much any lack of new knowledge, but that there is such a profusion of Papers that no one can keep properly abreast even of his own particular subject. As I believe Sir Josiah Stamp put it recently, knowledge is being mined in laboratories and buried in periodicals, just as gold is dug out of the earth with great labour and buried in the vaults of the banks. The present lecture is an attempt on my part to fulfil my duty to describe as simply as I can what we have found out and what we are trying to do.

In the second place, it is our duty in the Universities to train young men who are adepts at this particular kind of work and who can be taken over by industry. It is no good minimising the training which is required. One must not think that it is only a question of buying the necessary apparatus and asking any laboratory worker to employ it at odd times. An X-ray analyst needs as long and specialised a training as an organic chemist or metallurgist if he is to take advantage of all the tricks of the trade which we have learnt by bitter experience. To employ a man who has not had this advantage is to court disappointment. On the other hand, as I think we can claim that the experience of several big concerns in this country has shown, an X-ray analyst of the right kind, when let loose in an industrial laboratory, can attack problems from an entirely new angle and arrive at solutions which have previously been unattainable. I am personally extremely keen to see the new method used in the right way, and welcome the opportunity afforded by this lecture to further the good cause.

Interpretation of Phenomena

The analysis of crystal structures by X-rays is carried out by observing how the crystals scatter or diffract a beam of X-rays falling upon it. The regular serried ranks of atoms scatter wavelets as the X-ray waves pass over them, and these wavelets combine to build up diffracted waves in certain directions according to well-known optical principles. The art of X-ray analysis consists in deducing, from the distribution and strength of these diffracted beams, the nature of the atomic pattern which has produced them. It is a curious and rather specialised art, because one cannot proceed by any cut and dried method. It is more like solving a cross-word puzzle than applying a logical mathematical analysis. A series of guesses must be made, and when the right one is hit upon everything falls into place with such completeness that the correctness of the solution is obvious. A first object is the discovery of the crystal pattern, but in the case of metal structures this is often of a simple nature and is easy to recognise. Further refinements consist in noting how the atoms (if more than one kind is present) are distributed amongst the points of the pattern, how extended are the regiments of atoms which have a pattern with the same orientation, whether there are certain preferred directions of orientation, and so forth. These points, which will be dealt with more fully below, assume a very great importance in the study of metals and alloys, and demand a thorough knowledge of physical optics and long experience in interpretation.

The Powder Method

The most widely used method of studying the structure of a metal or alloy is known as the "powder method." The alloy is reduced to a state of fine powder by filing or grinding, and a speck of this powder (equivalent to the amount of metal in a pin's head) is attached to a fine hair or placed in a very thin glass

tube. The powder is mounted at the centre of a cylindrical "camera" and a photographic film is placed around its rim. A slit system allows a beam of X-rays to fall upon the speck of powdered material, and the diffracted X-rays are registered by the film. This is a method of universal application, since it is always possible to obtain the alloy in a powdered form, and it is easy to quench or anneal the powder and so get it into any desired condition. Often, however, the very act of powdering destroys some characteristic of the metal in bulk which we wish to study. In such cases one resorts to the less convenient method of allowing the X-rays to fall upon the surface of an entire specimen, and recording the rays which are diffracted backwards upon a film or plate. In special cases it may be possible to pick out single crystals of the alloy, or such crystals may form in a thin wire, and this permits a more thorough analysis of the diffraction. Whatever the method, the principle is that of recording the diffracted beams and deducing the nature of the atomic pattern which gave rise to them.

Face-Centred Cubic Structure

The structures of most metals belong to one or other of two very simple types, which are those we would expect for a number of spheres of equal size packed together tightly. Both these structures have "cubic" symmetry. Imagine a set of cubes stacked together in every direction, and then suppose the cubes to be represented by rods along the edges, making a sort of scaffolding as if we were erecting the steel framework of a building intended to have cubical rooms. We are going to sweep away this scaffolding eventually, it is merely a scheme of reference to describe how the atoms are arranged. In the first type of structure, called "face-centred cubic," an atom is placed at every cube corner and at the centre of every cube face. This is actually one of the most efficient ways of packing balls of a given size together. It would obviously be inefficient to place them at the corners of the cubes alone, for then the balls would ride on top of each other and leave large gaps. By placing them at cube corners and cube centres the greatest possible proportion of the available space is taken up, each atom having twelve neighbours packed tightly round it. The second way is not quite so space-saving, but nearly so. The atoms are placed at the corners of the cubes and at their centres, the so-called "body-centred cubic" lattice.

Copper, nickel, aluminium and lead, amongst the common metals, crystallise with a face-centred cubic structure, whereas iron and chromium have the body-centred cubic structure. Although the causes which lead to a metal taking up the one structure or the other are as yet imperfectly understood, it is clear that in the case of iron the balance is easily tipped one way or the other. Pure iron is body-centred at room temperature, becomes face-centred at 900 deg. C., and changes back to body-centred at 1,400 deg. C., not far below its melting point. This vacillation, as is well known, is an essential feature in the metallurgy of iron. Zinc and tin are examples of metals which have more complex structures.

Binary and Complex Alloys

When we pass from the structures of pure metals to those which are formed when two or more metals are alloyed together, the story becomes much more complicated. I may draw examples from a programme of research which has now been going on in my laboratory for several years under the direction of Dr. Bradley, who has been responsible for many developments of the powder method of X-ray analysis. We have been taking the common metals, iron, nickel, cobalt, copper and chromium, and examining their alloys with each other and with aluminium. I have put it in this way because there is a closer kinship between the members of the first-named group than between any of them and aluminium. Their alloys with each other are either body-centred or face-centred cubic like the pure metals, or are a mixture of body-centred and face-centred crystals when more than one phase is present. If aluminium is alloyed with them and while its quantity is still small, the simple structure of these metals continues to assert itself. The aluminium falls into line with them, and we get a structure in which, for instance, all the atoms are at the corners and face centres of cubes, but some of them are aluminium and the rest the atoms of the other metals. For brevity, the face-centred structures may be called α, and the body-centred β, irrespective of the constituent metals. The Greek letters α, β, γ were used for different types of alloys before their atomic patterns were known, and it is now somewhat difficult to devise a consistent nomenclature. Body-centred iron is conventionally called α for instance, and the face-centred alloys of copper are also called α. In the present general treatment it appears justifiable to override the former conventions and correlate these letters with structure types, because we otherwise get into such hopeless confusion when we come to deal with alloys of three or more metals. We may summarise by saying that the alloys of iron, copper, nickel, cobalt and chromium with aluminium are α or β, or a mixture of α and β, as long as the proportion of aluminium is not high. The iron-aluminium

alloys, for instance, are body-centred until the number of aluminium atoms exceeds that of iron atoms.

With increasing aluminium the structures become very complex. Some have been worked out, others still defy analysis. Many of them are rather like the β structure but with certain atoms left out in a symmetrical way and the others shunted up to close the holes thus left. Finally, after a desperate effort to crystallise with some fancy structure which can still accommodate the foreign aluminium atoms, the problem is given up as hopeless, and the next phase which appears is almost pure aluminium, the metal dissolving very little of those in the first group.

The study of these complex phases (each phase has a characteristic crystalline pattern) is of great interest because of its bearing on metallic chemistry, for we want to know the reasons for the formation of the many patterns. It is interesting to note, however, that practically all the alloys of technical importance are α or β alloys, the complex structures being so brittle that they are useless. I need not therefore inflict upon you any description of the latter. If we examine by X-rays almost any of the metals which are practically useful, we find the diffraction pattern characteristic of body-centred cubic or face-centred cubic structures. There are a few exceptions such as the light alloys of magnesium now coming to the fore, and alloys of base metals such as tin and antimony.

Structure and Mechanical Properties

If all that X-ray analysis could do were to discover that our useful metals and alloys have an α or β structure, you might well question whether it were performing much service. However, it goes much further than this. The important (and difficult) part of the analysis consists in tracking down curious and subtle modifications of the arrangement of atoms on the lattice points, which have a profound effect on the mechanical and other properties of the metal.

To take the question of mechanical strength first, upon what does it depend? To be strong is in many cases the primary duty of a metal, but as yet we have hardly any idea as to what determines the strength. A pure metal in which the atoms are arranged with complete regularity as a single crystal has a vanishingly small resistance to deformation. A thin rod of cadmium, for instance, which has been carefully grown as a single crystal, feels as soft as butter and can be pulled out between one's fingers, the sheets of atoms slithering over each other like a pack of cards. This behaviour of a metal is in sharp contrast to that of crystals of other kinds such as crystals of minerals. A piece of quartz is none the weaker because it is pure and perfectly crystallised. Its atoms are held together by bonds which have to be broken before deformation can take place. A metal can hardly be called a true solid, because its atoms can undergo an almost infinite relative movement without destruction of the coherence of the substance.

Imperfections in Structure and Strength of Metals

The strength of a metal appears to be based on imperfections of structure which can be introduced in two ways. If the perfect crystal is distorted by cold-working so that it is broken up into a mass of crystallites with different orientations, it becomes strong and resists deformation. Its strength is also increased if the regularity of its crystalline array is disturbed by the introduction of foreign atoms, by alloying it with another element. As an analogy, let us compare the atoms to a number of cars in a car park If the attendant of the park knows his business, the cars are all arranged in regular rows, in a crystalline arrangement in fact, and when the owners come to reclaim them they can easily be withdrawn. Relative movements of the cars are possible just because of the regularity of their arrangement However, if the owners are allowed to park their cars with no arrangement whatever, they become jammed in a "solid mass." The direction of easy movement of one car is athwart that of its neighbours, and it will take much time and patience before the mass can be broken up. Alternatively, difficulties would be experienced if we alloyed the cars with charabancs irregularly distributed through the mass. They are wider and longer than the cars, and spoil the regularity of arrangement, so that again the rows of cars cannot be moved past each other. The immovability of the cars is not due to any linking of one car to its neighbours, but to the confusion.

The study of metals has made it clear that their strength comes, not from bonds between neighbouring metal atoms, but from irregularities of structure. The sheets of atoms in the perfect metal slither over each other quite easily, but must do so in certain directions related to the crystalline structure. If the metal is broken up into crystallites with different directions of easy glide, the movement in one crystal is incompatible with that of its neighbours and the whole mass jams. If foreign atoms are present they set up centres of local disturbance and strain and block the avenues of easy glide like lorries in a narrow street.

Although it seems to be established that the strength of metals arises in this way, and that

their combined ductility and toughness are due to the ease with which atoms can glide past their neighbours combined with the jamming effect of the imperfections caused by the movement, yet the proper theoretical basis for calculations of strength is still lacking. We have no way of calculating the elastic limit in terms of the structure, no way of estimating the tensile strength in figures. This is one of the most fascinating problems in the realm of the properties of matter, and many people are attacking it, but there are at present almost as many tentative theories as researchers upon the subject.

Impure α or β Structures

I now wish to picture the state of affairs in a metal which has one of these simple α or β structures, but which is not pure. We will suppose that metal A has a certain amount of another metal B alloyed with it, and that the B atoms, which replace A atoms here and there, do not fit comfortably into the common pattern. I will again take an analogy, that of a number of soldiers drawn up on parade, and as we are to have two kinds of atoms we will suppose the A soldiers to be thin and the B soldiers stout. The men are told to fall in, and do so in the order in which they arrive at the parade ground, the succession of A and B soldiers in each rank being a random one. When they are ordered to "dress," so that the ranks may be in line and the men in the ranks behind covering those in front, the trouble begins. The parade is bound to be ragged, because the stout soldiers occupy more room than the thin ones. How can matters be straightened out?

I have taken this analogy because the various solutions I am going to proffer correspond to the arrangements which X-ray analysis reveals in alloy structures. A heroic solution would be to tell all the fat men to fall out and parade by themselves in another corner of the field, and then to close up the ranks of their thin comrades. Another solution, involving less drastic troop movements, would be to bunch the fat men at certain points, so that the eye of the reviewing general is less offended by the random alternation of the two types as he runs it along the line. Another solution would be to shuffle the B soldiers, while keeping each in his own rank, until the B soldiers in the rear ranks covered those in the front rank. This would have the advantage of keeping the files in correct alignment. Still another solution is possible when the ratio of B to A soldiers is a simple one, when for instance there are equal numbers of A and B soldiers or when one soldier in four is stout. In the first case the men would be told to reshuffle until there is a regular alternation stout-thin-stout-thin along each rank. This would have the advantage of realising an absolutely regular formation, though I am afraid the parade would have a certain comic aspect which would not be pleasing to the serious military mind.

Reshufflings of just this type take place in an alloy structure. One must remember that when the alloy solidifies from the melt, the atoms do not necessarily remain fixed in the positions they first take up in the crystalline structure. Very considerable movements of atoms may take place within the framework of the solid state. The well-known process of making an alloy homogeneous is an example. The first portions to solidify have a different composition from the last, yet if the alloy is held at a temperature which is high, yet well below the melting point, a diffusion of atoms takes place which renders the whole homogeneous. In performing such movements atoms must wander distances in the structure which are many thousand times greater than the distance between neighbours, and as this is done by a successive process of neighbours changing places, such changes must be taking place with the greatest of ease. The energy which is required to make neighbouring atoms interchange their positions is supplied by the heat. The atoms are in violent random movement, and once in a while it chances that this movement piles up so much at certain places that a reshuffle of atoms takes place, the more frequently the higher the temperature.

Application of the Analogy

The analogy between an alloy and the ranks of unequal soldiers may be clearer if I take some specific cases as examples. Let us take the case of a metal A which at a high temperature can hold a certain amount of a metal B in solution. For instance, above 500 deg. C. aluminium can hold over 5 per cent. of copper in solution, and at 750 deg. C. silver can hold 7 per cent. of copper in solution. This implies that at the elevated temperatures the heat movements are so violent that the copper atoms are being knocked about from one position to another on the aluminium lattice. Although their position on the lattice involves considerable strain, which would be relieved if they got together in clusters to form separate copper-rich crystals, the heat movements are continually breaking up such incipient clusters and distributing the copper atoms all through the lattice. As the alloy cools, the tendency for the copper atoms to concentrate and "come out of solution" asserts itself. The alloy breaks up into crystals of two types, one consisting of aluminium containing only a fractional percentage of copper, the other a copper-rich alloy which is roughly $CuAl_2$ in

the one case, and nearly pure copper in the other.

The final result of cooling the alloy depends, however, on the rate of cooling, and is the result of a compromise between two effects of temperature. The lessening violence of the heat movements as the alloy cools makes it possible for the copper clusters to hold together, instead of being evaporated throughout the aluminium lattice. At the same time the shuffling of atoms becomes a more sluggish affair, for the concentration of sufficient heat energy at one point to enable two atoms to interchange their positions becomes an even rarer event. We get different types of structure according to the rate of cooling, and in fact can illustrate with these alloys three of the methods of making a parade more regular which I have outlined above.

If annealed for a sufficient time at a temperature somewhat above 300 deg. C., the copper atoms come out of solution and form separate copper-rich crystals. This is the solution of withdrawing the stout soldiers from the ranks and drawing them up in a separate formation at the other end of the parade ground. If the alloy is rapidly quenched, the copper atoms have insufficient time to move, and remain in their random positions. This involves a state of considerable strain, and since even at room temperature the atoms are occasionally able to change their positions, a process takes place which relieves the strain somewhat. Its nature has been recently investigated by Preston at the National Physical Laboratory, and may be compared to reshuffling the soldiers till the stout ones in successive ranks " cover " each other so as to restore the regularity of the files. Copper atoms change place with nearest neighbours till they are arranged in minute flakes or sheets, a few atomic distances apart. If the alloy is warmed to between 200 and 300 deg. C., a further change takes place. The atomic movements become more lively, the flakes are broken up, and the copper atoms segregate into minute local clusters or islands, which is like grouping the stout soldiers at certain points in the ranks so that the break in regularity is not so apparent. At a still higher temperature, the mass movements take place which lead to the formation of separate large crystals. This succession of events has been confirmed by some recent measurements by Sykes and Swindells on the heat evolution or absorption which takes place in the alloy.

The rearrangements of the atoms have a profound influence on the mechanical properties of the alloy, which is known as " age-hardening." The random arrangement of the copper atoms in the freshly quenched alloy gives a Brinell hardness of about 65, which increases to 100 when the copper-rich flakes are formed, falls when they dissolve, and increases to about 80 for the general type of precipitation. In a copper-beryllium alloy the hardness increases from 160 to nearly 400 by the segregation of the beryllium atoms. Although we cannot calculate the hardness or mechanical strength, it is an important first step to have discovered the atomic arrangements which give rise to it. The segregation of the foreign atoms on this minute scale destroys the uniformity of the structure and gives rise to rapidly varying local strains which apparently stop the yield of the material under stress.

Another example is afforded by such an alloy as β-brass, which is composed of almost equal numbers of atoms of copper and zinc. The common pattern of points occupied by the atoms is the β structure, body-centred cubic. At high temperatures the points of the pattern are occupied indiscriminately by copper and zinc atoms. At low temperatures they sort themselves out, all copper atoms going to cube corners and zinc atoms to cube centres. This is the solution of placing equal numbers of A and B soldiers in a regular A-B-A-B arrangement in order to achieve uniform ranks. The rearrangement has a profound influence on certain physical properties of the material such as energy content and electrical resistance. Tammann many years ago divined that this reshuffling took place, but it is only recently that it has been confirmed by X-rays. Though not of great technical importance, it is of considerable scientific interest, because it affords one of the few cases where theory has been applied to a metallurgical phenomenon with conspicuous success. It has been found possible (Borelius, Dehlinger, the author and E. J. Williams, and others) to account thermodynamically for the course of the change. It is, of course, the heat movements which keep the atoms shuffled up at the higher temperatures, while they can sort themselves out at lower temperatures in a kind of further crystallisation within a crystal.

The Case of Permanent Magnets

As a last example, I may take certain alloys which are used for permanent magnets. It was discovered by Mishina in Japan that certain alloys of iron, nickel and aluminium are capable of retaining a very large amount of magnetic energy. The approximate composition is Fe_2NiAl. At high temperatures the atoms are arranged in a random way on a body-centred lattice. If annealed at lower temperatures, the alloy breaks up into two phases, one being almost

pure iron and the other approximately FeNiAl. In neither condition are its magnetic properties at all oustanding. If cooled at the right critical rate, however, the process of separation of the iron is arrested in an intermediate stage. The iron atoms come together to form iron-rich clusters, believed to be in the form of sheets or plates, but they remain on the same body-centred pattern as the other atoms. Since the iron pattern is smaller than that of FeNiAl by about $1\frac{1}{2}$ per cent. in volume, the constriction required to make all the atoms fit on the same pattern sets up enormous local strains. These strains make it difficult to reverse the direction of magnetisation of the material, once it is magnetised in a given direction, and hence a sample of the alloy magnetised by a strong electric current retains an intense magnetisation when removed from the field. This explanation was put forward by Bradley in the course of an investigation for the Permanent Magnet Association. Alloys of iron, copper and nickel show a similar effect.

The structures described above are not structures of ideal equilibrium. A cold-worked metal which has been broken up into a mass of crystallites has a higher energy than a single perfect crystal, and theoretically its atoms should re-sort themselves until it "self-anneals" to being a perfect crystal again. An alloy in one of these states of partial segregation is not in true equilibrium. Its constituent atoms should re-sort themselves into single large homogeneous crystals. In fact, a metal has no right to be strong. It is so because it has been caught in an intermediate stage before it has reached equilibrium, and although theoretically it is slowly working towards that end, the process is so slow that for practical purposes we may assume it is stable and build our bridges and machines with safety. Some recent very interesting work by Becker shows why equilibrium is so slow of attainment. A new arrangement of the atoms must start from a nucleus, and a very small nucleus of the new type of structure tends to disrupt or evaporate simply because there is not enough of it for it to be mechanically better than the existing one. We may compare it to a country in which the majority of inhabitants would like to change the form of government, but in which such a change does not take place because it is so easy to quell incipient rebellion at its source.

The Technique Indicated

It would take me too far afield if I described in detail in this lecture how it is possible to recognise these various forms of structure by X-ray analysis. As an indication of the principles involved, we may start from the case of a pure metal with a highly perfect crystalline structure. This gives diffracted beams which are sharply defined in direction, and from this arrangement we can deduce the crystalline pattern of the metal. Passing now to the case of an alloy, if this splits up into two types of crystal a double set of diffracted beams, each characteristic of the structure producing it, will be present. If the metal breaks up into a mass of small crystallites, the beams from being sharp become diffuse, and the size of the crystallites may be estimated from the breadth of the beams. If the crystallites are round, all beams are equally diffuse; if they are plate-shaped some are sharp and some diffuse, and again we can get an approximate idea of the dimensions of the plates. A random arrangement of A and B atoms on the crystal pattern gives diffracted beams like a simple crystal of α or β type; if the A B atoms take up a regular alternation A B A B A B new beams appear in intermediate positions which reveal what has happened. When the atoms segregate into certain sheets as in the age-hardening aluminium-copper alloy, certain beams are accompanied by faint "ghost" beams on either side. This is a well-known optical effect exhibited by a diffraction grating which has been ruled by a faulty engine, so that a periodic error is introduced into the spacing of the lines. These are merely a few examples; the whole story would be far too long to tell here.

I hope I have given you an indication of the possibilities opened up by X-ray analysis, and should like to end on the note with which I began. The new knowledge of the actual positions of the atoms in metals gives the pure scientist a foundation on which to base his explanations of metallic properties, and the subject of "metal physics" provides a unique opportunity for the collaboration of scientists in University and industrial laboratories.

PAPERS PRESENTED TO THE

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Bonding Clays and the Properties of Synthetic Moulding Sands*

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The use of synthetic moulding sands has extended rapidly over the last five years, as such material shows advantages in many cases over natural moulding sands. The chief advantages may be summarised as:—(1) Greater control of strength and permeability, and consequently fewer casting defects (natural sands have frequently a high silt percentage and too low a permeability); (2) suitability for mechanised sand plants; and (3) economy in operation.

The properties of synthetic moulding sands vary considerably, as they depend both on the type and amount of clay present and also on the base sand. The object of the present research was to determine the suitability of various clays for preparing satisfactory moulding sands when used as bonding clays, both for silica sands and natural moulding sands. Present knowledge of moulding sands has not yet reached a point where all the physical properties necessary for satisfactory moulding can be measured and specified, though continual advances are being made as the result of research, both in Europe and the United States of America. The properties of the synthetic mouldings investigated included the green and dry strengths, permeabilities and refractoriness and the influence of the clay and moisture content. These tests were supplemented by actual casting tests in which the influence of successive castings on the moulding sands was observed.

The clays examined were:—

China Clays.—Two china clays, termed A and B respectively, obtained from the large china clay deposits at St. Austell, Cornwall, were used for the tests. These clays occur together with quartz, felspar and mica and are separated from these coarse impurities by sedimentation. They had been milled to pass a 200-mesh sieve.

Ball Clays.—These were from two sources:—(1) Ball clays A and B, obtained from the ball clay mines at Wareham, Dorset. These clays are weathered in the open, and the lumps supplied were ground to pass a 30-mesh sieve before use. These ball clays are regarded as sedimentary clays and are believed to have been formed like the china clays from granite and to have been subsequently transported by river or other action to their present position. (2) Ball clay C, from a Devon deposit. It had been milled to pass a 200-mesh sieve.

Fireclays.—(*a*) Stourbridge fireclays. Six samples were obtained from the Stourbridge fireclay mines. They differed widely according to the seam from which they were obtained, some being highly siliceous. The nature of these deposits has been described in various publications.[1 2] The samples, which had been previously weathered, were ground to pass a 30-mesh sieve. (*b*) Scottish fireclay, a material obtained from the Bonnybridge district. It existed as a grey powder, and 98 per cent. of this material as used in the tests passed a 30-mesh sieve.

Bentonite.—A good quality bentonite from Wyoming, U.S.A., was used.†

Colloidal Clay A.—A proprietary bonding clay of Irish origin. It was an earthen coloured powder of ball clay character.

Red Clay from a natural moulding sand. For comparison with the other clays the red ferru-

* Presented on behalf of the British Cast Iron Research Association.

† Supplied by courtesy of the Frederick Crane Chemical Company, Limited, Birmingham.

ginous clay in a natural Bromsgrove moulding sand was separated by repeated sedimentation of the sand with water. The clay suspension containing particles less than 0.01 mm. diameter was allowed to settle after flocculation.

Nature of Basic Silica Sand

The synthetic sands were prepared under standardised conditions, the base silica sand being Frankley medium fine sand having the following mechanical analysis:—

Grade.	Per cent.
Clay	0.3
Fine silt	0.5
Coarse silt	0.5
Fine sand	37.6
Medium sand ..	60.4
Coarse sand	0.7
Gravel	—
	100.0

The sand was mixed with the dried clay, milled two minutes dry in an August Simpson laboratory mill, water added, and then milled ten minutes. Tests showed that green strength was developed in five minutes and milling longer than ten minutes produced little or no change.

The green compression strengths were measured by the B.C.I.R.A. method at ramming densities of 1.5, 1.6 and 1.65, the results at ramming density 1.6 being given in Table I and shown in Fig. 1.

It will be observed that each green strength: moisture curve shows a well-marked maximum, the left side of the maximum being the region where the sand grains are too dry to cohere well on ramming. Table II summarises the maximum green strengths attained and the corresponding moisture content.

TABLE II.—*Critical Moisture Content to Yield Maximum Green Strength.*

Clay.			Max. green strength.	Moisture.
				Per. cent
5 per cent.	bentonite		13.81	2.06
3 ,,	bentonite		6.0	1.7
5 ,,	colloidal clay A ..		5.7	1.5
5 ,,	china clay A ..		3.6	2.05
5 ,,	china clay B ..		2.9	2.6
5 ,,	ball clay A (Dorset)		6.1	2.3
5 ,,	ball clay C		4.2	2.8
5 ,,	fireclay No. 6 ..		5.15	2.35
5 ,,	fireclay No. 3 ..		5.0	2.1
5 ,,	fireclay No. 4 ..		4.19	2.44
5 ,,	fireclay No. 7 ..		4.13	2.3
5 ,,	fireclay No. 1 ..		3.7	2.3
5 ,,	fireclay No. 2 ..		2.25	2.0
5 ,,	Scottish fireclay ..		3.0	2.18
5 ,,	red clay		5.0	3.1

It is clear that bentonite has a greater bonding power than the other clays examined. Synthetic sands containing 3 per cent. of bentonite, 5 per cent. of colloidal clay A or 5 per cent. of

TABLE I.—*Green Compression Strengths of Synthetic Sands.*

3 PER CENT. BENTONITE.							
Water, per cent.	1.46	1.50	2.05	2.24	2.72		
Green strength	5.81	5.87	5.69	5.44	5.0		
5 PER CENT. BENTONITE.							
Water, per cent.	1.92	2.06	2.60	3.24	3.98		
Green strength	11.4	13.8	8.3	7.25	5.7		
5 PER CENT. COLLOIDAL CLAY A.							
Water, per cent.	1.02	1.32	1.38	1.54	1.80	1.94	2.80
Green strength	3.0	5.19	5.70	5.50	5.44	5.0	3.50
5 PER CENT. BALL CLAY A (DORSET).							
Water, per cent.	1.68	1.94	2.04	2.26	2.52	2.88	
Green strength	4.12	5.56	5.56	6.12	5.25	1.44	
5 PER CENT. FIRECLAY NO. 6.							
Water, per cent.	2.10	2.20	2.54	2.86	3.50		
Green strength	4.28	5.0	4.94	3.94	2.19		
5 PER CENT. SCOTTISH FIRECLAY.							
Water, per cent.	1.76	2.18	2.48	2.9			
Green strength ..	2.75	3.0	2.87	2.1			
5 PER CENT. CHINA CLAY A.							
Water, per cent.	1.44	1.78	1.84	2.24	2.46		
Green strength	2.26	2.37	3.56	3.5	3.34		
5 PER CENT. RED CLAY (FROM NATURAL MOULDING SAND).							
Water, per cent.	2.26	2.64	3.60	4.54			
Green strength	4.63	5.0	5.0	4.5			

ball clay A have approximately the same maximum green strength. The china clays have low bonding power and likewise the Scottish fireclay and No. 1 and No. 2 Stourbridge fireclays. Increasing the percentage of china clay to 8 to 12

TABLE III.—*Showing the Influence of Increasing China Clay Additions.*

	Permeability test. Secs. per litre air.	Green strength. Lbs. per sq. in.	Moisture. Per cent.
4 per cent. china clay	14.5	2.4	2.2
8 per cent. china clay	16.5	4.7	3.0
12 per cent. china clay	21.2	10.6	2.9
12 per cent. china clay	21.7	7.9	3.4

per cent. gives an adequate green strength, but the permeability of the moulding sand is greatly diminished, as the figures (A.F.A.) of Table III show.

Fig. 1 shows that the green strength : moisture percentage curve depends on the clay, the sand bonded with 3 per cent. of bentonite giving a curve with a more rounded peak than the others. Such a curve would appear advantageous in that the properties of the synthetic sand are less susceptible to changes in moisture content, alterations in the latter being unavoidable in the foundry owing to rapid evaporation from warm moulding sand. The properties of the sand bonded with the red clay extracted from a

TABLE IV.—*Tensile Strength of Moist Clays.*

	Bentonite.	Colloidal clay A.	Ball clay A.	China clay B.
Parts of water per 100 parts (dry) clay	56.6	30	46	52
Tensile strength in lbs. per sq. in.	9.5	6.4	5.1	2.2

natural Bromsgrove moulding sand are remarkable; the maximum is hardly appreciable, and occurs at a moisture content far higher than the true synthetic sands.

Green Strength and its Relation to the Clay

The green strength and bonding power depend very considerably on the type of clay, and, in view of the importance of this property in

TABLE V.—*Dry Strengths of Synthetic Moulding Sands.*

3 PER CENT. BENTONITE.						
Moisture, per cent.	1.50	1.90	2.40	3.76		
Drying temp., deg. C. 105	28	58	112	134		
Drying temp., deg. C. 150	30	56	91	90		
Drying temp., deg. C. 200	36	53	88	144		
Drying temp., deg. C. 250	30	63	87	134		
5 PER CENT. COLLOIDAL CLAY A.						
Moisture, per cent.	1.84	2.14	2.80	3.46		
Drying temp., deg. C. 105	32	33	56	74		
Drying temp., deg. C. 150	34	33	74	82		
Drying temp., deg. C. 200	26	36	60	80		
Drying temp., deg. C. 250	36	35	50	62		
5 PER CENT. BALL CLAY A.						
Moisture, per cent.	2.26	2.76	3.20			
Drying temp., deg. C. 150	8	30	36			
5 PER CENT. FIRECLAY No. 6.						
Moisture, per cent.	2.08	2.30	2.64	2.92	3.44	
Drying temp., deg. C. 250	4	8	13	10	16	
5 PER CENT. FIRECLAY No. 3.						
Moisture, per cent.	2.18	2.38	2.70	3.32		
Drying temp., deg. C. 250	13	18	22	31		
5 PER CENT. SCOTTISH FIRECLAY.						
Moisture, per cent.	1.76	2.18	2.48	2.96		
Drying temp., deg. C. 105	3.4	5.9	8.4	14.0		
5 PER CENT. CHINA CLAY A.						
Moisture, per cent.	2.16	2.74				
Drying temp., deg. C. 150	4.5	3.5				
5 PER CENT. RED CLAY (FROM NATURAL MOULDING SAND).						
Moisture, per cent.	3.60	4.54				
Drying temp., deg. C. 250	40	40				

moulding, it was of interest to investigate the relationship of green strength with the properties of the clay, and thus to elucidate the factors responsible for green strength.

A moulding sand consists essentially of sand grains coated with a thin layer of moist clay, and it is clear that the rupture of rammed moulding sand involving the separation of the coated sand grains must involve either the rupture of the moist clay layer or rupture between sand grain and clay layer. Experiments were carried out with two convex surfaces of glass coated with moist clay which were pressed together to imitate the sand surfaces in a moulding sand, and it was found that considerable force was required to separate the two surfaces and that, when separation occurred, the rupture took place in the clay layer itself. It thus appeared reasonable to expect, from these elementary experiments, that the green strength of the moulding sand would be related directly to the tensile strength of the moist clay. Experimental work proved that this was in fact the case.

The tensile strength of moist clay has been investigated by several workers, notably Hind and Degg.[3] They worked under conditions in which a gradual elongation of the clay could take place under the applied forces, and the time factor was therefore involved. To eliminate the influence of this gradual elongation as far as possible, and to imitate the conditions existing in a moulding sand, the tensile strength was determined on the moist clay with a length small in comparison with the cross-section. The moist clay was pressed between two glass surfaces to give a cross-section of 1 sq. in. and a clearance between the plates of 0.074 in., and the force required to separate the plates measured. The tensile strength decreased as the moisture percentage increased.

In Table IV the tensile strengths of the moist clay are given at the moisture content corresponding to the maximum green strengths of the moulding sand. It is clear that the green strength of the moulding sand, *i.e.*, the bonding power of the clay, is directly related to the tensile strength of the moist clay.

Dry Strength

This factor is important for green sand as well as dry sand moulding, as it is mainly on this property that the resistance of the mould surface to erosion by the stream of molten metal depends. Its value is especially important in the case of synthetic moulding sands which frequently have dry strengths considerably lower than those of natural moulding sands.

The dry strengths of the synthetic moulding sands at various temperatures of drying and initial moisture contents are given in Table V. The figures given, in lbs. per sq. in., are for a ramming density of 1.6.

The results, some of which are given in Fig. 2, show that the dry strength increases with moisture content and with the ramming density. The influence of drying temperature up to 250 deg. is not very marked. The bentonite bonded sand, using only 3 per cent. of bentonite, shows a higher dry strength than the other sands containing 5 per cent. of clay, and it is clear that for dry sand moulding its use is advantageous, as also for dry sand steel moulding sands, which are usually heavily bonded.

For green sand moulding the dry strength should be adequate to prevent erosion by the wash of molten metal. The greatest erosion occurs at the bottom of the ingate where the sand has to withstand the fall of metal from the ladle, and sand grains are liable to be carried into the

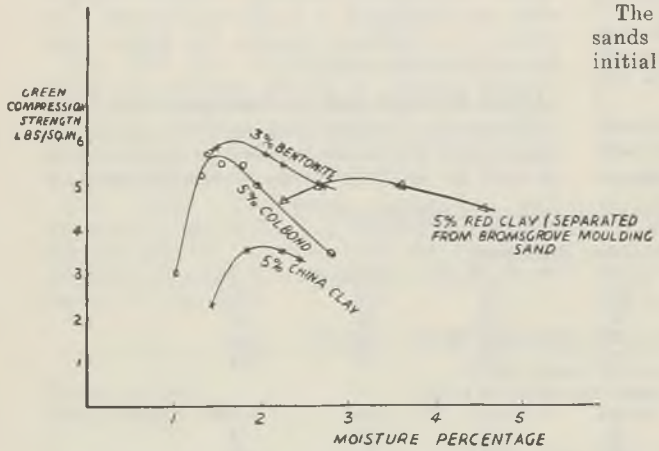

Fig. 1.—Green Compression Strength.

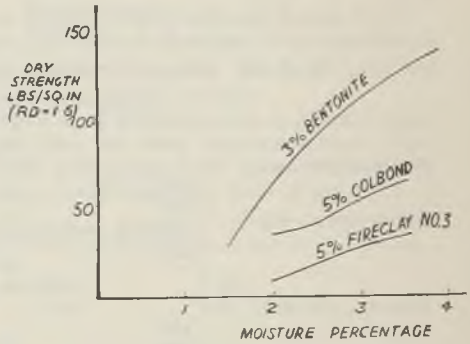

Fig. 2.—Dry Compression Strength.

mould and produce inclusions which are troublesome if the casting is to be enamelled or if a machined surface is required, as in the case of cylinder liners. It is difficult to fix a definite minimum dry strength since the erosion depends on other factors such as the type of casting, height from which the metal is poured, and the grain size of the sand, a coarse open sand probably resisting erosion less than a close packing fine sand. Further, if the effect of temperature rise is to diminish the dry strength, then the amount of erosion will depend on the dry strength at the higher temperature range where this weakness is shown.

Attempts to specify the dry compression strength necessary for green sand work have, however, been made. Dietert[4] gives figures found satisfactory for the following types of castings—flywheels, pipes, car wheels, cylinder blocks, the values ranging from 40 to 50 lb. per sq. in. (A.F.A.). F. Hudson[4] gives green sand figures which are known to give good results (railway chairs and hydraulic valves), the dry compression strengths ranging from 40 to 60 lb. per sq. in. (A.F.A.). Additions of sulphite lye were recommended when the dry strength fell too low.

Table VI gives the dry strengths at the moisture percentage at which these particular sands would be used for green sand moulding. A used green sand facing sand made from a natural Bromsgrove moulding sand and containing coal dust is included for comparison, the moisture content being 6.0 per cent., a normal value for a natural sand of this type.

In order to compare these figures with Dietert's figures obtained by the A.F.A. method, a synthetic sand containing 5 per cent. fireclay No. 4 and 2.26 per cent. moisture was tested by both methods, with the following results.

	Dry strength.
B.C.I.R.A. method (R.D.=1.6) ..	6 lb. per sq. in.
A.F.A. method	6.7 lb. per sq. in.

It is clear from Table VI that while the first six sands have approximately the same green strengths, the dry strengths of the synthetic sands are, with the exception of the 3 per cent. bentonite mixture, considerably less than those of the natural moulding sands. The dry strengths of the sands bonded with 5 per cent. of the ball or fireclays and not containing coal dust are considerably less than the values specified by Dietert and Hudson. It would appear that this low dry strength is indirectly responsible for the opposition to synthetic sand by some hand moulders, since the synthetic sand made by combining a clay of this type with a highly permeable sand dries off at the surface more rapidly than a natural moulding sand, giving a friable surface which is not readily patched or "sleeked."

A practical trial was made in the foundry to ascertain whether satisfactory synthetic sands could be prepared with the fireclays or ball clays, in spite of the low dry strength. The sand consisted of Southport sand with 7 per cent. fireclay No. 6, 6 per cent. coal dust, milled for 10 min. and tempered to 3.2 per cent. moisture. No difficulty was experienced by the hand moulder in ramming this sand and an iron box was successfully cast in the mould. An extended trial was not made. It appears that synthetic sands containing fireclays of this type are usable, but careful control of the moisture content is necessary.

The incorporation of coal dust in a sand produces a considerable increase in the dry strength amounting in some cases to as much as 50 per cent. The increase occurs after the sand has been in use for moulding several times, the effect being probably related to the formation of tarry products in the sand. The utilisation of synthetic sands containing fireclay is thus extended when coal dust is used.

TABLE VI.—*Dry Strengths at Normal Moisture Contents.*

	Moisture. Per cent.	Green strength. (R.D.=1.6). Lb. per sq. in.	Dry strength. (R.D.=1.6). Lb. per sq. in.
Facing sand ..	6.0	4.2	63
3 per cent. Bentonite.. ..	2.0	5.8	65
5 per cent. Colloidal Clay A	2.0	5.0	35
5 per cent. Fireclay No. 3 ..	2.3	5.0	20
5 per cent. Fireclay No. 6 ..	2.3	5.0	8
5 per cent. Ball Clay A ..	2.3	5.1	10
5 per cent. Ball Clay C ..	2.3	4.0	6
5 per cent. China Clay A ..	2.3	3.5	5

The change in the dry strength after the sand has been in use for some time for making castings was investigated in durability trials carried out by the Association. The synthetic sands consisted of Erith silica sand with 3.5 per cent. bentonite and 7 per cent. colloidal clay respectively. The dry strength of the former fell from 45.5 lb. per sq. in. (A.F.A.) to 19.1 lb. per sq. in. after fourteen castings and the latter from 22.6 to the low value of 2.5 lb. per sq. in. A similar series in which coal dust was used with the latter sand showed, however, a much smaller decrease.

Refractoriness

The moulding sand in contact with the molten metal has to withstand for a short time a high

temperature which causes considerable changes in its physical and chemical properties. The sand actually in contact with the metal may fuse or burn on to it if its fusion point is not sufficiently high, while the sand slightly further away loses its bond.

In a mechanised foundry the used sand is continually re-bonded by further additions of clay. An inferior bonding clay may thus exert a cumulative deleterious influence on the moulding sand and if readily fusible impurities are present in the clay they will accumulate in the moulding sand and progressively decrease the refractoriness.

TABLE VII.—*Fusion Points of Various Bonding Clays.*

Clay.	Fusion Point.
Colloidal Clay A ..	Exceeds 1,450 deg. C.
Ball Clay A .. .	Exceeds 1,430 deg. C.
Ball Clay B .. .	Exceeds 1,450 deg. C.
Fireclay No. 6 .	Exceeds 1,430 deg. C.
China Clay A	Exceeds 1,450 deg. C.
Bentonite	1,330 deg. C.
Bentonite No. 2 ..	1,270 deg. C.

The fusion points of the bonding clays, determined by the Sinnatt apparatus, are given in Table VII. The fusion points are here the temperatures at which the thread of clay bends over.

For comparison the fusion points of the clay grade contained in various natural moulding sands are given below.

Sand.	Fusion point of clay grade.
Erith—Medium Loam ..	1,315 deg. C.
Pickering	1,270 deg. C.
Bromsgrove — Middle Bed	1,390 deg. C.
Scottish—Greenfoot ..	1,400 deg. C.

The refractoriness of bentonite is lower than that of the other bonding clays, and is of the same order as that of the clay bonds in natural moulding sands. The reason is apparent from the chemical analysis (Table VIII), the percentage of Fe_2O_3, MgO and combined alkalis all being greater than in the case of the ball and china clays.

Burning-on of the sand is the chief defect that may result from the use of a clay of low refractoriness. The question is not one that has been investigated, however, and other factors which have not been studied appear to be involved, such as the refractoriness of the base sand, ease of penetration of the metal between the sand grains, and the surface skin on the molten metal. Two cases may be distinguished, according as to whether the moulding sand is used with coal dust or not.

Coal dust is added to moulding sand to prevent burning on and give a smoother finish. Its function is not fully understood, although considerable work has been done by Hird,[5] Winterton[6] and others. It is possible that the volatile matter driven off is decomposed by contact with the iron, coating the latter with a thin sooty layer, preventing the sand grains from burning on to the metal; the pressure of the gases evolved may also prevent penetration of the metal between the grains. Where coal dust is added, the refractoriness of the bonding clay is of minor importance in comparison with that of the coal ash accumulating. A typical coal dust of British origin[7] may give 5 per cent. of ash, with a fusion point between 1,200 and 1,450 deg. C. and analysing 43 per cent. silica, 31 per cent. Al_2O_3, 15 per cent. Fe_2O_3, 4 per cent. CaO and 5 per cent. other bases.

Synthetic sands without coal dust are in use. It was found that a synthetic sand, consisting of Frankley sand with 5 per cent. of colloidal clay A, burnt on badly when castings were made in it, except when the molten metal was poured cold. Replacing the Frankley sand with Erith silica or Leighton Buzzard No. 26A silica sand gave synthetic sands which did not burn on to the casting, an improvement explained by the higher refractoriness of these silica sands in comparison with the Frankley sand, which contains appreciable amounts of felspar and micaceous impurities. These Erith or Leighton Buzzard sands, when bonded with 3.5 per cent. of bentonite, also gave no burning on, in spite of the lower fusion point of the bentonite.

In the case of a constant sand cycle, the same sand is continually rebonded with further additions of clay. The effect of successive castings on a moulding sand has been under investigation in the durability tests, and is believed to take place along the following lines. At temperatures of 500 deg. C. and above, the bonding clay loses its combined water and cannot be made plastic again. At much higher temperatures near the fusion point, the clay, being in contact with the grains of silica sand, will soften and fuse at the eutectic temperature of the alumina, silica and flux mixture. In the mould the temperature of the sand falls rapidly as the distance from the hot metal increases, and fusion of the bonding clay will only occur in the layer nearest to the casting, and if the clay has a sufficiently low softening point. A considerable portion of the sand is exposed to temperatures of 500 deg. C. and above, however, and the dehydrated clay may behave in two ways—(1) fall off the sand grains, or (2) vitrify or burn on to the sand grains, since clays harden or vitrify at temperatures considerably below their fusion point.

The type of bonding clay probably decides which alternative actually occurs, but in the durability experiments it was established that colloidal clay A vitrified or burnt on to the sand grains, though the increase in silt percentage suggested that a part of the clay became detached from the sand. The film of burnt clay will have the same composition and refractoriness as the bonding clay itself, and it may be assumed that the tendency of the sand to burn on to the casting, when no coal dust is present, depends on the softening point of this film of clay and on its thickness. The thickness gradually increases as the used sand is continually rebonded with fresh clay.

The synthetic sand containing 3.5 per cent. of bentonite showed no burning-on, but it appeared possible that, owing to the fusion point of bentonite being 1,330 deg. C., some burning-on might be experienced where the used sand was being rebonded and a thick film of burnt bentonite had accumulated on the sand grains. To test this possibility, a synthetic sand was made of Erith silica sand with 20 per cent. of bentonite, the mould skin-dried and molten metal poured in. In spite of the thick clay film coating the sand grains no burning-on took place, and the sand readily fell off the casting. The use of bentonite thus appears satisfactory, even in the absence of coal dust.

Properties of the Clays and Relation to Bonding Power

The clays show large differences in tensile strength and in bonding power. Some of the purest clays—the china clays—show the lowest bonding power, and it is clear that the differences can only in part be attributed to the presence of natural diluent impurities such as silica. The fundamental properties of the clays responsible for these differences was therefore investigated, as it appeared possible that the bonding power of the clay might be increased by appropriate treatment.

The chemical analyses of the clays are given in Table VIII, and include a red (iron-rich) clay extracted from a natural Bromsgrove moulding sand. The molecular silica to alumina ratio and the *p*H values of the clays (determined by the hydrogen electrode) are also given.

The analyses of carefully purified china clays correspond to the formula $Al_2O_3 . 2SiO_2 . 2H_2O$ (china clay B corresponds to $Al_2O_3 . 2.01\ SiO_2 . 1.93\ H_2O$), which is that of the mineral kaolinite, and it was at one time held that all clays have as basis this clay substance and that silica in excess of the two to one ratio to alumina is present as free silica. This view does not explain the poor bonding power of the pure china clays, and it is now recognised that the clays may contain minerals other than kaolinite as their clay substance. The properties of bentonite are markedly different from English clays, *i.e.*, the small loss on ignition and base exchange properties, and Ross and Shannon[8] suggested that the clay substance consisted of montmorillonite. Its identity with this mineral $Al_2O_3 . 4SiO_2 . H_2O$ has been confirmed by X-ray analysis.[9] The iron-rich clay from the natural moulding sand also shows marked differences from the kaolins.

TABLE VIII.—*Chemical Analysis of the Clays.*

	China clay A.	China clay B.	Ball clay A.	Ball clay C.	Colloidal clay A.	Fireclay. No. 1.	Fireclay. No. 2.	Fireclay. No. 3.	Fireclay. No. 6.	Fireclay (Scottish).	Red clay (Bromsgrove).	Bentonite.
SiO_2 ..	55.94	45.50	48.70	50.77	60.44	53.08	70.40	45.10	41.38	52.3	53.76	61.51
Al_2O_3 ..	29.55	38.42	34.77	33.65	19.20	29.79	19.74	33.46	29.06	30.5	25.39	22.09
Fe_2O_3 ..	1.25	0.75	1.37	1.25	3.31	2.01	1.60	2.50	2.14	2.5	6.94	4.16
CaO	1.10	0.60	0.47	0.93	1.59	1.20	0.53	1.20	1.20	0.5	0.34	1.74
MgO ..	0.61	0.67	0.22	0.57	1.01	0.76	1.00	0.94	0.81	0.6	2.06	2.87
TiO_2 ..	1.50	0.60	1.05	1.35	0.97	1.50	1.38	1.55	1.30	1.1	0.62	0.22
K_2O ..	0.80	} 1.05	1.64	1.20	{ 0.68	} 0.69	1.01	{ 0.66	} 1.73	—	3.12	1.56
Na_2O ..	0.99				0.27			0.17				
Loss on ignition	9.12	13.07	11.68	10.23	10.36	11.40	4.08	14.60	22.00	12.0	7.77	5.77
SiO_2/Al_2O_3	3.2	2.01	2.3	2.5	5.3	3.0	6.0	2.3	2.4	—	—	4.7
*p*H value ..	6.33	5.14	3.48	5.10	5.43	—	7.51	7.53	6.92	—	—	9.0

The clays in general consist of extremely fine particles which cohere strongly when the clay is made plastic with water. The particles are disc shaped, which is probably the reason for the high plasticity of clays compared with other solid powders. The suspension in water behaves as a colloid, the particles being negatively charged and having effective diameters less than 10 microns (1 micron = 0.001 mm.).

The particle sizes were measured by the sedimentation method of Vinther and Lasson,[10] using a 0.002 M sodium pyrophosphate solution for obtaining maximum deflocculation. The suspensions were made up of the 0.002 M pyrophosphate

solution with 2 per cent. of clay and agitated for 16 hours in a shaking machine revolving at 85 revolutions per minute. The results expressed as the percentage weights of clay less than 10, 2 and 0.5 microns diameter are given in Table IX.

TABLE IX.—*Particle Size Analysis.*

	10μ	2μ	0.5μ
China Clay B	83.0	56.6	24.6
China Clay A	92.6	72.8	47.2
Fireclay No. 6	50.5	37.8	17.2
Ball Clay A	99.0	94.0	81.0
Colloidal Clay A ..	88.3	67.6	53.4
Bentonite	98.4	92.5	80.8

Bentonite and ball clay A have the greatest percentage of fine material less than 0.5 micron diameter, and it is clear that there is a rough relation between this percentage and the bonding power of the clay. Fireclay No. 6 is an exception to this rule, although this may possibly be due to the presence of coarse clay aggregates in the suspension, since the clay has a gritty feeling when moistened, and only after rubbing does the full plasticity develop and the grittiness disappear.

A more exact relation was found between the bonding power and the quantity of water adsorbed by the clays when exposed to atmosphere humidity. The results are given in Table X. The dry strengths are also given (initial moisture 2.3 per cent. with the exception of the red clay) and the water adsorption seems to show an even closer relation with this property.

TABLE X.—*Showing Relation between Moisture Adsorption and Bonding Power.*

Bonding clay.	Water adsorbed per 100 gm. clay.	Optimum green strength.	Dry strength.
Bentonite (3 per cent.	12.86	13.8	100
Ball Clay A ..	3.63	6.1	10
Colloidal Clay A ..	5.46	5.7	40
Fireclay No. 6 ..	3.96	5.15	8
Natural Red Clay ..	6.30	5.0	(40)
Ball Clay C ..	2.32	4.2	6
China Clay A ..	1.94	3.6	5
China Clay B ..	1.40	2.9	—

On theoretical grounds, the quantity of water adsorbed under these conditions would be expected to depend on (1) the total surface area of the clay particles, and (2) the force of attracinto between the surface and the water—a strong attraction resulting in a comparatively thick film of adsorbed water. These considerations and the relation found enable one to form a clearer view, on the following lines, of the factors governing tensile strength of moist clay and thus the bonding power.

Owing to its high adsorptive power, the clay particle has a strong attraction for water, and when moistened surrounds itself with a firmly attracted water film. If the water is not sufficient for the complete saturation of the adsorption forces, adjacent clay particles with their water envelopes are strongly attracted, resulting in a firmly coherent mass of clay. The tensile strength of the moist clay will thus depend on the amount of water present and the adsorptive power of the clay for water. The tensile strength may be considerable if slip between adjacent layers of clay, due to the applied forces, is prevented. The ease with which slip between adjacent layers may take place will depend on the viscosity of the aqueous medium between the particles, a relationship which is demonstrated in the high tensile strength obtained by kneading a clay with a viscous liquid such as molasses. Regarding the clay, for simplicity, as a mixture of coarse and very fine particles, the aqueous medium between the coarse particles may be regarded as consisting of the colloidal suspension of very fine particles. The viscosity of a colloidal suspension is known to depend on the amount of colloidal material, the electric charge on the particles, and to be inversely dependent on the diameter of the particles, *i.e.*, the smaller the particle size, the greater the viscosity. Considering all these factors, it may be concluded that the tensile strength of the moist clay and the bonding power depend on (1) the purity of the clay and the absence of silica impurities; (2) the adsorptive power of the clay for water; (3) the fineness of the particle size and the electric charge; and (4) the chemical composition of the clay substance or clay substances, if more than one be present.

Comparison of Natural and Synthetic Sands

The natural moulding sands show marked differences from the synthetic sands discussed. A Bromsgrove natural moulding sand will be actually used at about 6 per cent. moisture, which is considerably higher than in the case of synthetic sands; it has a lower permeability than the latter, and has a good dry strength. These differences may be attributed to (1) differences in the sizes and surface properties of the sand grains; and (2) the particular clay in the natural moulding sand. The results obtained by combining the red clay extracted from the natural moulding sand with the same base silica sand used for the preparation of the synthetic sands, so as to eliminate (1), were thus of particular interest.

The green strength figures for this pseudo synthetic sand are given in Table I. It was found that the percentage of moisture required was higher, since at 2.26 per cent. moisture, a

suitable figure for the other synthetic sands, the sand felt too dry for satisfactory moulding. A moisture percentage of 3.6 appeared most satisfactory; in comparison, the other synthetic sands felt wet and sticky, and would have stuck to the pattern at this moisture content. The dry strength of 40 lbs. per sq. in. (Table V) is greater than the other synthetic sands, with the exception of the 3 per cent. bentonite mixture, making the comparison at the moisture contents suitable for green sand moulding.

The results show that the characteristic features of Bromsgrove moulding sand—(1) large percentage of water required; (2) flat topped green strength : moisture curves; and (3) good dry strength—are due mainly to the particular type of clay present in the sand.

The lower moisture content of synthetic sands gives them an advantage over natural moulding sands, as less steam is generated during casting. In changing over from natural to synthetic moulding sands, the moisture content has to be carefully controlled, since in general the dry strengths are lower than in the case of natural moulding sands and evaporation losses from the hot moulding sand are high when the synthetic sand is prepared from a highly permeable silica sand.

The use of bentonite appears advantageous in that the synthetic sands bonded with it combine many of the good points of the natural moulding sands in regard to dry strength and small variation in properties with moisture content, *i.e.*, greater latitude. The durability is also satisfactory. On the other hand, colloidal clay A occurs naturally in the British Isles, and thus uninterrupted supplies are available. As an alternative, the more plastic fireclays are suitable, provided that due regard is made to their lower dry strength. Trials showed that there is no advantage in grinding these fireclays finer than 60 mesh.

The work described in this Paper was carried out by the author when a member of the research staff of the British Cast Iron Research Association, and thanks are due to the Council of the Association for permitting publication.

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Paper No. 659

Core-Shop Control

By J. J. SHEEHAN, B.Sc., A.R.C.Sc.I. (Member)

Adequate control of a core shop will consist of the control of materials, processes and mechanical operations. Under these headings the control may be extended to include the following items:—

(1) *Control of Materials*, which will include sands; binders; washes; pastes; chaplets; wires; parting powders; and the miscellaneous materials of a foundry stores.

(2) *Control of Processes*: for example, sand mixing; core baking; mixing, application and drying of washes; jointing of core assemblies; gauging and inspecting.

(3) *Control of Mechanical Operations*, such as the mechanical handling, transport and storage of raw materials and finished product; core blowing and core moulding; and sand recovery systems.

It would be difficult to cover the subject matter as extended above in a single Paper. The difficulty is avoided by making a selection, influenced by the fact that most attention is given to problems that arise in practice. It is therefore hoped that while the whole subject is not treated in detail, those items which are, will be of practical interest and value.

The foundry where the work in connection with this Paper was carried out is a motor vehicle foundry operating a steel, an iron and a non-ferrous section, and the materials used in the core shop are those common to foundries making light to medium-weight castings in steel, cast iron and non-ferrous metals.

CONTROL OF MATERIALS

Sands

Silica sands only are employed; no moulding sands or naturally-bonded sands are used in making cores. While it is realised that clay-bonded sands are used extensively particularly in the non-ferrous section of the industry, all the technique used in the foundry concerned has been built around silica sands bonded with organic binders, and these sands only will be considered.

Three types of sand are used, two extensively and one for special purposes. They are typified according to their grain size, and may be conveniently referred to as large, medium and fine sands, and are represented by the following:—

Large grain ...	Leighton Buzzard.
Medium grain ..	Somerford.
Fine grain ...	Arnold's 26A—Leighton Buzzard.

The exact chemical composition of these silica sands is not important when core making is the only end in view. As, however, the spent sands from the core knock-out are utilised as the base grain for synthetic moulding sand, and it is also intended ultimately to instal a core-sand recovery system, then the chemical composition will become of importance.

A control process on the mixing platform is also influenced by the chemical composition. This process will be described later, but at present it is sufficient to mention that the absence of free lime and of calcium carbonate in the sand is necessary for the success of the process. The incorporation of burnt core sand in the steel and cast-iron moulding systems necessitates the use of as pure a silica sand as it is possible to obtain economically.

The chemical composition of the sands used is given below:—

Garside's Leighton Buzzard (Large Grain Sand).

	Per cent.
Loss on ignition	0.10
Silica	99.50
Ferric oxide	0.03
Alumina	0.26
Titanium dioxide	Nil
Lime	Nil
Magnesia	0.20
Alkalis	Nil

Somerford (Medium Grain Sand).

	Per cent.
Loss on ignition	0.45
Silica	94.66
Ferric oxide	0.45
Alumina	2.10
Titanium dioxide	0.08
Lime	0.58
Magnesia	0.20
Alkalis	1.61

Arnold's 26A (Unwashed).

	Per cent.
Loss on ignition	0.72
Silica	96.20
Ferric oxide	0.25
Alumina	1.98
Titanium dioxide	0.05
Lime	0.03
Magnesia	0.15
Alkalis	0.72

The chemical composition of these sands influenced the selection for the reasons already given, but the main consideration in their ultimate adoption for use in the core shop is

their grading or grain size. The grading of these sands is given in Table I.

Using this selection and balancing the proportions of each in the sand mixture, it is possible to obtain a measure of control of:—(*a*) The permeability of the cores; (*b*) the amount of binder used; (*c*) the finish on the castings (where

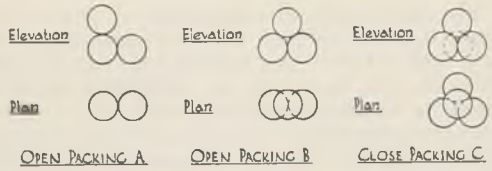


FIG. 1. FIG. 2. FIG. 3.

external cores are used); (*d*) the tendency to give expansion cracks, and also to a considerable extent (*e*) to prevent sagging of the green core.

All these factors are of considerable importance in the making of a good core, and are

TABLE I.—*Percentage Grading of Core Sands Used.*

I.M.M. Screens.	Leighton Buzzard.	Somerford.	Arnold's 26A.
+ 10	0.1	—	0.1
20	1.2	0.2	0.2
30	14.9	1.5	0.2
40	60.4	9.0	0.4
50	17.7	18.1	1.6
70	4.4	37.7	19.3
100	1.0	21.7	46.5
150	0.3	8.8	26.1
200	—	2.2	2.5
—200	—	0.6	1.2
Clay ..	—	1.1	2.2

influenced basically by the grading and condition of the sand grains.

It is possible (with grading control) to regulate any one of the conditions mentioned above, but only at the expense of the others; for example, the permeability may be increased by increasing

PLAN of OPEN-PACKED LAYER.

FIG. 4.

PLAN of CLOSE-PACKED LAYER.

FIG. 5.

the size of the sand grains, but this increase is accompanied by a rougher finish on the castings. It is possible to maintain good permeability, with good finish, by using a fine round-grained sand, the grains being also uniform in size. The expansion troubles produced by this type of sand are, however, considerable.

It is obvious that many and complex factors in this control must be taken into consideration, and that a unity of conception must be maintained if trouble is to be avoided in practice. This unity of conception can best be attained

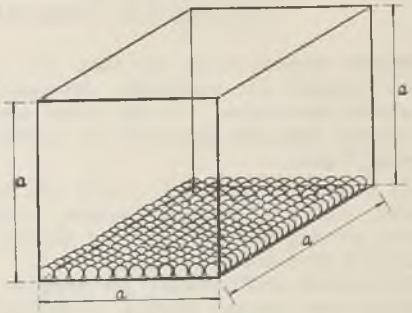
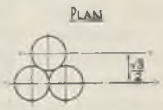


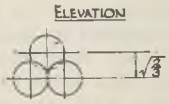
FIG. 6.

by a mathematical consideration of the factors involved, and can be fixed in the mind by a practical demonstration of the mathematical deductions. For the purposes of the following calculations it is assumed that the sand grains are spherical.



DISTANCE BETWEEN ROWS

FIG. 7.



DISTANCE BETWEEN LAYERS

FIG. 8.

A superimposed layer of sand does not ordinarily rest on the lower layer, as illustrated in Fig. 1, with one grain immediately over one other grain, or with one grain resting on two grains of the lower layer, as in Fig. 2; but for maximum compaction with unit grains one grain

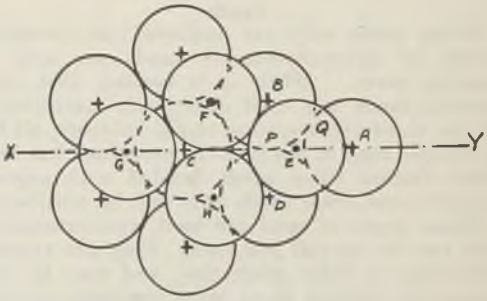


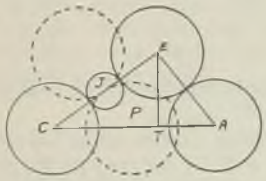
FIG. 9.

rests on a base of three grains, and over two layers as illustrated in Fig. 3. The foundation layer does not ordinarily arrange itself in a condition illustrated in Fig. 4, but in the condition

of close packing (Fig. 5). The mass of sand then tends to arrange itself in a condition of close packing (*c*) on a foundation layer of close packing.

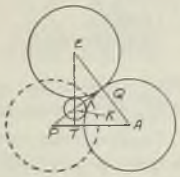
The next most likely condition is open packing on a foundation layer of close packing (*b*), and a further condition is open packing (*a*) on a foundation layer of close packing. It can be shown mathematically that these last two conditions are less compact, and it will be demonstrated later that they do not exist in a sand mass composed of a mixture of grain sizes.

To obtain the volume of sand and the volume of voids in a perfectly compacted sand consisting



SECTION XY.
SECONDARY SPHERE.

FIG. 10.



SECTION XY
TERTIARY SPHERE

FIG. 11.

of spherical grains of uniform diameter, *i.e.*, in the condition of close packing (*c*):

Take the diameter of each grain as a unit and consider the number of spheres to be packed in a cube of side a units long (Fig. 6): then a row of spheres along one edge will contain a spheres. The distance perpendicular to the side of the cube between one row and the next will be $\frac{\sqrt{3}}{2}$ (Fig. 7) and the number of rows will be $\frac{2a}{\sqrt{3}}$ and the number of spheres in a layer will be $\frac{2a^2}{\sqrt{3}}$.

The perpendicular distance from one layer to the next is $\sqrt{\frac{2}{3}}$ units (Fig. 8) and the number of layers is $\frac{a\sqrt{3}}{\sqrt{2}}$.

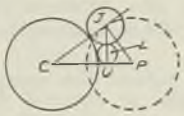
Then the total number of spheres is $\frac{2a^2}{\sqrt{3}} \cdot \frac{a\sqrt{3}}{\sqrt{2}}$ $= \sqrt{2}\, a^3$.

This is only true where a is large, which is the case with moulds and cores.

The volume of a sphere is $\frac{4}{3}\pi r^3$; if the diameter is one unit, the volume becomes $\frac{4\pi}{3}\frac{1}{2^3}$ or $\frac{\pi}{6}$.

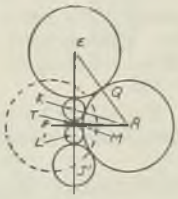
The total volume of perfectly compacted unit spheres in a cube of a units side is $\sqrt{2}\, a^3 . \frac{\pi}{6}$ or $\frac{\pi\sqrt{2}}{6}\, a^3$ or $0.74\, a^3$; and since the volume of the cube is a^3, then the volume of the voids is $0.26\, a^3$, *i.e.*, 74 per cent. of the space is occupied by sand and 26 per cent. of the space is *void*.

Similarly for the condition of open packing (*b*) on a foundation layer of close packing, it can be shown that 70 per cent. of the space is occupied by sand and 30 per cent. of the space is void, and for open packing (*a*) on a foundation layer of close packing, the space occupied by sand is 60 per cent., and the void is 40 per cent. The condition of close packing (*c*) is the condition of lowest void content, *i.e.*, 26 per cent. voids.



SECTION XY
QUATERNARY SPHERE

FIG. 12.



SECTION XY
QUINARY SPHERE

FIG. 13.

This is in agreement with H. A. Schwartz in a Paper given to the American Foundrymen's Association, in which he shows that the closest packing of a mass of spheres free to move or rammed into place in a container having dimensions a multiple of their diameters is the tetrahedral.

H. E. White and S. F. Walton in a Paper entitled "Particle Packing and Particle Shape," given in the Journal and Ceramic Abstracts, American Ceramic Society, May, 1937, also give the tetrahedral system as the condition of closest packing.

Having established this condition of closest packing for grains of unit size, the sizes of rounded grains, which can fit in the voids existing between these unit grains of this tetrahedral arrangement, were calculated and found to be as follows:—

Where d is the diameter of the unit grain,

	No. of grains.
d	1
$0.414d$	1
$0.22d$	2
$0.18d$	8
$0.15d$	7

White and Walton give an alternative to the 0.15 size (it is $0.116d$), and arrange the fitting sizes in the following series:—

	No. of grains.
Primary sphere d	1
Secondary sphere $0.414d$	1
Tertiary sphere $0.225d$	2
Quaternary sphere $0.177d$	8
Quinary sphere $0.15d$ and an alternative $0.116d$	8

Schwartz arranges the fitting-in sizes in two series as follows:—

		No. of grains.
Primary and secondary series	d	1
	$0.414d$	1
	$0.22d$	2
Ternary series	d	1
	$0.414d$	1
	$0.22d$	2
	$0.154d$	7

The tetrahedral arrangement is shown and the sizes represented diagrammatically with letters J, K, L in White and Walton's Paper by Figs. 9, 10, 11 and 12. The alternative to $0.15d$ is shown with letter M (Fig. 13). Figs. 14 and 15 are photographs showing the arrangement of three "fitting-in" sizes—the $0.414d$, $0.22d$, and $0.18d$.

Expressed by weight or volume this compacted tetrahedral series becomes:—

No. of grains.	Diameter.	Wt. or Vol.	Per cent. Wt.
1	d	$1.000 \frac{\pi d^3}{6}$	74.2
1	$0.414d$	0.071 „	5.2
2	$0.220d$	0.021 „	1.6
8	$0.180d$	0.047 „	3.5
8	$0.116d$	0.012 „	0.9
		1.15 „	85.4

The total volume of grains is now $1.15 \frac{\pi d^3}{6}$.

The total number of *unit* grains in a cube of a sides is $\sqrt{2}\ a^3$, and the volume is $\frac{\pi \sqrt{2}\ a^3}{6}$ or $\underline{\underline{0.74a^3}}$, and the total volume of the compacted series in a cube of a sides is

$$1.15 \frac{\pi d^3 \sqrt{2}}{6} a^3 \text{ or } \underline{\underline{0.854a^3}}$$

The fitting-in grains have increased the sand content by 11.4 per cent. and decreased the voids from 26 to 14.6 per cent. Although the void content is considerably reduced, there remains 14.6 per cent. to be filled by material in size less than $0.116d$ to infinitely small.

A completely compacted series, which would obviously be absolutely impervious, can then be represented as follows:—

Diameter of grains.	Per cent.	Wt. or Vol. per cent.
d	74.2	
$0.414d$	5.2	
$0.22d$	1.6	85.4
$0.18d$	3.5	
$0.116d$	0.9	
Less than $0.116d$	—	14.6

or as $0.22d$ and $0.18d$ are almost equal:—

Diameter of grains.	Wt. or Vol. per cent.
d	74.2
$0.414d$	5.2
$0.22d$	5.1
$0.116d$ to infinitely small	15.5

This can be approximated to read

Diameter of grains.	Wt. or Vol. per cent.
d	74.2
$2/5d$	5.2
$1/5d$	5.1
$1/10d$ to infinitely small	15.5

This constitutes a simple mathematical relationship, easily remembered.

In order to relate these sizes to those actually found in practice, it will be convenient to give here the screens used and the size in inches of the mesh openings.

The screens used in control work are the I.M.M. series, and are as follow:—

	Ins.
+ 10	0.0500
+ 20	0.2500
+ 30	0.0166
+ 40	0.0125
+ 50	0.0100
+ 70	0.0071
+100	0.0050
+150	0.0033
+200	0.0025
−200	<0.0025

If d is made equal to the mesh size of the + 30 I.M.M. screens, *i.e.*, to 0.0166 in., $2/5d$ becomes 0.0066 in., *i.e.*, + 75 mesh; $1/5d$ becomes 0.0033 in., *i.e.*, + 150 mesh; $1/10d$ becomes 0.00166 in. *i.e.*, − 200 mesh. (The + 75 mesh is not at present made in the I.M.M. series, and the + 70 is substituted in these considerations.)

The completely compacted series might then be expressed by the weights on the sieves:—

	Ins.	Per cent.
+ 30	0.0166	74.2
+ 70	0.0071	5.2
+150	0.0033	5.1
Pan material	0.00166	15.5

or arranged in columns as follows:—

d	$2/5d$	$1/5d$	$1/10d$
+ 30	+ 70	+150	Pan material

and extended to include other mesh sizes:—

d	$2/5d$	$1/5d$	$1/10d$
+ 30	+ 70	+150	Pan material
+ 40	+100	+200	Pan material
+ 50	+150	−200	Pan material

This completely compacted series

Unit	2/5 Unit	1/5 Unit	1/10 Unit
+ 30	+ 70	+150	Pan material
74.2 per cent.	5.2 per cent.	5.2 per cent.	15.5 per cent.

would give imperviousness and maximum density provided the pan material contained all sizes from 0.00166 in. dia. to infinitely small.

It is most important to consider, however, that the exact positioning of each grain according to the diagram illustrated is impossible to attain in practice, but it is possible to know exactly what grain sizes are most effective in controlling permeability and density.

A few experiments will illustrate this. To show that fitting-in does take place, a series of test-pieces was made by ramming together a mixture of two sands.

	Per cent.		Per cent. 100 for comparison.
(I)		+ 20	
(II) + 30	10	+ 20	90
(III) + 40	10	+ 20	90
(IV) + 50	10	+ 20	90
(V) + 70	10	+ 20	90
(VI) +100	10	+ 20	90

The lengths of the test-pieces in inches were then accurately measured:—

Number of blows.	(I)	(II)	(III)	(IV)	(V)	(VI)
0	2.180	2.180	2.170	2.050	2.082	2.110
1	2.032	2.030	2.000	1.950	1.966	1.928
2	1.994	2.004	1.968	1.930	1.936	1.898
3	1.978	1.990	1.950	1.912	1.916	1.880
4	1.964	1.980	1.942	1.900	1.902	1.880
5	1.954	1.966	1.928	1.892	1.892	1.870
7	1.940	1.950	1.912	1.878	1.878	1.860
10	1.926	1.936	1.894	1.860	1.860	1.828
15	1.906	1.910	1.872	1.844	1.840	1.808
25	1.880	1.884	1.848	1.822	1.814	1.784
50	1.846	1.850	1.812	1.786	1.778	1.752

The percentage decrease obtained after 50 blows was—

	Per cent. decrease.
I.—+ 30	0.2
II.—+ 40	1.8
III.—+ 50	3.25
IV.—+ 70	3.70
V.—+100	5.10

No decrease occurs with the + 30 size, but a slight decrease occurs with the + 40, due to the + 20 containing all sizes from − 10 to + 20, *i.e.*, from 0.0499 in. to 0.0250 in. The first substantial decrease occurs with the + 50, *i.e.*, with the size 2/5 of the + 20.

A better illustration of the fact that fitting-in does take place is produced by using a larger quantity of a fitting-in size. Once again + 20 and + 100 mesh were used, and 50 per cent. of both sizes were used to make the test-pieces. One test-piece was made by placing a layer of the + 20 on a layer of + 100, and the other test-piece was made by intimately mixing the + 20 and + 100 (see table below).

No. of blows.	Sand in layers. Length of test-piece.	Sand mixed. Length of test-piece.
0	2.094	1.858
1	2.020	1.774
7	1.950	1.716
25	1.886	1.678
50	1.856	—
Permeability after 7 blows.. ..	210	80

The decrease in length when the sands were intimately mixed was 12 per cent., and is illustrated graphically in Fig. 16. The permeability was reduced by more than 60 per cent.

As a further illustration, and to show that a mixture of sand grains does arrange itself in the condition of close packing (*c*), *i.e.*, the tetrahedral system, the lengths of test-pieces obtained by ramming mixtures of + 40 mesh and + 70 mesh in proportions from 100 per cent. of one to 100 per cent. of the other were measured. No fitting-in occurs. If the + 40 sand was in the condition of open packing (*a*), *i.e.*, the cubic system, the largest size of sand grain capable of fitting-in would be 0.732 times the diameter of the + 40 or 0.00915 in.; then the + 70 with a diameter of 0.0071 in. would readily fit-in, producing a decrease in the length of the test-piece.

The graph in Fig. 17 shows a maximum reduction of 3 per cent. in the length of the test-piece when increasing percentages of + 70 are mixed with + 40. This slight reduction in length of the test-piece is accounted for by the fact that it is practically impossible to sieve the +70 grains free from small quantities of − 70 grains which would fit into the − 30 + 40 grains; and

also the accuracy of standard sieves cannot be relied upon within very fine limits. This figure also indicates that the reduction in permeability is less than that obtained by mixing sands that have a greater difference in grain size.

Further work done in association with Mr. Parkes, of the British Cast Iron Research Association, some of which has been reproduced in Research Report No. 138 (January, 1938), also confirms and illustrates this assumption.

Fig. 18 graphically represents the length of test-piece and the permeability numbers obtained with mixtures of + 20 and + 100 mesh sand, showing fitting-in and reduction in permeability obtained. Fig. 19 is a graph showing the fitting-in obtained with two sands from the Leighton Buzzard deposits actually in use in the core shop. The mixture giving maximum density, indicated by this graph, was used to make test-piece III in Fig. 24.

With this conception of a simple relationship between the grain sizes,

$$d, \quad \frac{2d}{5}, \frac{1d}{5} \text{ and } \frac{1d}{10}$$

the control of permeability becomes more certain, and the relationship between permeability requirements and other required qualities in a core, more obvious. Core mixtures currently used for some obscure or forgotten reason were re-examined in the light of this relationship, and many of the mixtures were eliminated, and those retained were improved.

Previously it has been mentioned that a fine sand consisting of rounded grains of uniform size would give good permeability with good finish, but unfortunately there are many disabilities accompanying the use of such a sand. These disabilities can be overcome by the use of a mixture of grain sizes, maintaining at the same time good permeability and good finish on the castings and other requirements of a good core and good core-shop practice.

Using fine sand alone increases the amount of binder required. In unit quantity of sand, the number of grains is inversely proportional to the cube of the diameter, *i.e.*, $1/(\text{diameter})^3$. The surface area of each grain is proportional to $(\text{diameter})^2$. Therefore, the total surface area in unit quantity is directly proportional to the number of grains, or the resultant increase in total surface area is inversely proportional to the size. The smaller the grain size the larger the surface area.

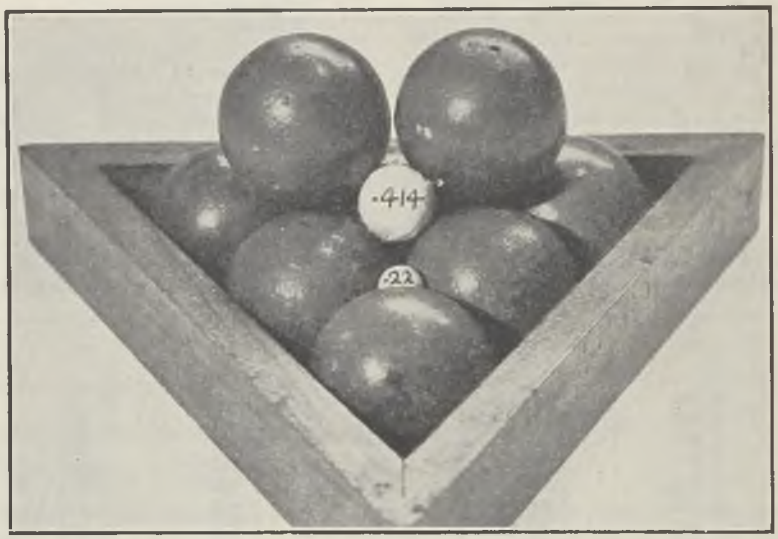


Fig. 14.—"Fitting-in" Arrangements of Three Sizes.

Then + 70 sand should require $2\frac{1}{2}$ times the amount of binder required by a + 30 sand. The amount however is a little less than this, as the strength of the core is influenced also by the number of points of contact between the grains. For economy in binder, it is essential, therefore, to use as large a grain size, or as large a proportion of large-grained sand, in the mix as is possible. Where good finish on the surface of the casting is the main consideration, small-grained sand is again obviously the choice, and for good permeability these grains should be uniform in size.

Fin Inhibition

However, in addition to a greater cost in binder, there are two other very serious disabilities in the use of this latter type of sand, becoming more serious as the grain size becomes larger. The most troublesome of these defects is an expansion fin, produced on the casting when cores with sand grains of uniform size are used. (All sizes in any one column in the arrangement of sizes already given are considered as a single size, since no fitting-in is possible.)

This defect is shown in Fig. 20, and is represented diagrammatically by Fig. 21. A thin fin of metal is produced at the corners of the casting, which is very difficult to remove in the fettling shop. These figures illustrate the defect produced with internal cores, *i.e.*, cores completely or almost completely surrounded by metal. This defect is also produced with external cores, and is illustrated by Figs. 22 and 23.

While this latter type of fin is easier to dress off, it still necessitates extra work and is otherwise undesirable. An examination of the defect readily showed that it was produced by liquid metal penetrating into a crack in the core, and that this crack was produced by the expansion of the sand. Cores of rectangular section crack at the corners, and cores of circular section crack at the weakest point of the circumference.

In cores made of uniform rounded grains, the flowability of the sand is good, and good compaction is a normal condition. Under these conditions, when expansion occurs, there is no room within the core structure to take up this expansion, and cracking occurs. It can readily be seen, however, that if the sand mass consists of grains of unit size mixed with grains of less diameter than 2/5 unit size, the smaller grains can expand in the voids between the unit sizes. Again, since the surface area of the smaller grains is greater in proportion to the mass than the larger grains, they will heat up more rapidly and expand, reducing at the same time the amount of heat available later to expand the larger grains; in other words, the expansion can take part in stages.

Such a core has within its structure room for sufficient expansion to reduce the tendency to crack, and Fig. 24 illustrates these assertions. No. I is made of coarse uniform-grained sand; No. II is made of fine uniform-grained sand, and No. III is made of a mixture of coarse and fine grained sand. The cores were heated rapidly to a temperature of 800 deg. C., and Nos. 1 and II show large cracks, whilst No. III is entirely free from cracks.

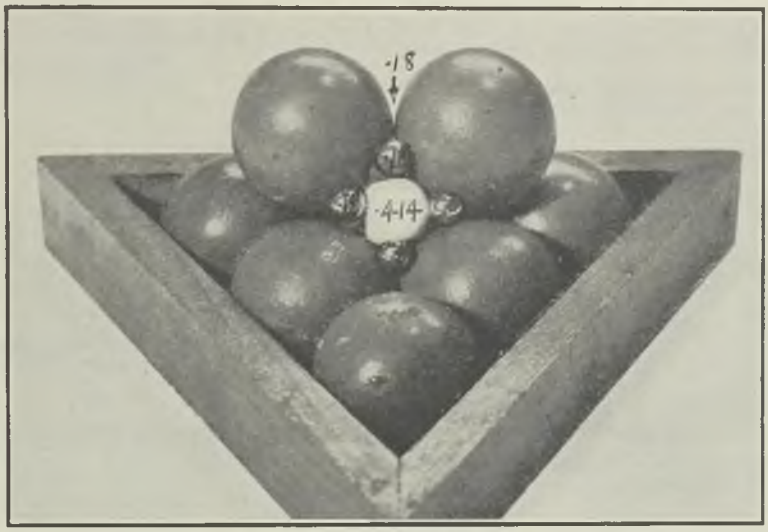


Fig. 15.—A Second Arrangement of "Fitting-in."

When the fins produced by these cracks occur on the casting, the trouble and cost of fettling are increased. When the cracks occur in runner cores, erosion of the edge of the crack frequently occurs, and dirty castings are a consequence. The runner core of a bottom-filled steel ingot mould exhibited this defect and was rectified by the additions to the core mass of small grains in the form of silica flour. Fig. 25 shows the condition of the runner before and after this addition.

Influence of Grain Size and Distribution in Green State

Rounded sand grains of uniform size produce in a core which consists entirely of such grains a tendency to sag while in the green condition. This tendency is most marked with large grains. It can be controlled to an extent by using a mixture of grain sizes or by using a fine-grained sand. There are other methods of controlling and eliminating this defect which will be referred to later. Fig. 26 illustrates this tendency to sagging, and the reduction in the tendency when using a blend of sizes, wherein No. I test-piece consists of + 40 mesh sand; No. II test-piece consists of + 100 mesh sand, and No. III test-piece consists of a mixture of + 100 mesh and + 40 mesh sand in those proportions previously found to give the maximum amount of fitting-in, *i.e.*, 66.6 per cent. of the finer material with 33.3 per cent. of the coarser sand.

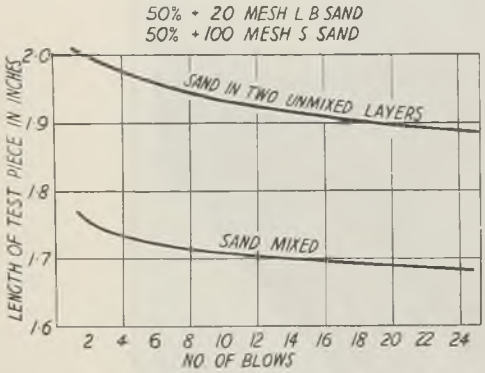


Fig. 16.—Influence of Mixing on Length of Test-Piece.

With the foregoing considerations in mind, it is possible to select sands and sand mixtures for the core shop which will give a maximum in effectiveness with a minimum of cost in materials and in processes, and by using the tabulation of sizes suggested it is possible to regulate the mixtures with some knowledge of the results to be expected.

Core Binders

The selection of core binders is based on the requirements in green strength of the core-sand mixtures and the requirements in dry strength of the finished core. The dry strength is of ultimate importance in the baked and finished core, and offers few difficulties either in the selection or control of materials or processes. The green strength is of importance during the manufacture of the core only. There is a large variety of materials capable of giving satisfactory service, and the final selection is often determined by a peculiar condition of the shop or requirement in practice.

The shop condition which most influenced the ultimate selection of green binder was the method of mechanical delivery of the prepared sand mass, and the transportation of the green cores.

The special requirement was an ashless binder. This latter consideration was necessitated by the intention eventually to install a core-sand recovery plant, and also by the fact that burnt core sand is the base material of the synthetic moulding sand systems now in operation. Any

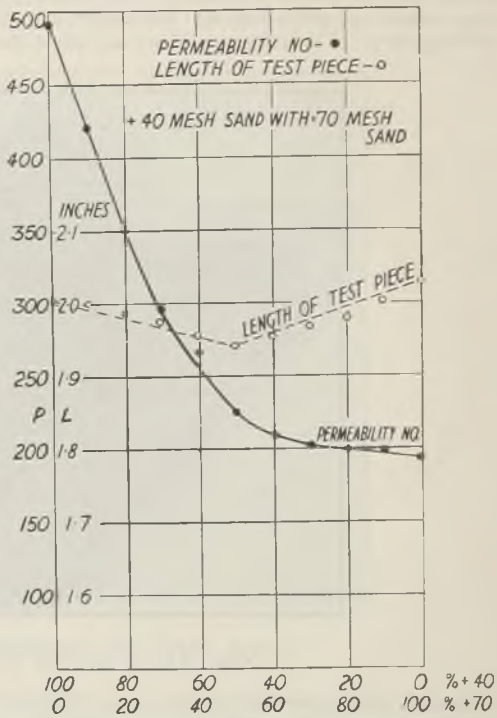


Fig. 17.—Test-Piece Length and Permeability Correlated with Sand Mixes.

ash would be undesirable under either of these conditions, and a fusible ash particularly so. Molasses and wood-extract concentrates were consequently undesirable, and the ashless cereal binders were indicated.

Transport System

The mechanical transportation of the prepared sand mass consists of an overhead bucket conveyor, shown in Fig. 27. Each bucket holds approximately 70 lbs. of prepared sand. This means that every 6½-cwt. batch of sand milled is divided into 10 smaller lots, exposing a con-

siderable area of the mass to the atmosphere of the shop for periods of time, dependent upon the distance of the core bench from the preparation platform, and the immediate requirements of the core bench. (Should sand not be required on the bench the full buckets continue to circulate and are not tipped until needed later.) These conditions require a green bond that does not readily dry out. The green cores are transported to the drying oven on a tray conveyor of the type shown in Fig. 28.

This is an excellent conveyor of high capacity and speed, but from the nature of the design subject to some vibration. Green cores on a vibrating conveyor are liable to sag. This

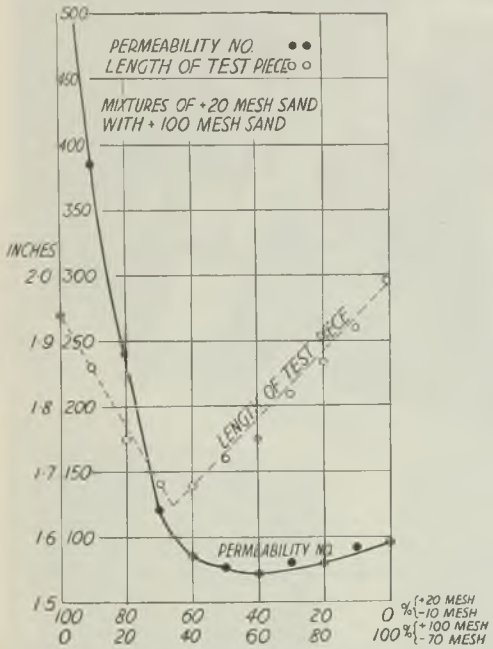


Fig. 18.—Influence of Mixing on Length of Test-Piece and Permeability.

tendency to sag can be offset to an extent by a selection of the grain sizes of the sand mass, as already mentioned and illustrated, and can be reduced to a further considerable extent if the surface of the green core air-dries rapidly. One conveyor therefore calls for a green bond that air-dries slowly, and the other for a green bond that air-dries rapidly. A balance between these two conditions is, however, possible. The rate of air drying can be maintained between limits suitable to both conditions.

Factors in Air Drying

The rate of drying of the mass is dependent upon: (1) The surface area of the sand grains, and (2) the vapour tension of the solution of the binder. (1) is predetermined by considerations of permeability and economy, and (2) is a variable dependent upon the humidity and temperature of the atmosphere of the shop.

The atmosphere of the shop cannot at present be conveniently controlled. The alternative is a control of the vapour tension of the solution of the binder, and this is conveniently obtained by additions of ammonium nitrate. According to Raoult's law, which says: "The diminution of the vapour pressure of a solution of a non-

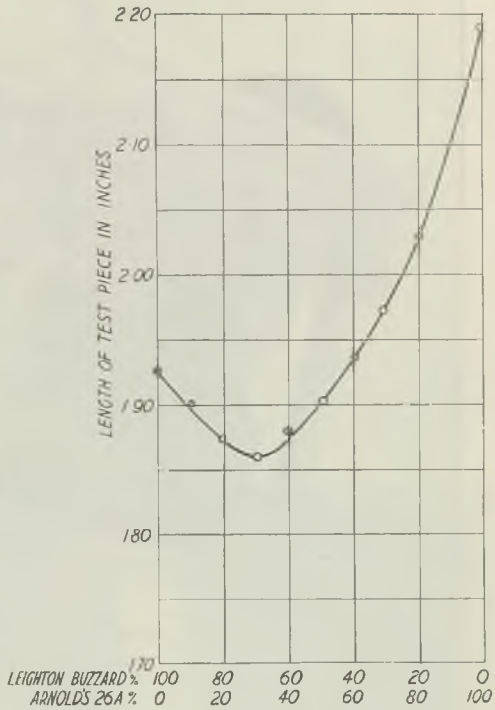


Fig. 19.—Influence of Mixing on Length of Test-Piece.

volatile substance is proportional to the number of molecules dissolved in a constant weight of the pure solvent," the control might conceivably be obtained by varying the amount of binder used. This method is undesirable mainly owing to the consequent variation in green strength produced.

The use of an electrolyte is preferable, as it produces no variation in the green strength of the sand mass, and by dissociation produces approximately double the molecular diminution in vapour pressure of substances which do not ionise in solution. The electrolyte selected, as already mentioned, is ammonium nitrate, which

has a high solubility and decomposes at the temperature of the drying ovens, leaving no solid residue or ash and assisting to an extent in the oxidation of the unsaturated core oil, particularly in the centre of heavy cores.

cent. solution; No. 2, with a specific gravity of 1.070—20 per cent. solution, and No. 3, with a specific gravity of 1.035—10 per cent. solution.

The condition of the atmosphere of the shop, *i.e.*, the percentage humidity and temperature

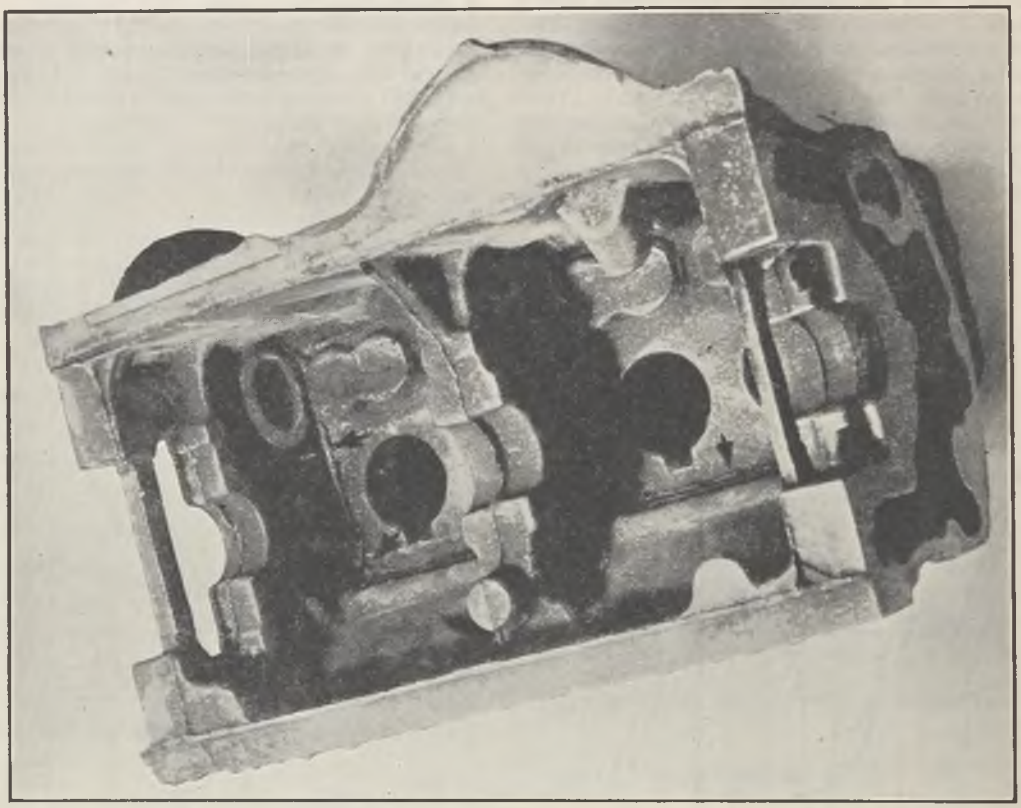


Fig. 20.—Fin Defect due to Expansion.

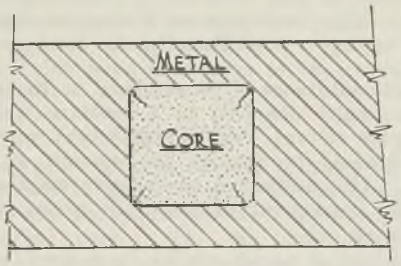


Fig. 21.—Cause of Expansion Fins.

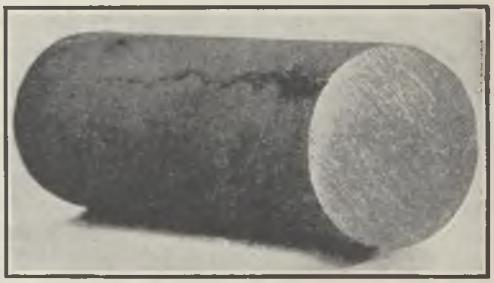


Fig. 22.—Fin due to Expansion of External Core.

The method of control consists in using solutions of ammonium nitrate of varying concentrations to replace the water ordinarily used in the sand mix. Three concentrations are used:—No. 1, with a specific gravity of 1.120—40 per

and consequent vapour pressure of a water solution under those conditions, is obtained from the wet and dry bulb thermometer, and No. 1, 2 or 3

solution is used according to the indications given.

Control Method

The following is an illustration of the method:—

Read off the percentage relative humidity from the chart accompanying the wet and dry bulb thermometer; subtract from 100, multiply by vapour pressure of water at the air temperature noted, and use No. 1 solution when the resultant is above 8; No. 2 solution when from 5 to 8, and No. 3 solution when below 5.

Example.—

Dry bulb reading 68 deg. Fah.
Wet bulb reading 60 deg. Fah.
Humidity 60 per cent.
Vapour pressure of water at 68 deg. Fah. is 13.1 mm.

$$\frac{100 - 60}{100} \times 13.1 = 5.2.$$

Use No. 2 solution.

The resultant may be called the *index of the rate of drying.* It is a direct measure of the amount of unsaturation existing under the conditions noted. A practical method of controlling the rate of air drying without the necessity of wet and dry bulb equipment is of some interest. The green strength of a test-piece is obtained immediately the test core is made and again after a time interval of two minutes. The rate of drying suitable to the shop conditions can be decided upon, and can then be controlled by the use of a suitable strength solution of ammonium nitrate, the equipment necessary being illustrated in Fig. 29. The stripping post in the position shown is an essential part of the equipment. It enables the core to be tested for strength immediately it is made.

The cereal binder used is dextrin; but a soluble starch compound has also been used with success. The operators prefer dextrin, however, mainly because the flowability of the sand made with dextrin is better, and there is less difficulty in ramming intricate cores.

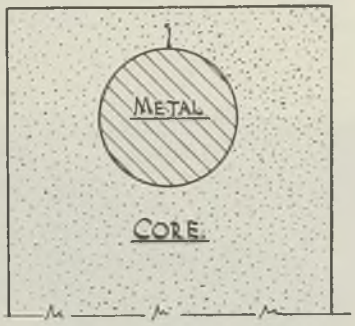


Fig. 23.—Cause of Fin with External Core.

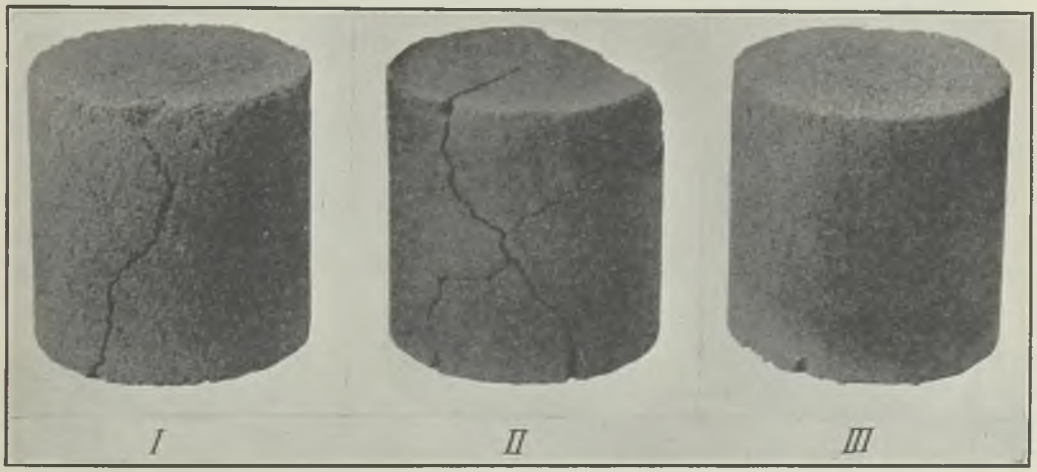


Fig. 24.—Influence of Core Mixtures on Tendency to Crack.

Washes

Core washes are used extensively in the cast iron, steel and non-ferrous foundries. The function of the wash is to protect the surface of the core from the action of the molten metal, *i.e.*,

from erosion, penetration between sand grains or penetration of cracked cores. These penetration effects are increased by higher pouring temperatures.

Silica flour is used in the steel section, and has recently replaced plumbago and blackings in the iron foundry. Talc is used in the non-ferrous section. The silica flour mixture used consists of:—Silica flour, 21 galls. (210 lbs.); Colbond, 9 galls. (72 lbs.); water, 36 galls.; dextrin solution (50 per cent.), 4 pints.

This gives a Beaumé gravity of about 52 to 60 deg., and is thinned down to requirements, *e.g.*, Beaumé 50 deg. for port and runner cores and 48 deg. for jacket cores (these cores are dipped), and 40 deg. for cores that are sprayed, such as end cores, body cores and chest cores.

The change to silica flour was necessitated

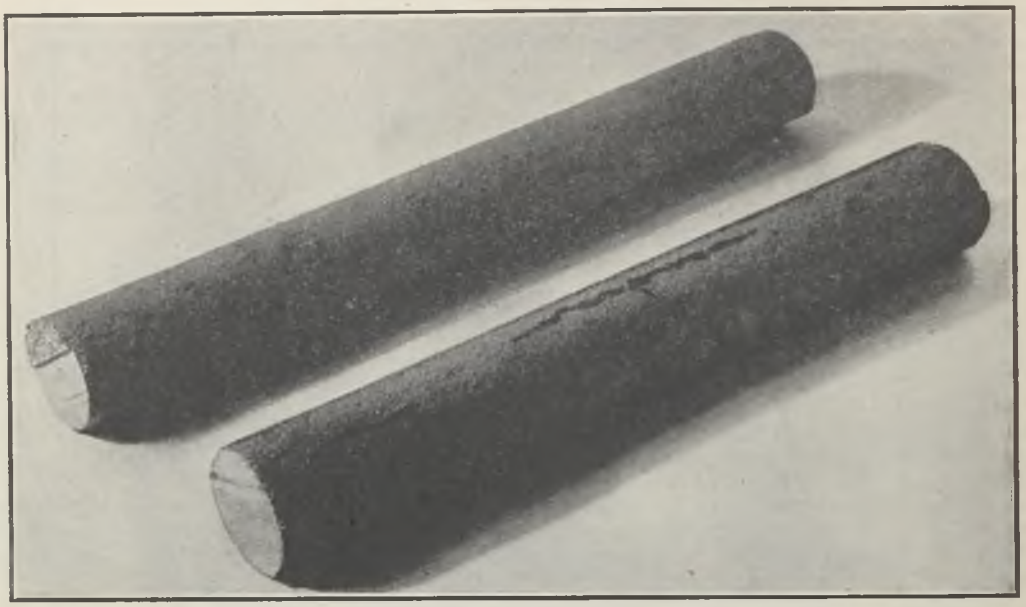


Fig. 25.—Illustration of Elimination of Fins by Silica-Flour Addition.

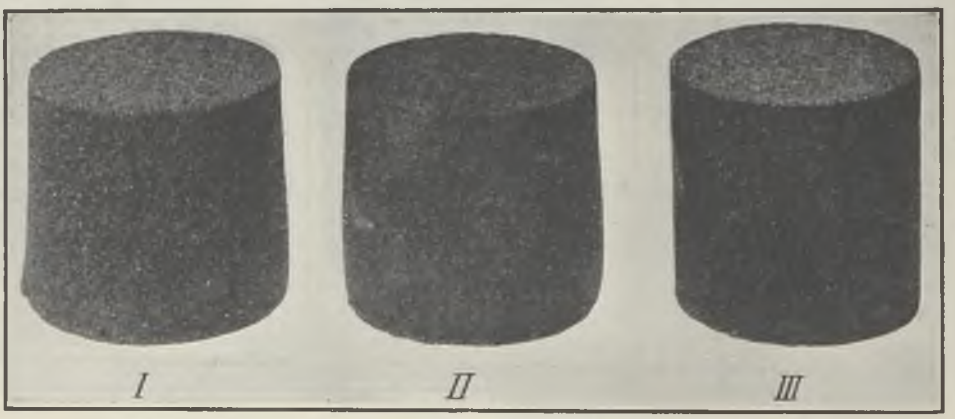


Fig. 26.—Tendency to Sagging.

mainly by a change in the type of iron used, but a considerable economy also resulted. The iron now used in the foundry is a copper-chrome alloy with a low phosphorus and total-carbon content. Its main characteristics are: phosphorus, less than 0.10 per cent.; total carbon, 3.10 to 3.30 per cent., and silicon, 2.10 to 2.30 per cent.

The pouring temperature of such an iron needs to be high. This high temperature requires mould and core conditions approximating to those obtaining in steel practice. It was found that graphite did not give sufficient protection to the cores when high pouring temperatures were used. The better performance of silica wash in this respect depends upon the consideration that, while the heat capacities of both types of wash are approximately equal, the thermal conductivity of the graphite wash is more than one hundred times as great as that of the silica wash. Using a graphite wash, the rate of heat transmission was sufficiently rapid to expand and crack the core before the metal had set, thus allowing the metal to penetrate the crack, forming a fin which was difficult to fettle off.

The equality in the heat capacities of the two washes is not evident from a consideration of the specific heats of graphite and silica only; the relative amounts of these materials per square inch of surface area of the core must also be taken into consideration. These relative amounts were determined experimentally, using a paint viscometer of the type illustrated in Fig. 30.

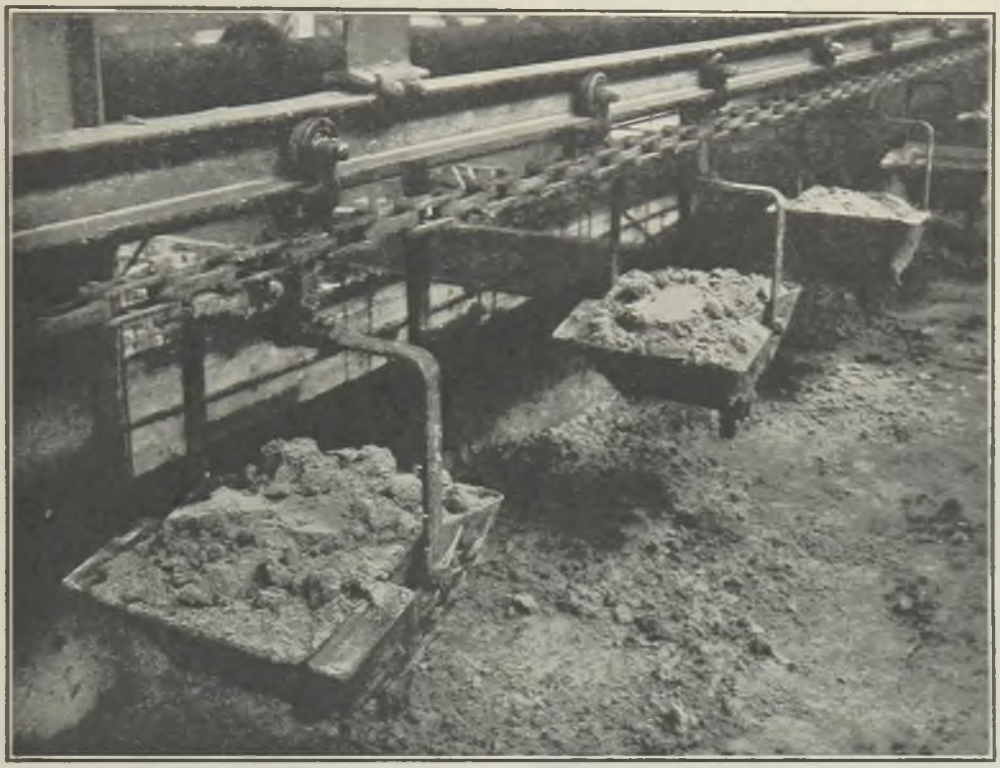


Fig. 27.—Overhead Bucket Conveyor.

The dry materials in the silica wash used were in the amounts already mentioned; the materials in the plumbago or graphite wash were identical, but for the substitution of graphite for silica flour.

The viscosities and Beaumé strengths of the water suspensions, and the thickness and weight of dried wash on clean glass plates were determined. The results obtained are given in the table on the next page.

The viscosity of 54 given in Series I is the

viscosity of the wash which is used when cores are dipped. The viscosity of 46 given in Series II is the viscosity of the wash which is used when cores are sprayed.

Series.	Type of wash.	Temp. of wash. Deg. C.	Viscosity.	Beaumé strength. Deg.	Thickness of coating. Ins.	Wt. of coating.* Grams.
I	Graphite ..	17.0	54	33	0.00275	0.95
	Silica ..	17.2	54	52	0.00425	1.56
II	Graphite ..	16.8	46	30	0.001	0.48
	Silica ..	16.0	46	50	0.0025	0.62

* The weight of coating is the weight of dried material on $10\frac{9}{16}$ sq. in. of glass plate.

The following calculations show that heat capacities of the washes for equal areas of core surface in Series I are equal, and in Series II approximately so.

Series I.—

Specific heat of graphite = 0.4670.
Specific heat of silica flour = 0.29.
Wt. of graphite on $10\frac{9}{16}$ sq. in. = 0.95 gms.
Wt. of silica on $10\frac{9}{16}$ sq. in. = 1.56 gms.
Heat capacity of graphite wash is 0.4670 × 0.95 = 0.44 calories.
Heat capacity of silica wash is 0.286 × 1.56 = 0.44 calories.

For Series II the relationship is:—

Heat capacity of graphite wash = 0.22 calories.
Heat capacity of silica wash = 0.18 calories.
The coefficient of thermal conductivity of graphite is 0.24 and of silica 0.0025, so that in Series I the rate of conduction of heat through the wash is proportional to $0.24 \times \frac{1}{0.00275}$ for graphite and $0.0024 \times \frac{1}{0.00425}$ for silica, *i.e.*, the rate of conduction is $\frac{0.24}{0.00275} \times \frac{0.00425}{0.0024}$ or 154.5 times greater through the graphite wash.

Fig. 28.—Green Core Conveyor.

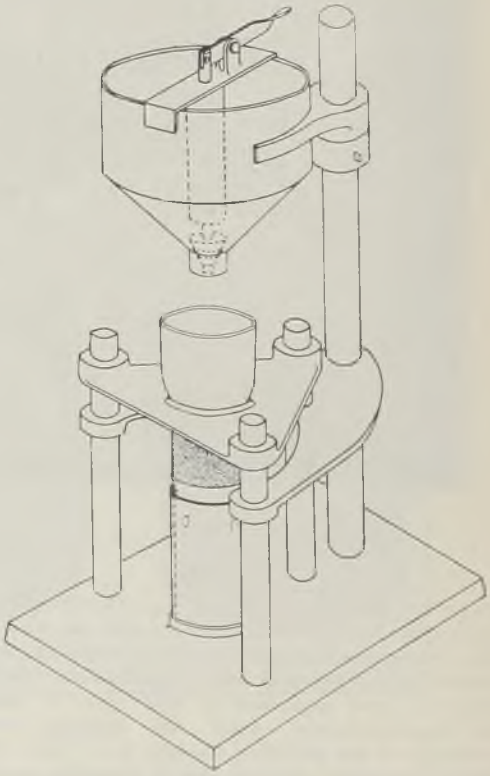


Fig. 29.—Testing Machine for Green-Sand Cores.

The authorities for values used in the above calculations are:—

Specific heats.	Authority.
Graphite at 978 deg. C. is 0.4670	Geber.
Silica at 1,000 deg. C. is 0.286.	Calculated according to Woestyn's hypothesis.

Coefficient of thermal conductivity is defined as the quantity of heat which passes through a cubic centimetre in one second divided by the

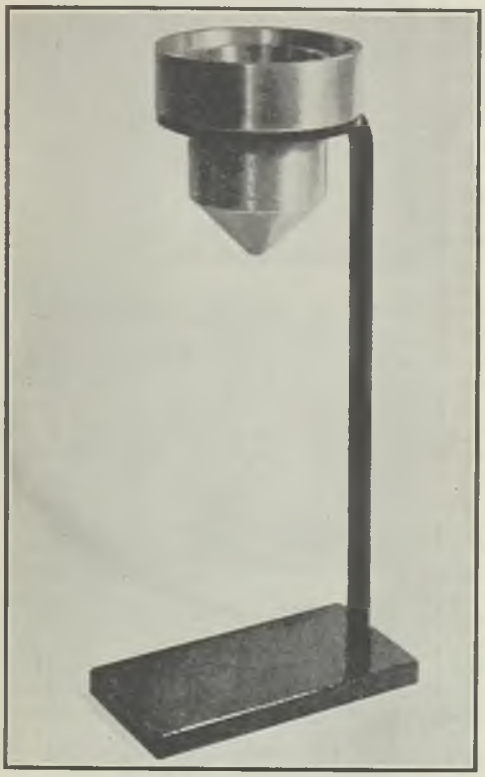


Fig. 30.—Viscometer.

difference of temperature in deg. C. between the two faces through which the heat passes.

Graphite (consolidated), 0·24		Wologdine.
Silica granulated (consolidated),	0.002	Wologdine.
	0.003	

The relationship found in the above experiments between the weights of graphite and silica flour in suspension in a wash at equal viscosities is confirmed by the work of Bingham and Durham* (from which the graph shown in Fig. 31 is taken), and by E. Lips and H. Nipper in "An Investigation of the Influence of Crystallisation on the Fluidity of Melts,"† from which the graphs in Figs. 32 and 33 are taken.

A secondary result of this investigation was a more accurate control of the washes used in the

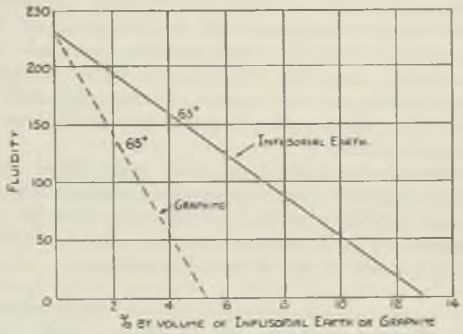


Fig. 31.—Fluidity $\left(\frac{1}{\text{viscosity}}\right)$ of Suspensions of Infusorial Earth and Graphite in Water at Different Temperatures. (Bingham and Durham.)

core shop, based on the viscosity of the washes rather than the Beaumé gravity. The wash is now made up in large capacity tanks in the core shop to a specified Beaumé gravity, and minor adjustments made if necessary from a deter-

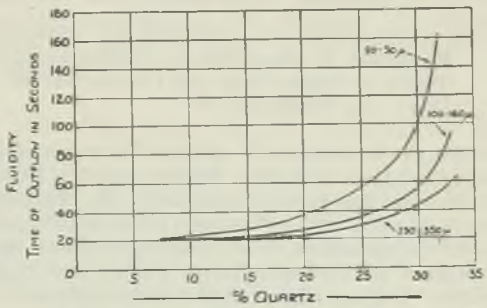


Fig. 32.—Times of Outflow of Various Mixtures of Quartz in Suspension in Terms of Grain Size and Concentration. (Lips and Nipper.)

mination of the viscosity carried out in the laboratory. The instrument used is already shown in Fig. 30.

Defects in the wash can also be correlated to viscosity figures, and thus readily corrected.

* Trans. Amer. Chem. Soc. Vol. XLVI, 1911, p. 278.

† "Die Giesserei," July, 1938, p. 369,

Some of the defects observed are illustrated in Fig. 34, wherein (*a*) shows a tear in the wash film (viscosity of silica wash 54 secs. and graphite wash 64 secs.); (*b*) shows granulations of the wash film (viscosity of silica wash 40 secs.), and (*c*) shows smooth finish (viscosity of silica wash 46 secs. and graphite wash 53 secs.).

Improvement in these illustrated conditions may also be obtained by modification of the amounts of materials used to make the wash, but once these amounts are decided upon, accurate reproduction of the good results obtained is dependent upon the maintenance of a correct viscosity value.

Laboratory control is also maintained with pastes, chaplets, parting powders, and core wires. In connection with these materials, however, no problem of sufficient interest to justify further prolongation of the Paper has arisen.

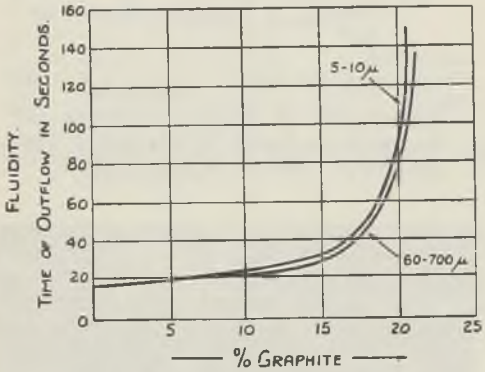


Fig. 33.—Times of Outflow of Various Mixtures of Graphite in Suspension in Terms of Grain Size and Concentration. (Lips and Nipper.)

The preliminary work of this Paper was done in association with Mr. Parkes, of the British Cast Iron Research Association. Mr. Thonger, of the Austin Motor Company's laboratories, has been the mainstay of its continuation and completion. To both gentlemen and to the Austin Motor Company the author is much indebted.

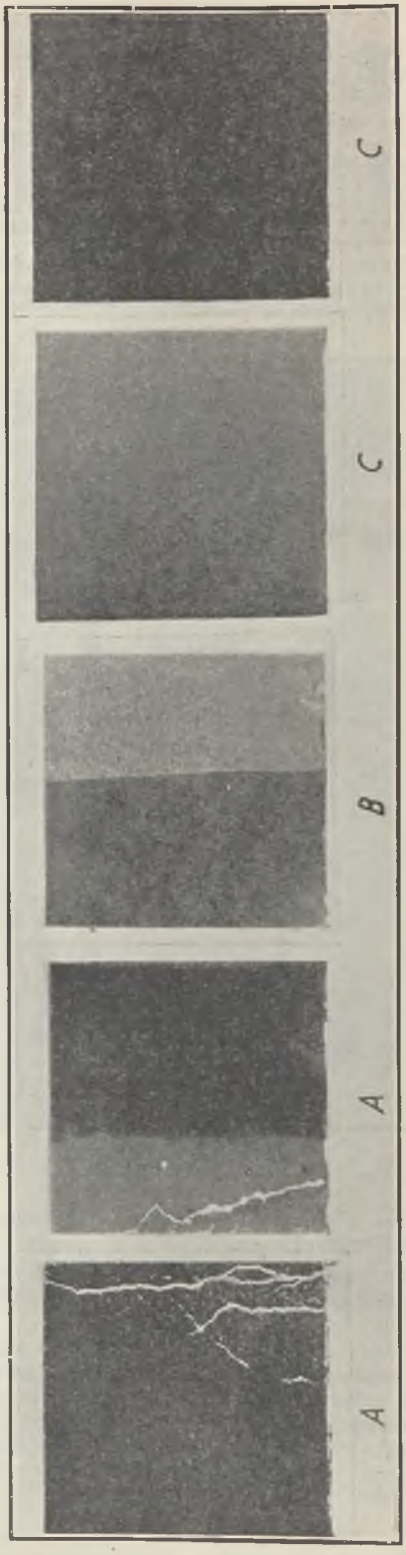


Fig. 34.—Correlation of Viscosity Figures with Core Defects.

JOINT DISCUSSION ON PAPERS Nos. 658 and 659

Dr. Piper's and Mr. J. J. Sheehan's Papers were discussed jointly at a technical session held during the Congress under the chairmanship of Mr. W. B. Lake, J.P.

Moisture Content Control in Practice

Dr. J. G. A. Skerl said the subject matter of Dr. Piper's Paper was well known to him, as a member of the Sands Committee of the British Cast Iron Research Association, and also because the work was initiated when he was a member of the staff. He could vouch for the very great importance of some of the conclusions which Dr. Piper had drawn, especially those dealing with the more theoretical side of the conditions of clay necessary to bond a silica sand in the foundry. Unfortunately, it had not been possible to carry out the very full scheme of research that he had thought would be necessary. The work described in the Paper dealt with the laboratory side, but one really wanted the practical results in the foundry, because quite frankly in the foundry one could not deal with some of the moisture contents that were given in the Paper. With the 3 and 5 per cent. mixtures, the optimum strength was attained at anything in the region down to 1.5 per cent. of moisture and such figures were impossible of attainment under practical conditions. In general one found in foundries, even when dealing with synthetic sands, that the moisture content must be in the region of approximately 4 per cent. That meant that it was necessary to add a large excess of the bonding medium. A synthetic sand as used in the foundry did not contain 3 or 5 per cent. bentonite or other bonding material, but usually contained from 8 to 12 per cent., such contents being necessary to take care of the water which had to be added to make the material usable in the foundry. Even so, when using synthetic sands it was often found necessary to hasten in casting the moulds because of the tendency to drying off. From his experience he felt certain that under practical conditions the benefit arising from the use of bentonite could not be shown up quite so greatly as in laboratory work. In the Paper bentonite was shown to give very superior results, but under actual foundry conditions that superiority was not maintained to so great an extent.

Influence of Coal-Dust Ash

Commenting on a statement in the Paper that where coal dust was added, the refractoriness of the bonding clay was of minor importance as compared with that of the coal ash accumulating, and that a typical coal dust of British origin might give 5 per cent. of ash, the fusion point and analysis being given, Dr. Skerl agreed, of course, that coal ash would accumulate, but he pointed out that if 5 per cent. of coal dust containing 5 per cent. of ash were added, the amount of ash present was very small. At the same time, there would be 3 or 5 or 10 per cent. of bentonite present; the bentonite would always be the preponderating factor, and since bentonite was shown in the Paper to have as low a refractoriness as the coal dust, he hardly agreed with the statement that the refractoriness of bonding clay was of minor importance in comparison with that of the coal ash.

Expressing his very greatest admiration of Mr. Sheehan's Paper, he said he had read it three times already and could find nothing in it which he could criticise, because it dealt with facts only. Commenting, however, upon the point made by Mr. Sheehan that the use of sand which consisted only of rounded grains had resulted in chaos in the foundry, he said he would like to know the name of that particular sand, because such knowledge would give one rather a greater insight into the Paper and into the difficulties which had been surmounted in the method described by Mr. Sheehan. The Paper was the finest he knew of on the subject of core shop control.

Tar Oil Films

Mr. Ben Hird, having congratulated Dr. Piper on his valuable Paper, referred particularly to the reference to coal dust giving added strength to the dry compression, and asked if Dr. Piper had found that the coal dust also gave added strength in the green stage, after it had been used for casting five or six times. He also asked for Dr. Piper's opinion on the usefulness of the clay bond on the grains of an ordinary sand, say a red sand such as the Bromsgrove sand, after it had been coated by the carbon film derived from the coal. When a grain of sand had been turned from a red to a black grain, obviously it had acquired a carbon coating, and he asked whether that destroyed entirely the bond of the clay.

Bentonite and Moisture Content

Mr. R. J. Richardson (Pontypridd) said that having read some data on bentonite mixtures

and having attempted to use them in the foundry, at the moisture contents suggested by one of the sellers, and indicated by laboratory tests, he found them absolutely useless for moulding purposes, the percentage of moisture being so low that the sands were too dry to bond by the time they reached the moulding machines.

Recently, before he had known that Dr. Piper was presenting a Paper, he made tests on Dorset clay, and found them helpful, because when using Dorset clay, owing to the amount of clay and the necessary water being considerably greater than when using bentonite, it was found the sands did not dry up so quickly, and could be used at the suggested moisture contents shown in Dr. Piper's Paper. One of the principal difficulties encountered when using Dorset clay was to add it in such a manner that it was distributed equally throughout the mass. An operator had been told to mix a batch by rule of thumb methods, and produced a mixture which appeared to feel very good, but on testing it was found to contain 45 per cent. of clay, 10 per cent. of which was distributed, the other 35 per cent. being in small lump form. During the past week he had tried adding the clay in a form of slurry, and he asked the views of others on this question.

Whereas bentonite had the advantage that it was solid and could be added in a dry dust form, the natural clays could not be obtained in this form, and it was rather difficult in foundry practice to dry these clays and prepare them by ball milling to make them suitable for adding correctly for sand mixing.

The same sort of problem of unequal distribution had arisen in Mr. Sheehan's Paper, in which reference is made to the advantage of silica flour. He asked by what method Mr. Sheehan was able to ensure that the silica flour was suspended uniformly. When spraying silica flour water was used, and there was a danger of the silica flour being left at the bottom of the containers.

Sand Control in Mechanised Foundries

Mr. F. J. Cook (Past-President, Institute of British Foundrymen) said the fact mentioned by Dr. Piper, that bentonite had very good bonding power, sometimes led foundrymen astray. One was rather tempted to use bentonite in excess because of its great green strength bonding power, but owing to its increased *dry bond* strength over Colbond it may give trouble in mechanised plants. On one occasion he had experienced trouble in a mechanised plant in which a bentonite mixture was used; it was found that at the knock-out half the sand came through the riddle unbroken, due to the great dry strength attained when the metal was poured into the mould. Therefore, it had been necessary to resort to Colbond, which was as strong in green sand and much weaker in dry strength, but which gave no trouble in that respect. Practically all the sand then passed through the riddle, there being very little discard, whereas, when using bentonite, with its extra dry strength bonding power, most of the sand came through in the discard.

Moisture Absorption Tests

Mr. A. Tipper, M.Sc.(Eng.), asked Dr. Piper whether, in his tests for determining the bonding strength of clays, the method of measuring the moisture absorption was found to be a practical test for the ordinary laboratory. It would be very convenient, he said, if it were possible to adapt one or two simple tests which would show immediately whether a clay was useless or very good, and the moisture absorption test in particular was mentioned as giving results which compared favourably with the dry strength and green strength figures, and placed clays in the same order. He asked for more information concerning the details of that test, and whether it could be carried out easily under comparable conditions.

Another question was whether it was possible to effect the bonding of red sands synthetically. Several people in practice had actually added ferric hydroxide, and claimed that they had derived benefit from it. He wondered whether any further tests had been made on the addition of ferric hydroxide or the production of a type of red mineral bonding matter.

The Paper by Mr. Sheehan was another extraordinarily fine example of the application of scientific principles in the foundry, and one could say definitely that it was the best example to date of the application of those principles to the core shop. The success achieved by Mr. Sheehan under conditions which presumably were really difficult was sufficient to encourage others in the same direction. In the past some of the aspects of core making which were dealt with in the Paper, such as the effect of grain size on permeability and surface finish, had been realised, but they had been tackled more or less by methods of trial and error, and not on fundamental principles.

Conversion to B.S. Units

There was obviously the possibility of adopting those principles, not only for core sands but for moulding sands in general, and particularly as applied to synthetic sand practice (he referred particularly to the calculation of the fitting-in of grain size and its effect on permeability, expansion characteristics and other properties). It was worth mentioning, too, that, although the grouping into four classes of grain size was given by Mr. Sheehan, based on the I.M.M. screen

size, it could also apply in just the same way to our other British Standard screen sizes. In this one had to take the 30 mesh as the unit dimension of the screen. Assuming D to be 0.50 mm. (B.S.S. sieve No. 30), then 72 corresponded to 2/5D, 150 corresponded to 1/5D and 300 corresponded to 1/10D.

The Fitting-In Theory Applied

He asked Mr. Sheehan whether in his opinion his statement regarding the application of those principles to irregular shaped grains, as distinct from spheres, really did hold good in practice, as a generality, because all our natural deposits consisted of irregular or sub-angular grains or fragments, and if those fragments did obey the same law of fitting in as did round spheres, then the industry could go ahead and say that every sand would obey that law in a general way, and it could start to develop mixtures of particular types of sand which would give either the maximum fitting in or the minimum fitting in.

Considering one or two actual mixtures in that connection, he said he had found, for instance, that a mixture of Southport sea sand (containing 45 and 55 per cent. respectively of groups I and II) and Ryarsh silica sand (containing 2.5, 71 and 26 per cent. respectively of groups I, II, and III), if mixed in the proportion of 2 parts of Southport sea sand to 1 part of Ryarsh silica sand, gave a very considerable degree of fitting in, and the permeability, which was 140 in the case of the Southport sand, was reduced to 60 in the mixture.

Core Baking Control

Very wisely, Mr. Sheehan had not attempted to deal with all aspects of control in his paper. One regretted particularly, however, that he had not dealt with core baking control, which had a very definite bearing on conditions in the foundry. The troublesome fumes occurring during casting were largely accentuated by incomplete baking and the determination of volatile matter or gas content of dry cores afforded a useful guide to correct baking conditions. Fortunately, conditions in the mould usually allowed a large factor of safety, and it was probably for that reason that Mr. Sheehan had found it unnecessary to adopt any strict control of the baking. Local conditions would naturally make all the difference and must always determine the exact baking procedure.

Congratulating Mr. Sheehan particularly on his control of air drying of core sand mixtures, he said it was a very difficult matter to tackle successfully in a mechanised core shop. The problem, he believed, was one of controlling the loss of moisture. Drying out was simply a case of loss of moisture from the mixture, and one could adopt several methods to prevent it. For example, one could place the mixture in a completely enclosed box, cover it over and keep the sand for weeks in reasonably good condition. That might not be practical in Mr. Sheehan's works but it might at least be considered as an alternative to other methods. One disadvantage of adopting a chemical method of preventing drying out was the difficulty of ensuring sufficient drying out of the prepared core to prevent sagging. If the mixture did not air-dry reasonably fast, there was every chance of some cores distorting or squatting on the conveyor; or conversely, if it did dry out reasonably fast, then considerable core sand might have to be wasted. If one avoided drying out on the first conveyor, before the core was made, then the rate of drying might not be sufficient after the core was made to prevent some slight sagging or distortion.

Quantity of Binder and Grain Size

He did not agree with Mr. Sheehan that the proportion of binder required was proportional to the grain size of the sand used. Other factors besides the surface area of the sand came into that question. Probably it applied where one used a thin binder, such as a fluid oil, which gave a maximum distribution; but in many mixtures there was not complete distribution, and many factors other than surface area of the grains affected the bond obtained with a definite proportion of compound. It was more important to consider the conditions of mixing and possibly the additions of such substances as water or some other agent which would aid the distribution, than to consider merely the percentage of material added.

The Necessity for Fineness in Clays

Mr. W. J. Rees (Sheffield University) confirmed, as the result of tests on a completely different series of clays, the relationship found by Dr. Piper between the moisture absorption and the bonding power. In his laboratory, he had made the test on a series of more than 20 clays from different parts of the country—ball clays, kaolins and various fireclays—and had found the relationship to be quite important. He saw no difficulty at all in translating it into a laboratory test, provided the conditions of exposure were maintained absolutely constant. Given that condition, he was of opinion that it could be made an exceedingly useful ancillary method for evaluating bond clays for synthetic sand mixtures.

An important consideration with regard to the use of clays in synthetic sand mixtures was that they must be finely ground initially. Although Dr. Piper had referred to the use of clays ground to pass 30 mesh, Mr. Rees expressed the view that that was not sufficiently fine to ensure that

the greatest efficiency would be obtained from the sand. The clays really needed pulverising so that at any rate more than half would pass 50 or 60 mesh. Their distribution was aided thereby and the efficiency of bonding was very definitely increased.

Distribution of Slurry

Commenting upon Mr. Richardson's reference to the possibility of adding the clay to the sand as a slurry or slip, he agreed that that did aid very much the distribution of the clay. The only difficulty was that when a slip was used it was by no means easy to control the proportion of water. If one added sufficient slip to give the required content of clay, one would, at the same time, add too much water. However, there were possibilities in that direction in the use of a de-flocculating slip, produced by adding to the slip a trace of alkali, so that the slip could be made to contain almost as much clay as a lump of solid plastic clay of corresponding size. The clay added in that form was distributed very easily throughout the mass of sand and gave a very excellent mixture.

Discussing the relationship between the green strength and the dry strength, discussed in Dr. Piper's Paper, he said the figures in the Paper showed that, comparing, say, bentonite with ball clay, the optimum green strengths were much the same, but the dry strength of the bentonite was very much higher. That was of great interest, and so far as he was aware there was no complete explanation of that difference. One noted this difference with a number of clays, and it is probably connected with the ultimate grain size and colloid content, but if one could obtain a complete answer to the question as to why that considerable increase in dry strength was obtained, with little or no increase in the green strength, a great step forward would be made in the study of synthetic sands.

The Paper by Mr. Sheehan, he said, must be of the very greatest use to the practical foundryman; and it would also be of very great service to those engaged more with the theoretical aspects of foundry sands. He congratulated Mr. Sheehan upon the very lucid form in which he had presented the Paper.

Dr. Piper's Reply

Dr. Piper, replying to Dr. Skerl, said that one reason for the low moisture content of the synthetic moulding sands given in Tables I and II was the fact that a silica sand containing very little silt was used. If the sand used had contained a greater silt proportion, there was no doubt that a greater amount of water would have been required for the synthetic moulding sand.

The results in the Paper were obtained from a research by the British Cast Iron Research Association and it had not been possible to include all the results. In particular, there was one in which an old moulding sand was rebonded with the bonding clays to a moisture content of about 5 or 6 per cent., which was more in agreement with what would be done actually in the foundry, and it was found that the same results held true, that the bentonite gave twice as much increase of bonding power as Colbond.

The difficulty about carrying out tests in the foundry was that in general coal dust was added at the same time, and as Mr. Hird had pointed out, the addition of coal dust increased the dry strength as well as the green strength. That result was found in the durability trial. If extensive comparisons of the bonding clays could be made in the foundry, it would be necessary to exercise a very careful control of the amount of coal dust in order to see that the increased bond produced by coal dust additions was the same in each case.

Commenting on Mr. Rees' confirmation of the results of the water absorption tests, and the possibility of modifying the tests to render them convenient for assessing the bonding clays, he said that in the work described in the Paper on clay absorption, *i.e.*, the amount of water absorption by the clay under atmospheric moisture conditions, the clays were allowed to absorb water and were kept in an enclosed space for about a week to enable them to reach equilibrium. There was no doubt that the test could be made into a very convenient practical test of bonding clays.

The particle size of the ground clays was important. The fireclays were ground to pass a 30 mesh sieve actually, although he had not made a sieve analysis of the pulverised clay. There was no doubt that the clay used in the tests was considerably finer than 30 mesh.

The bond obtained by adding the fireclay to the sand in the form of a slip with water was not appreciably different, however, than when the clay was added as a dry powder and water added during milling.

Agreeing with Mr. Rees that there was a great deal of difference between the green and dry strengths of the mixtures, he said he did not know the cause of that exactly, for he had not investigated it; but possibly it was due to the dry strength being dependent in some way on the grip between the clay and the sand grains.

Mr. Sheehan's Reply

Mr. Sheehan, replying to the discussion, said it would be invidious to give the name of the rounded-grain sand which had caused trouble in use, but he assured Dr. Skerl that he could select several sands which would give rise to such

trouble. That was the result of using any sand falling within the grouping indicated in the Paper, and the more narrowly it came within that grouping the greater the trouble that would be experienced. The coarser sand would give more trouble, of course, in the production of fins than would a finer one, but even the finer one would give considerable trouble.

Replying to Mr. Richardson, he said that silica flour was very conveniently added in the powdered form, and there was no difficulty nowadays in obtaining silica flour suitably graded. Recently he had not found it necessary to add the flour to the moulding sand, although it was American practice to do so. He also used it very successfully as a wash, more successfully than he had been able to use a plumbago wash, for the reasons given in the Paper. It was kept in suspension by following the formula given in the section of the Paper headed "Washes," *i.e.*, silica flour 21 galls., Colbond 9 galls., water 36 galls. and dextrin 4 pints. It was regulated to a suitable viscosity, dependent upon how it was applied. There had been a little trouble in getting a suitable medium in which to suspend silica flour, but once the viscometer came to be used for control, the matter became comparatively simple. He and his colleagues did not use the viscometer very extensively, because once they had obtained their control by that method, the Beaumé gravity was sufficient to keep it within usable limits.

Binder Quantities Defined

With regard to Mr. Tipper's criticism concerning the statement that the proportion of binder used was determined by the size of the grain, he said that possibly that should have been qualified by stating that it depended, of course, also on the type of binder used. The binders used were one of an oil type, and dextrin, and both were very easily distributed. Taking that factor into account, the amounts of those two binders which should be used were definitely proportional to the size of the sand grain in the mass of sand used. He appreciated that cereal binders with low solubility were now being used considerably, and that their distribution, of course, was a factor of the mill and not necessarily a factor of the grain size of the sand. However, he did believe that the grain size of the cereal binder would be a contributing factor to the ultimate strength obtained.

Discussing the possibility, mentioned by Mr. Tipper, of applying the findings to the control of synthetic moulding sand practice, he said that he and his colleagues were doing that in their foundry in selecting sands, but also in another way in that all their synthetic sand was based on the core sand. The core sand disintegrated and the burnt core sand was used as the basis of the synthetic sand. In other words, they bought no sand at all for moulding purposes. That practice was working very well in the steel section of the plant, where the strength of the core was regulated so that it disintegrated in sufficient proportion to balance the wastage from the sand system.

As to the remark by Mr. Tipper that the grouping could be obtained on the basis of the British Standards Institution sieves, he said he had confined himself to the Institute of Mining and Metallurgy sieves, as he had found them most convenient. Nevertheless, he welcomed Mr. Tipper's remarks that the B.S.I. sieves could be applied.

Expressing appreciation of the remarks by Mr. Rees concerning the value of the Paper, he welcomed those remarks, particularly from a University with a reputation such as that of Sheffield, and from Mr. Rees himself, who had contributed considerably to all the pioneer work in this country on sands, whether moulding sands or core sands.

WRITTEN CONTRIBUTIONS TO THE DISCUSSION OF PAPER No. 659

Fin Formation

Mr. E. J. Crawley wrote that he was most interested in the method described for overcoming the tendency of fin formation by the use of an irregularly graded sand mixture. He understood that a similar principle had also been adopted for preventing metal penetration in cores surrounded with heavy-section steel castings. In this case, however, the advantage obtained relied on reduced permeability.

Mr. Sheehan's explanation of the reason why this process reduced the tendency for fin formation appeared very likely. However, there was another factor which perhaps should be taken into consideration. A core composed of uniformly-sized sand grains depended almost wholly upon the bonding properties of the binder to give it strength. When this binder was partly or wholly destroyed, the core became so weak that slight stress (resulting from expansion) caused a tear, which had relation to a fin being formed. On the other hand, a core composed of sand grains of two sizes, particularly if one was very fine, was much more compact and consequently stronger, irrespective of the cohesion given by the binder. This factor might have bearing on the reduced tendency for the core to tear following an uneven expansion.

In support of Mr. Sheehan's explanation, it would be interesting to learn whether a core of uniform sand grains such as in No. 1 (Fig. 24) showed a steeper expansion curve when heated rapidly than did No. 3, composed of coarse and fine sand mixed.

Preventing Metal Penetration

Mr. J. J. Sheehan wrote in reply that Mr. Crawley was correct in assuming that a mixture of sand grain sizes in a core was of advantage in preventing metal penetration. The advantage was obtained by a reduction in the void spaces. A reduced permeability in the core was a parallel effect and not the direct cause of the reduced penetration.

He was in agreement with Mr. Crawley's statements in the second paragraph of his communication, but did not accept the assumption that the difference in strength between the two types of core was sufficient to account for the absence of an expansion crack in the core with a mixture of grain sizes. He was certain that the force of expansion produced by a change from quartzite to cristobalite was of a much higher order than the frictional strength produced in a core by using a mixture of grain sizes.

He was not in a position further to confirm the explanation of the expansion effects, by the method suggested by Mr. Crawley, but he considered the method good and the confirmation a desirable one, and would welcome such confirmation from a laboratory equipped with an accurate extensometer and a suitable furnace.

Analogy with Prof. Bragg's Lecture

In a written contribution, Mr. A. J. Shore stated that Mr. Sheehan's Paper could be considered as supplementary to Prof. Bragg's lecture delivered to the Congress. At first sight, there seemed to be little in common between such subjects as "Core Shop Control" and the "Atomic Pattern of Metals." However, scientific method was so powerful an instrument that both investigators uncovered similar facts. No one, for instance, could fail to appreciate the similarity between the body-centred and face-centred cubes in Prof. Bragg's atomic space-lattice and Mr. Sheehan's conditions of open and close packing of uniform grains of sand.

Prof. Bragg had shown how extraordinarily ductile and weak a single crystal of metal was, explaining that in this case the atoms were uniformly arranged in regular order. Mr. Sheehan also had experienced—very forcibly—the weakness of bodies regularly compacted of uniform particles. He mentioned the rather disastrous results produced in the fettling shop when an attempt was made to use a uniformly-grained core sand. His solution of the problem was the same as Prof. Bragg's; he made an "alloy" to increase the strength by adding other suitable grades of sand. In other words, he produced what the Professor had called "organised muddle." The ability to produce "organised muddle" as distinct from "muddle" was the essence of core-shop control, and for that matter, of any human activity.

In conclusion, Mr. Shore observed that Mr. Sheehan's Paper was of the type which was most likely to benefit the foundry industry, and that it formed that link between academic research on the one hand and commercial production on the other, which Prof. Bragg had said was so desirable.

A New Nomenclature

Mr. Sheehan, in his reply, thought Mr. Shore's similes were very good. His appreciation of the usefulness of "sand alloys," and his coining of the phrase had induced him to consider another borrowed phrase, "eutectic," to describe the point where a mixture of sizes produced the greatest density and least length of the test-piece. Such a point was shown in Fig. 18 and in Fig. 19, and coincided in both figures with a proportion of about 66.6 per cent. of the larger grained sand. He did not, however, suggest that either of these metallurgical terms should be applied seriously.

Influence of Flowability

Mr. W. Y. Buchanan wrote that he was specially interested in the reference to mixing of grains of different size, because that line of argument was at one time brought into the discussion on his suggested "Index of Ramming" method of test-piece ramming evaluation. As stated in his Paper* to the Sheffield Branch the argument does not apply. While the assumption of perfect packing in the case of spheres is possible in ideal circumstances—for example where they are packed a layer at a time—and also to some extent in unbonded sands. Such mathematical forecasts of the behaviour of natural bonded sands are completely masked by their low flowability.

The situation of small grains in any mass of sand is largely a matter of efficiency of mixing rather than ramming, but conclusions should be based on tests on natural sands (unless they are to be excluded) rammed by the standard three blows of a 14-lb. rammer.

The writer's own conclusion was:—

> "While the unmixed test-pieces are longer, it will be seen that hardness on the bottom of the test-piece is very low, and that the increase in length is due to the poor flowability and not to fine material becoming packed in air spaces of the coarse sand in the case of the mixed test-piece."

Mr. Sheehan used a specific heat for silica of 0.286 at 1,000 deg. C. and for graphite at 978 deg. C. What did these temperatures represent?

* "Modern Sand Testing." See Foundry Trade Journal, May 11, 1939, pp. 385-8.

The writer had found that published details of specific heat and specific gravity of moulding materials, etc., at high temperatures were almost non-existent and rather vague, so that he had determined these properties himself, and he would have liked Mr. Sheehan to have extended the data available by personal research.

The testing machine for green-sand cores was evidently a form of compression test. What was its particular advantage over the existing spring balance?

Mr. Buchanan added that he had controlled his blackwash by tank mixing for the last five years by a system of specific gravity and constituent analysis as a check. He readily agreed with Mr. Sheehan that the viscometer would be far better than specific gravity measurement, because the specific gravity of blacking, for example, was very low, and its percentage could vary considerably without altering the specific gravity of the liquid blackwash. If this was not done elsewhere, could Mr. Sheehan publish dimensions of the particular viscometer used, as this could be adopted, if not by the Committee, at least by those interested in their own work.

Mr. Sheehan's Reply

In reply to Mr. Buchanan, Mr. Sheehan pointed out that he could not contribute much to the first portion of Mr. Buchanan's observations, which dealt, not with the author's paper, but with one given by Mr. Buchanan to the Sheffield Branch of the Institute of British Foundrymen. In that Paper Mr. Buchanan did not give the mechanical analysis of any of the materials he used, nor did he produce any evidence such as the quantative relation between the flowability and hardness to show that his explanation was correct.

The tests mentioned in the author's Paper were carried out up to 500 blows, and if the difference shown was due to flowability the curves should get closer together as ramming was increased. This did not occur.

Mr. Buchanan had asked what the temperatures represented in the statement: "Specific heat of silica is 0.286 at 1,000 deg. C." The answer was that they represented the temperatures at which the specific heat was measured, and could obviously represent nothing else.

The testing machine for green sand, the necessity for which Mr. Buchanan queried, was built because no other compression machine capable of giving accurate readings at the low level required was available. The usual range required was about 200 grams (7 ozs.) on the A.F.A. testpiece or 2 ozs. per sq. in. The type of machine used also gave a very uniform rate of loading.

No specification for the viscometer was given as it was considered that the standardisation of such equipment was a matter for the Technical Committee of the Institute of British Foundrymen or some similar body, and Mr. Sheehan hesitated to give any dimensional details outside the authority of the above-mentioned committees.

Paper No. 660

Selection and Testing of Cupola Refractories

By W. J. REES, M.Sc.Tech. F.I.C. (Member)

Cupolas are in general lined in one or other of the three following ways:—(1) With firebricks; (2) with bricks or blocks cut to shape from a natural siliceous rock or "firestone," and (3) with a plastic or semi-plastic material, having either a silica or burned fireclay base, rammed round a former. The firebricks used are normally in the grade with refractoriness in the range of Cone 29 to 32, but under special conditions of melting it may be desirable to use firebricks in the special grade with a refractoriness higher than Cone 32 in the melting zone. Bricks of the "super-refractory" class made from materials such as chrome, calcined or fused alumina, sillimanite, etc., have been used experimentally but their service has not been commensurate with their much higher cost. Silica bricks have generally been ruled out because of their high spalling tendency, but it is not impossible that silica bricks with a clay bond instead of the normal lime bond would give good service (see Table I), as with the change in bond the susceptibility to spalling is decidedly reduced. Silica bricks made from quartzites containing from 1 to 3 per cent. of titanium oxide finely dispersed, when properly graded, have a much higher spalling resistance than bricks made from normal quartzites, and would be likely to behave satisfactorily in the cupola lining. These bricks should be burned to a powder density of 2.36 to 2.40, so that in service there will be a little permanent expansion which will close the joints and prevent slag ingress.

Slag Corrosion

The relative resistance of the fireclay and silica materials to corrosion by cupola slag is indicated in Table I. In making these tests, the refractory material and the slag were ground to powder, mixed together in the indicated proportions, and, after moistening with dextrin solution, made into test cones. The fusion point of these cones was then determined in a gas-fired furnace. The approximate composition of the slag used is SiO_2, 45; Al_2O_3, 5; FeO, 12, and CaO, 35 per cent.

It is evident from these tests that from the chemical standpoint aluminous firebricks are likely to be advantageous, but it is necessary to qualify this, because corrosion tests made by placing a pellet of slag (20 to 30 grammes) on a brick and heating for 2 hrs. at 1,500 deg. C. show that although a dense 40 per cent. Al_2O_3 brick is more resistant to corrosion than a dense 32 per cent. Al_2O_3 brick, the latter is more resistant to corrosion and slag penetration than a 40 per cent. Al_2O_3 brick of open texture. It is desirable that cupola bricks and blocks should be of low porosity, hard fired and cleaned burned. With modern methods of brickmaking, such as de-airing, machine pressing, dry-pressing, etc., bricks with porosities in the range 16 to 22 per cent. are being produced, and it is notable that the reduction in permeability is decidedly greater in proportion than the reduction in porosity, as shown in the following recent test results:—

TABLE I.—*Resistance of Firebricks to Slag Corrosion.*

	Slag percentage in mixtures.			
	0	10	25	50
	Fusion points, deg. C.			
Firebrick, 40 per cent. Al_2O_3 ..	1,730	1,580	1,380	1,320
Firebrick, 32 per cent. Al_2O_3 ..	1,690	1,530	1,320	1,240
Firebrick, 24 per cent. Al_2O_3 ..	1,640	1,440	1,250	1,160
Silica brick, 94 per cent. SiO_2	1,710	1,660	1,580	1,150
Cupola ganister, 86 per cent. SiO_2	1,620	1,540	1,460	1,180

	Porosity. Per cent.	Permeability in C.G.S. units.
Hand-moulded brick ..	27.8	0.25
Machine-pressed from plastic de-aired clay ..	21.0	0.06
Semi-dry pressed with high pressure	19.5	0.05

Another important resultant of the modern methods of brickmaking is that perfection of

shape and finish which enables very close jointing of the bricks. It is of importance, too, that the jointing cement used is of high refractory value and small drying and firing shrinkage; the modern refractory air-setting cements are especially worthy of attention.

The volume stability of firebricks in cupola service should be such as will preclude any opening of joints, or bulging of the brickwork. In a reheating test, a test-piece about 3 in. by 2 in. by 1½ in. slowly heated to 1,410 deg. C. and maintained at that temperature for 2 hours (the atmosphere of the furnace containing free oxygen) should not show when cold more than 0.75 per cent. linear contraction or expansion.

It is desirable that the bricks shall contain no segregations of uncombined iron oxide, as these lead to carbon deposition and consequent weakening or disintegration of the bricks from the catalytic dissociation of carbon monoxide. As the optimum temperature for this dissociation and carbon deposition is about 500 deg. C., it is negligible on the inner face of the brick but it may occur nearer the casing where the temperature range will be favourable, and the consequent weakening of the structure of the cooler part of the brickwork may have a detrimental effect on the durability of the lining.

It is necessary, too, that some attention should be given to the mechanical strength of the firebricks at the working temperature. Incidently, the refractoriness-under-load test not only gives information as to the high temperature load-bearing (or pressure-resisting) capacity of a firebrick, but also provides information as to the efficiency of its burning. It is likely that the high-temperature "creep" tests which are being studied at present will provide information which can be applied in the selection of cupola firebricks.

Firestone Blocks

Silica firestone blocks or bricks are not much used in British foundry practice, but their use in American foundries is being followed with interest. The "firestones" which are available in Great Britain are fine-grained sandstones of the following chemical composition:—Silica 92 to 94 per cent.; alumina 2 to 5 per cent.; iron oxide 1 to 2 per cent.; lime 0.2 to 1.0 per cent.; magnesia 0.1 to 0.4 per cent.; alkalis 0.5 to 2.0 per cent., and ignition loss 0.5 to 1.0 per cent. The chemical composition quoted above is not very different from the published analyses of the Ohio bedded silica firestone which is being used successfully in some American foundries, but in the tests made so far the British firestones are less resistant to the thermal shock almost inevitable in the heating-up of a cupola.

Rammed Linings

The plastic or semi-plastic materials are usually highly siliceous, though a few ironfounders use mixtures containing a high proportion of fireclay grog with a bond of plastic fireclay. The siliceous mixtures used for the production of rammed linings and for patching are of two types:—

(*a*) Natural silica "clays" which consist of sand grains in small size uniformly coated with a highly plastic siliceous clay.

(*b*) Silica rocks of "ganister" type which are crushed and ground with a plastic fireclay.

The plastic or semi-plastic siliceous materials fall in silica-alumina ratio between points A and B on the portion of the alumina-silica fusion

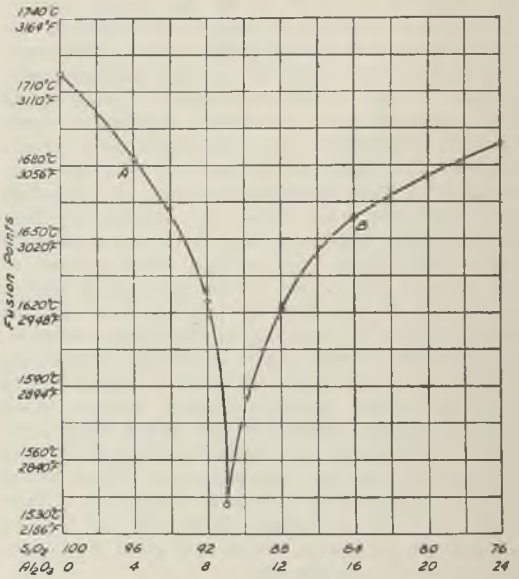


Fig. 1.—Fusion Point Curve of Alumina-Silica.

point curve shown in Fig. 1. It is to be noted that in mixtures containing between 7 and 10 per cent. of alumina (that is 20 to 30 per cent. of an average 30 per cent. alumina fireclay) there is a rapid fall in the fusion point, and that the presence of fluxing impurities in the silica rock and fireclay move the lowest fusion point in the direction of a lower silica-alumina ratio.

Occasionally, synthetic mixtures of similar composition to the naturally-bonded mixtures of type (*a*) are made by thoroughly mixing a high-silica sand with a fine-ground plastic refractory clay. It is exceedingly difficult however to ob-

tain by mechanical mixing such uniform dispersion of the clay over the sand grains as is found with the naturally-bonded siliceous materials. With wet mixing the dispersion of the clay is assisted by deflocculating it by the addition of about 0.5 per cent. of a mixture of sodium silicate and sodium carbonate, or by adding the clay in the form of a deflocculated slip.

Synthetic mixtures made with crushed burned fireclay (grog) and a plastic refractory clay are used by some ironfounders. In these mixtures it is essential that the grog used is hard-burned and that the drying and firing shrinkage is small and will not lead to the opening of cracks in the lining. The same considerations as to chemical composition and refractoriness of the grog and clay apply as with firebricks

Rotary Furnace Linings

In the lining of rotary melting furnaces, mixtures of both the natural and synthetic types are used, but where the melting temperature is higher than normal it is advantageous to replace the clay bond with lime, producing a mixture which has a chemical composition and grading comparable with that of a good silica brick. The plasticity and " workability " of the lime-bonded mixtures may be increased by the addition of an organic bond such as dextrin or one of the cheaper by-product bonds of the " sulphite-lye " type. It would seem to be feasible to line a rotary furnace with unburned silica bricks compacted under hydraulic pressure, which would avoid the difficulties of uniform ramming and lamination with granular lining mixtures, and would give a much denser lining. These unburned bricks could be moulded under high pressure with a tongue and groove to facilitate building together. Unburned bricks of this type are being used successfully in the lining of induction furnaces for steel melting.

The function of the clay in the clay-bonded cupola ganisters is primarily to bind the fragments of silica together both in the green and fired condition, but it serves an important secondary purpose in lowering the sintering temperature and causing that incipient fusion of the lining which promotes its mechanical strength and increases its resistance to abrasion and to slag penetration.

Properties of Cupola Lining Materials

To give satisfactory service in the cupola, the materials, whether natural or synthetic mixtures, used for rammed linings, must develop sufficient mechanical strength on drying and heating to resist the stresses set up. When the rammed material is heated it must not only vitrify sufficiently to produce mechanical strength, but it must have satisfactory volume stability, as excessive shrinkage may lead to the formation and opening of cracks, with consequent slag ingress and general weakness. When naturally-bonded materials are used, it is especially important that care should be exercised in working them to " keep to a sample " and avoid variations in bond content or texture. It is possible to improve the properties of some of these natural siliceous materials by making additions to them of high-silica sand or crushed silica rock.

TABLE II.—*Properties of Two Naturally-Bonded Refractory Materials.*

Mechanical grading.

B.S.I. sieves.	1.	2.
	Per cent.	Per cent.
+ 5 mesh ..	0.5	3.5
+ 16 ,, ..	1.5	2.8
+ 30 ,, ..	1.5	5.5
+ 60 ,, ..	2.5	15.0
+ 85 ,, ..	8.0	14.0
+ 100 ,, ..	27.0	10.5
+ 150 ,, ..	21.5	10.0
+ 200 ,, ..	8.0	7.5
— 200 ,, ..	4.0	2.5
Clay grade	25.5	28.7
	100.0	100.0

Chemical analysis of air-dried materials.

	1.	2.	Clay grade from No. 1.
	Per cent.	Per cent.	Per cent.
Silica	76.59	84.02	45.61
Alumina ..	14.70	9.85	35.55
Iron oxide ..	1.90	1.15	2.15
Titanium oxide	0.35	0.32	0.85
Lime	0.74	0.35	0.71
Magnesia ..	0.18	0.22	0.10
Potassium oxide	0.62	0.58	1.24
Sodium oxide ..	0.22	0.24	0.44
Loss on ignition	4.55	3.15	13.25
	99.85	99.88	99.90

The mechanical grading and chemical composition of two typical naturally-bonded materials occurring in Great Britain are set out in Table II.

Both materials give good service in rammed linings, but it is important to keep the moisture content as low as is compatible with adequate workability in ramming to avoid undue drying shrinkage, especially with materials of fine grain-size such as No. 1 above. The effect of water content on drying shrinkage for the above two materials is shown by the figures in

Table III obtained with representative samples.

Both these materials show a permanent expansion of approximately 1.0 per cent. when a dry test-piece is fired at 1,450 deg. C.; this compensates for the drying shrinkage if the added water does not exceed 7.5 per cent. In the forming of rammed linings in the cupola great care must be taken to avoid laminations, as these are likely to lead to spalling of the lining in service. The deleterious effect of laminations in a rammed lining is shown in Fig. 2,

TABLE III.—*Effect of Water Content on Shrinkage.*

Water added to air-dry material. Per cent.	Wet-to-dry shrinkage (linear). Per cent.	
	1.	2.
5.0	0.4	0.5
6.0	0.7	1.0
7.5	1.0	1.2
10.0	1.9	2.0
12.5	2.5	2.5
15.0	3.5	3.0

which is from the lining of a rotary melting furnace in which trouble was experienced through spalling. The method of ramming used must be such as will ensure complete keying of the layers of material.

Patching Materials

In Great Britain, whilst some foundries use materials such as those detailed above for patching and general maintenance, the majority use materials which are much coarser in fragment size and which are described as cupola ganister. These materials are made by mixing a crushed silica rock containing not less than 92 per cent. silica with from 10 to 30 per cent. of a refractory plastic fireclay, the proportion of clay used depending on the character of the silica rock, the chemical composition and plasticity of the clay, and the required plasticity of the mixture. Photomicrographs of silica rocks used in the production of cupola ganister are shown in Fig. 3 *et seq.* It is desirable that the physical character of the silica rock should be such that when it is crushed it will give angular fragments. Rounded fragments tend to slip over each other, and so lead to weakness, whilst angular fragments tend to interlock, and so promote strength. The plastic fireclays which are used in admixture with the crushed rock have an alumina content (when calcined) between 25 and 35 per cent. and a refractoriness between 1,600 and 1,700 deg. C. In the best practice the silica rock used is of the fine-grained type with 97 per cent. (minimum) silica, and the plastic fireclay of the aluminous type (more than 36 per cent. alumina when calcined) with a refractoriness above 1,700 deg. C. It is important that the matrix of the cupola ganister (*i.e.*, the finer fragments of silica plus the bond clay) should have a chemical composition which is not too near the eutectic (Fig. 1) as this will lead to rapid fusion and possible dripping or running out of the matrix and a "honeycomb" type of corrosion or wear. The use of a refractory clay of a "sticky" nature is advantageous as it will give better bonding in the unfired material, better workability with the minimum proportion of clay, and will allow the use of low water content.

FIG. 2.—DELETERIOUS EFFECT OF LAMINATIONS IN A RAMMED LINING INDUCING CONDITIONS PRODUCTIVE OF SPALLING.

All patching materials must have such characteristics as will enable them to adhere without spalling when heated. After the moist patching material is forced into position, the worn place made good, and the cupola heated, the following cycle takes place:—(1) The water in the material is driven off; (2) the combined water in the bond clay is driven off; and (3) sufficient vitrification is induced to make the patch adhere to the rest of the lining.

It will be seen that a severe condition is set up, and the material used must be one which will withstand the inevitable strain. Patching materials must be used always with only just enough water to give the necessary workability, as over-wetting will not only necessitate slower drying-out, but will also tend

to the development of cracks and give a porous patch. Before patching it is, of course, essential that the slag should be removed as completely as possible from the worn place in the cupola.

The actual standardisation of the properties of cupola ganister is made difficult by the great variation in cupola conditions. It is by no means unusual for a ganister mixture which gives good service in one cupola to be totally unsatisfactory in another working under conditions which do not appear to be very dissimilar. It is evident, therefore, that the method of using the ganister has a definite influence on its durability.

TABLE IV.—*Average Properties of Cupola Ganister.*

Mechanical grading.	
B.S.I. sieves.	Per cent.
+ 5 mesh	3 to 20
+ 30 ,, ...	30 ,, 40
+ 60 ,, ...	4 ,, 12
+ 100 ,, ...	5 ,, 15
− 100 ,, ...	30 ,, 37

Chemical composition of air-dried materials.	
	Per cent.
Silica	78 to 90
Alumina	5 ,, 15
Iron oxide	1 ,, 3
Titanium oxide	0.1 ,, 0.5
Lime	0.1 ,, 0.8
Magnesia	0.1 ,, 0.5
Alkalis	0.4 ,, 2.0
Loss on ignition	3.0 ,, 8.0

Mechanical Grading of Patching Materials

The mechanical grading of a cupola ganister should be such that when it is dried off, and burned, it gives a closely packed lining with a low porosity and permeability. This close packing will also tend to quick and uniform sintering.

To obtain this close packing, the proportion of grains or fragments of middle size should be low, and the proportions of coarse and fine fragments and grains roughly equal. In most cupola ganister mills, the final grading produced is a fortuitous one, but it is possible by control of the grinding time to produce a ganister mixture which has a reasonably satisfactory grading, and which varies very little from batch to batch. It would be preferable, and probably advantageous, first to crush and screen the silica rock and then to mix the necessary proportions of the various screen grades with the proper proportion of fine-ground refractory clay, and finally to wet in a mixer which is so designed as to give thorough mixing without any further grinding. In this way, very complete control of grading, clay proportion, and water content would be possible.

The mechanical grading and chemical composition of cupola ganisters as delivered to iron foundries vary in a larger number of samples which have been examined within the limits set out in Table IV.

Influence of Moisture

The moisture (*i.e.*, added water) in the materials as used varies between 10 and 20 per cent., and the drying shrinkage is from nil to 2.0 per cent. The volume change of dry test-pieces fired at 1,500 to 1,550 deg. C. varies from a small shrinkage to an expansion of 7 or 8 per cent. A small expansion is preferable to a large expansion or a shrinkage, but where the melting conditions are severe it is essential to have a high silica content in the ganister mixture (bearing in mind, of course, the necessity of keeping clear of the eutectic composition) despite the expansion it will show in service. In addition to drying tests, grading tests, and chemical analyses, there are several useful laboratory tests for cupola ganister.

Refractoriness

With fine-grained materials cones may be made and their refractoriness determined in the usual manner against standard cones. It is impossible to make cones from the coarse-grained materials, but a useful alternative is to make test briquettes 4 in. by $1\frac{1}{2}$ in. by 1 in. and heat them at 1,550 deg. C. for 4 hrs. With good cupola ganisters there will not be much distortion of the briquette after this heat-treatment, but it will have become vitrified and will have developed considerable mechanical strength.

TABLE V.—*Cupola Slag Erosion of Firebrick Tile Expressed as Inches.*

	Before run.	After run.	Erosion per panel.
	In.	In.	In.
Standard ganister ..	$26\frac{7}{8}$	$27\frac{3}{8}$	0.25
Test material *a* ..	$25\frac{15}{16}$	$26\frac{7}{8}$	0.78
Standard ganister ..	$30\frac{5}{8}$	$31\frac{9}{16}$	0.47
Test material *b* ..	$31\frac{1}{8}$	$31\frac{5}{8}$	0.25

Ratio of erosion of test material *a* to that of the standard ganister, 3 : 1.

Ratio of erosion of test material *b* to that of the standard ganister, 0.5 : 1.

Slag Resistance

A test briquette 3 in. by 3 in. by 2 in. is made with a cylindrical depression 1 in. dia. and 1 in. deep in the middle of one 3 in. by 3 in.

face. This is dried, the depression filled with ground cupola slag, and heated for 2 hrs. at 1,500 deg. C. After cooling the extent of slag penetration and corrosion can be examined by breaking the briquette through across the middle of the depression.

An alternative method for evaluating slag resistance is to make a solid briquette, say 2 in. by 2 in. by 2 in. and, after drying, place on top of it a cylindrical pellet made from about 20 to 30 grammes of ground slag (moistened with a dextrin solution) and then heat for 2 hrs. at 1,500 deg. C. The slag attack is observed after cooling the test briquette. This second method is particularly useful for observing the effect of the porosity and permeability of the ganister on slag penetration as well as its resistance to chemical corrosion. Both methods of test may be amplified by mixing fine-ground iron oxide (iron scale for example) with the cupola slag.

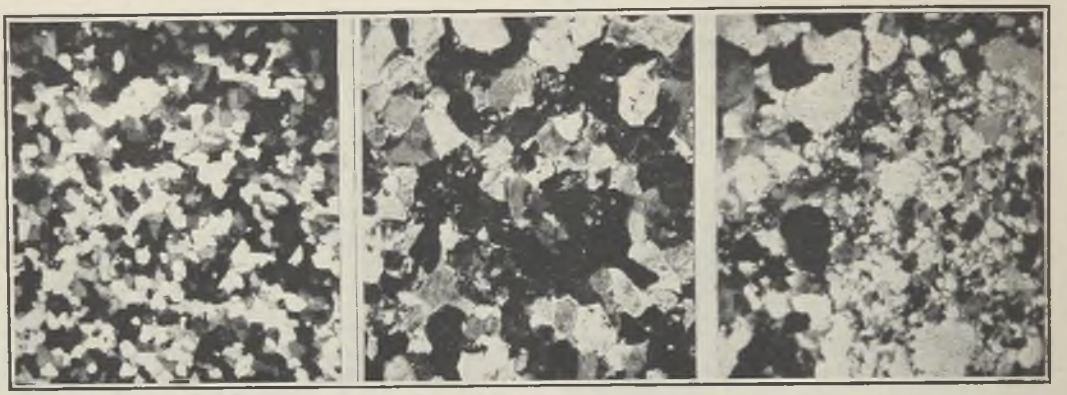


Fig. 3.—Ganister, Sheffield. Fig. 4.—Quartzite, Durham. Fig. 5.—Quartzite, Anglesey.

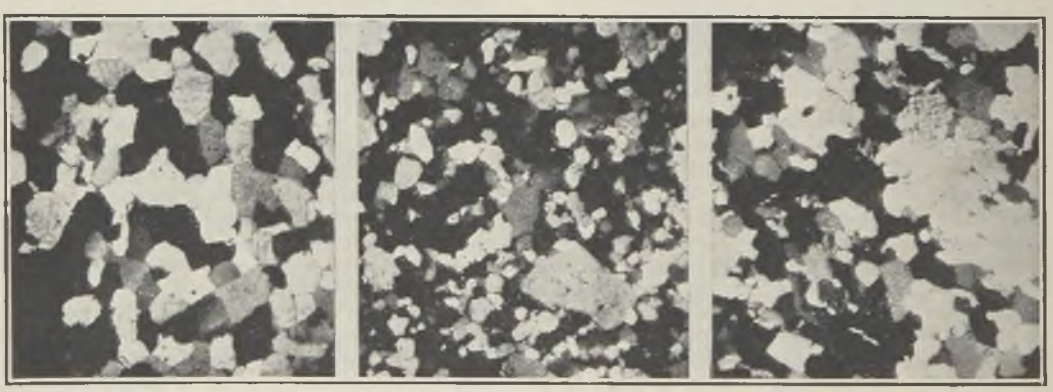


Fig. 6.—Quartzite, North Wales. Fig. 7.—Quartzite, Derbyshire. Fig. 8.—Quartzite, Scotland.

Refractoriness under Load

As the actual pressure due to the weight of the charge in the cupola may have some influence on the effective refractoriness of the cupola lining or patching, it is useful to make tests on dried test-pieces under a load of 28 lbs. per sq. in. (*i.e.*, 2 kg. per sq. cm.).

With the co-operation of Mr. E. S. Renshaw, of Ford Motor Company, Limited, Dagenham, Essex, the Refractories Committee of the Institute have been able to make simulative tests in a cupola fitted with a continuous tapping device. A cupola of this type gives suitable conditions as, after the first tap is made, the cupola well is soon filled with slag only, the

metal running immediately into a receiver on reaching the cupola bottom. Test panels 6 in. square by 1 in. thick, backed with thin fire-brick tile, are fitted into the cupola well exactly opposite to each other, and are in contact with molten slag for the duration of the run, which is about 7 hrs. The distance between the two panels before and after the run, divided by two, may be taken as the measurement of the erosion. A material of known satisfactory behaviour in the cupola may be used for standard panels alongside the other materials under test. Table V gives the particulars of two materials tested in this way against a standard ganister.

Where a cupola of this type is available this method of test is to be recommended, as it more nearly simulates actual working conditions than any laboratory test for erosion or corrosion.

old sand, black sand, etc., and the men had to dig it out as best they could.

Brick-Lined Rotary Furnaces

Discussing bricks for lining rotary furnaces, he said one had to consider the expansion of bricks containing a large amount of silica as compared with the contraction of bricks having a high percentage of alumina. In consequence of that difference, one found that in a rotary furnace which was working under stress, the lining was no longer fixed to the casing of the furnace after a few days, so that the lining broke down due to circumstances which were not dependent entirely upon the refractoriness of the material.

In 94 per cent. silica bricks there might be possibilities; but he asked Mr. Rees how he could account for a lining which was reduced to

Fig. 9.—Quartzite, Neath (South Wales). Fig. 10.—Quartzite, S. Wales. Fig. 11.—Typical Firestone.

DISCUSSION

Mr. J. H. Cooper (Darlington) said that for many years he had been concerned with cupolas, but he failed to see exactly the effect of the slag reduction which Mr. Rees had mentioned, as reducing the temperature of fusion from 1,620 to 1,180 deg. C. He asked what was the amount of oxide present in the slags when the tests were made, because a cupola always reacted according to the amount of blast and the quality of iron melted—malleable, steel-mix, low-silicon iron, etc.

A good deal of trouble was caused as the result of the wrong method of storing the cupola repairing material when it arrived at a foundry. The manufacturers, having sent a first-class material, would sometimes receive complaints, and when their representatives arrived at the foundry they found that it was not in anything like its original state; it was a combination of

1,150 deg. C. standing up at all, because in the melting zone of any cupola there must be a temperature of 1,500 or 1,550 deg. C. to give a tapping temperature of approximately 1,400 deg.

Close-Jointed Linings

Mr. A. J. Shore (Birmingham) questioned whether it really mattered that the bricks should be so very close together at the joints as had been indicated by Mr. Rees, and he asked if most cupolas were not protected by a ganister covering. He also asked whether Mr. Rees considered that it would be of advantage to use insulating bricks between the outside of the refractory lining and the shell.

With regard to the use of a lining of ganister rock as a basis for a cupola lining, he asked whether there were in this country any natural deposits of rocks which could be used as substitutes for brick; he had in mind something like

the silica stone which was used in America. It seemed that silica bricks were not good things to use in a cupola, due to their spalling, whereas certain natural stones were not prone to that trouble.

Standardisation of Ganister

Dr. J. G. A. Skerl asked for the opinion of Mr. Rees as to whether the life of a cupola lining could be affected by more rigid control of the slag in the cupola. He wondered whether, by an increase in the lime charge in the cupola, the life of the lining would be affected.

With regard to ganister, which had been a very "mixed" material, he said the time was rapidly approaching when some sort of standardisation should be attempted for the benefit both of the suppliers and of the users. He suggested that grading was a direction in which the manufacturers could help; but one would like to feel that the constituents of the ganister were materials which were really suitable for the job.

The use of the unburned brick, both in the cupola and in the rotary furnace, offered great possibilities. The unburned brick had been used very successfully in the induction furnace; but in many cupolas a form of unburned brick was used in the rammed linings, and in many cases those rammed linings were giving a very good life, much better, in his opinion, than that of a brick lining. The rammed lining had a composition round about a figure of 94 per cent. silica.

American Practice Discussed

Mr. W. R. Bean (Past-President, American Foundrymen's Association), commenting upon the reference made to the characteristics of the slag from the standpoint of oxide carriers, said that in America that had been found to be one of the most important considerations to makers of cupola linings. Also, the basic and acid elements present played a very vital part in the life of linings and in the results obtained. A great deal of the work in the U.S.A. nowadays involved long hours of operation, and that had given rise to further difficulties in obtaining linings to withstand the heavy blast and pressures, etc., involved in driving cupolas for 8, 12, 14 and sometimes 24 hrs. continuously.

Probably the industry in the United States had not gone so far as had the industry in this country in the adaptation of the rotary furnace to melting operations; it did not quite fit into the picture of foundry operations in the United States. But there were some 12 or 15 rotary furnaces in use there for the production of blackheart malleable iron and some of the pearlitic metals.

The best linings there were found to be of silica brick, which experience had proved to be superior to ganister linings. Records of 5-ton furnaces melting malleable iron showed from 200 to 220 heats, and in one particular case that number of 6-ton heats was obtained, representing a life of from 1,300 to 1,400 tons. Behind that silica brick lining, which was 6 in. thick, there was a permanent lining of fire brick against the shell, also 6 in. thick, so that the total thickness was 12 in. But the lining had to be treated carefully, especially during the initial heating-up. The size of brick used was 3 in. by 6 in. by 12 in., the 12 in. length being longitudinal in the furnace, and an allowance was made for expansion in laying the bricks. There was a paper or cardboard slightly in excess of $\frac{1}{8}$ in. at each of the end joints, and between $\frac{1}{64}$ in. and $\frac{1}{32}$ in. at each of the side joints; so that there was very little spalling when the lining was subjected to temperature, provided the firing was done carefully during the first heats. The furnaces in which those linings were used were turning out metal at 1,370 to 1,600 deg. C. constantly throughout their lives. The linings were easy to build, when once that practice had been established; they were built in much shorter time than was required for the ramming of a ganister lining.

AUTHOR'S REPLY

Mr. Rees, replying to the discussion, said that the slag which was used in the tests he had illustrated was obtained from a local foundry; it contained 12 per cent. of FeO and 35 per cent. of lime. He agreed with the suggestion made by one or two speakers that the composition of the slag did have a determining effect on the behaviour of the lining, and he agreed with Dr. Skerl that more complete control of slag composition would be helpful in promoting the durability of the cupola lining.

Commenting on Mr. Cooper's reference to the change in the character of the cupola ganister which sometimes occurred between the time it left the yard of the maker and its application in the cupola, he agreed that some ironfounders, at any rate, could with advantage take rather more care in the storing of such raw materials than in fact they did. He had seen cases where trouble had arisen in the application of patching as the result of leaving the ganister exposed to rain, so that it had become over-wetted; nothing was more likely to give rise to trouble in the cupola lining than the use of an over-wet patching material.

The question by Mr. Cooper concerning the expansion of rotary furnace linings had been answered most admirably by Mr. Bean. The reference by Mr. Bean to the use of silica bricks

in the linings of rotary furnaces, and the methods adopted for taking up the expansion of the bricks, showed that that type of lining was not only feasible, but could be especially advantageous in a rotary furnace. As Mr. Bean had very properly pointed out, it was very important indeed that silica bricks, and especially well-burned silica bricks, should be heated slowly between 200 and 300 deg. C. Once that particular temperature range was safely passed, and so long as the temperature of the bricks was kept constantly above that range, no spalling trouble was likely to ensue.

South African Titaniferous Bricks

The silica brick referred to in the Paper was clay-bonded and had a lower spalling tendency than the normal lime-bonded silica brick. Another type of silica brick which he believed might be feasible, and indeed was already feasible in one part of the world, was made from a natural quartzite containing from 2 to 3 per cent. of titanium oxide, very uniformly dispersed throughout the rock. A silica brick made from those quartzites, containing from 2 to 3 per cent. of titanium oxide, was for some reason still obscure, very highly resistant to thermal shock. Quartzites with high titanium oxide content occurred in quite considerable quantities in South Africa; he had had the opportunity of examining silica bricks made in South Africa from those rocks, and they were very nearly as resistant to thermal shock as was the average firebrick. They were very much superior in that respect to the normal silica brick one had to deal with in this country.

Dealing with Mr. Shore's remarks concerning jointing, Mr. Rees said he considered that it was advantageous to the durability of the brick lining in any part of the furnace to use good-shaped bricks and close jointing; especially was that so in the upper parts of the lining, where the protection by any patching was much less complete than it was elsewhere.

Insulation of Linings Commended

Insulation was exceedingly important. He believed that, given a much more efficient selection of the highest grades of refractories, it might be possible to insulate the cupola and thereby to improve definitely, not only its thermal efficiency, but also the efficiency of the firebricks, because by the application of a layer of insulating brick between the lining and the case it would be possible to obtain a much more uniform temperature gradient through the bricks themselves and so avoid thermal stresses due to a steep temperature gradient. That matter had exercised many minds. Insulation was being applied successfully in many other types of furnaces, and he would like someone to try it in a cupola and to publish the results.

WRITTEN DISCUSSION

Mr. E. J. Crawley wrote that Mr. Rees' remarks concerning the ground ganister and the desirability of obtaining standardisation by grading of the ganister rock aggregate were most interesting. However, in considering such an application to plastic mixtures of ganister rock and fireclay, irrespective of the many other types of patching compositions available, one essential property (the importance of which was stressed by cupola operators, and which was difficult to define in the laboratory) had always to be borne in mind, *i.e.*, the property of adhesion to the cupola lining. If a ground ganister was produced to give proper packing of the aggregate and bonded with a minimum amount of fireclay to give plasticity without materially reducing refractoriness, a mixture would be obtained which probably would not be acceptable to the foundry industry, because it would not adhere to the lining. It had been found that the most successful ganisters were those which contained an excessive amount of clay, giving a reduced refractoriness, which had some relation to prevention of the patch flaking off the lining at the beginning of the blow.

If adequate importance was attached to this factor in designing a "better" ground ganister, the advantages of producing more highly standardised mixtures as regards grading, which at the present time was not controllable to the extent desired, would be fully appreciated.

Mr. Rees, writing in reply to Mr. Crawley, agreed that the property of adhesion to the cupola lining was an important characteristic of satisfactory cupola ganisters, and he did not intend to convey the idea that the proportion of clay in the mixtures should be so low as to affect their adhesion. He did say that the proportion of clay used should be such that the mixture should not be on, or close to, the silica-alumina eutectic; but it was quite safe, from the refractoriness standpoint, to use a clay proportion which would bring the mixture on to the Al_2O_3 side of the eutectic, as shown in Fig. 1 of the Paper. It should be borne in mind, however, that an excessive proportion of clay, whilst it might increase adhesion to the cupola wall, would tend to form shrinkage cracks on drying and fixing which might not only tend to pull the patching away from the wall, but would also allow slag to penetrate and so lead to rapid corrosion. In considering a cupola ganister with a controlled grading, it should be quite satisfactory to regard the added clay as "fines," especially if added in a finely ground condition.

Paper No. 661

Gating with Special Reference to the Optimum Flow Conditions in the Molten Metal*

By Dr. E. M. H. LIPS

The importance of the question concerning the manner in which the molten metal should be fed to a mould is too well known to every practical foundryman to require discussion here. It may therefore be regarded as characteristic that during the past few years attempts have been made to investigate more fundamentally the processes which take place during the filling of moulds and thus to break away from the previous custom of describing the effects produced on the quality of the casting by interfering with foundry practice.

It is now recognised that the application of important conclusions made in related subjects will generally ensure a satisfactory result. It is also an obvious step to apply the laws of flow dynamics in the foundry where liquid metal is handled, especially since the importance of flow dynamics was first proved in hydraulics and later in aeroplane design. The application of the principles of flow dynamics at a relatively late date in foundry practice may be explained as being due to the fact that through the use of moulding boxes the flow of the metal through the mould is not visible to the eye, so that it is more or less impossible to observe the phenomena which occur during pouring. The present Paper is intended to draw attention to some laws of flow which are important for foundry practice and which permit general rules to be established for the design of casting gates.

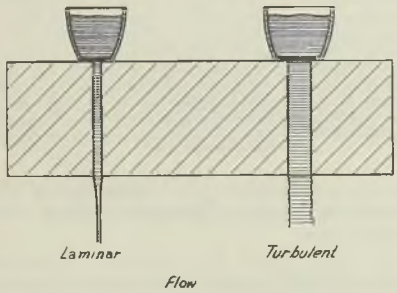


FIG. 1.—SMALL AND LARGE DIAMETER RUNNERS GIVING LAMINAR AND TURBULENT FLOW RESPECTIVELY.

For the purpose of considering the process of pouring metal into a mould, the latter may be subdivided into three parts:—

(1) All the channels through which the molten metal has to pass before entering the mould proper.

(2) The mould proper.

(3) The channels provided for the purpose of obviating the effects of cooling phenomena, such as the formation of cavities, after the mould has been filled with the molten metal.

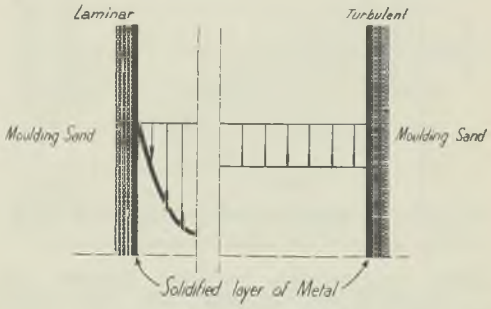


FIG. 2.—LAMINAR AND TURBULENT FLOW THROUGH RUNNERS.

It is clear that the channels mentioned under (1) have primarily to satisfy hydrodynamical requirements, while the channels mentioned under (3) have nothing to do with the flow of the molten metal, but are only operative after the molten metal has come to rest.

Consideration therefore will be confined almost exclusively to the channels mentioned under (1). Fig. 1 shows two runners on top of which is placed a pouring bush. If the bush is filled, for example, with molten iron and the stopper is removed, the iron will flow through the runner into any cavity located beneath. If the diameter of the runner in the case of one mould is small, for example, 4 mm., and in the case of the other

* Presented on behalf of the Nederlandsche Vereeniging van Gieterij-Technici.

is large, for example, 40 mm., it is found that the nature of the flow from the exit is very different in the two cases.

The molten metal issues from the runner of larger diameter in the form of a very turbulent and unsteady flow, while a very steady and smooth-exit flow occurs in the case of the runner with the smaller diameter. The metal flowing through the runner of large diameter produces considerable frothing in any receptacle situated beneath it, while the same metal flowing through the channel of small diameter causes practically no frothing. In the case of molten aluminium, this difference is, if possible, even more pronounced.

The differences outlined above may be fully explained by reference to Fig. 2. The flow of the metal through a channel or runner of small diameter is laminar or streamline, that is to

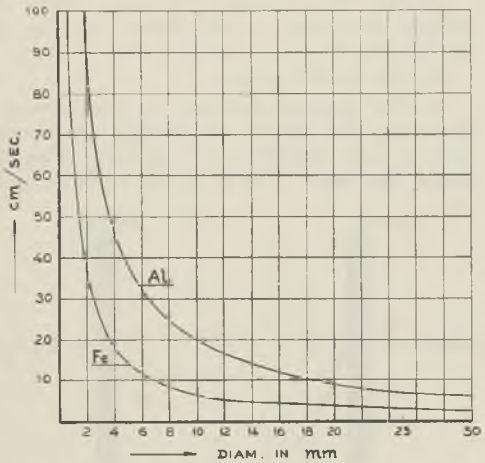


Fig. 3.—Critical Velocity related to Diameter of Runner for Iron and Aluminium.

say, the mean velocity of the flowing metal is a maximum in the centre and approaches zero at the wall of the channel. The curve showing the distribution of the velocity is a parabola. The flow of the metal passing through the runner of large diameter is, on the contrary, turbulent, that is to say, the mean velocity of the flowing metal is almost constant throughout the entire cross-section of the channel.

If a particle moving in laminar flow be considered, its path is found to be rectilinear. In the case of a particle moving in turbulent flow, on the contrary, its motion takes place along wholly irregular and curved paths. If the flow of metal through a pouring gate is streamline, the thin film solidifying on the wall of the gate will remain intact, because the velocity of the flowing metal is practically zero along the wall. The sand of the mould is thus protected by a film of solidified metal.

In the case of turbulent flow, a film of solidified metal will likewise be formed, but will be partly detached by the metal flowing along it at a considerable velocity and will take particles of sand along with it. With turbulent flow, a slight suction is also produced in places, in consequence of which gases present in the material of the mould are carried along and contaminate the metal. It is clear that this will result in the formation of dirt which can practically no longer be removed. This may be expressed as follows:—Laminar or streamline flow prevents the formation of dirt, while turbulent flow promotes such formation.

The question which now arises is, therefore: how can laminar flow be attained or at least approached more closely? The nature of the flow of any fluid through a channel or pipe

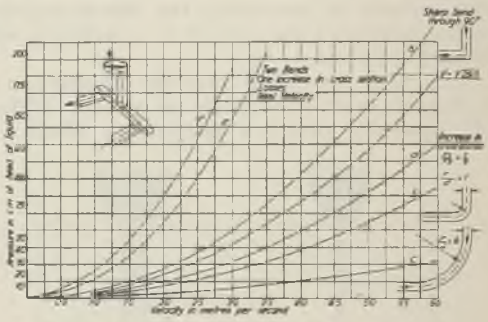


Fig. 4.—Variation of Velocity of Metal through the Pouring Gate with Pressure.

depends directly upon the velocity V_o [m.sec.$^{-1}$], the pipe diameter d [m.] and the kinematic viscosity ν (nu) [m^2.sec.$^{-1}$]

$$R = V_o \frac{d}{\nu} \quad . \quad . \quad . \quad . \quad . \quad (1).$$

For smooth runner or "pipe" walls, flow is only laminar when $R \leq 2{,}500$. For greater values of R, the flow is turbulent. It will be seen that V_o and d denote values depending upon the dimensions of the mould, while ν is a constant of the material. Assuming for cast iron a viscosity of $200 \,.\, 10^{-6}$ [kg.sec.m.$^{-2}$], then

$$\nu = \frac{200 \,.\, 10^{-6}}{715} = 0.28 \,.\, 10^{-6} \text{ [m}^2\text{.sec.}^{-1}] \quad . \quad (2).$$

Taking the limit value of R as 2,500, it is possible to calculate, for example, for a given pipe diameter, the permissible velocity of the liquid which just produces laminar flow. This velocity is also called the critical velocity. The

curve in Fig. 3 shows these relationships. Although the viscosity of aluminium is not yet known, a curve has also been given for this metal on the assumption that the viscosity is approximately the same as that of iron. The fundamentally more satisfactory behaviour of light metals with regard to running power may be gathered from these curves.

It can furthermore be deduced from Fig. 3 that the diameter of the pouring gate must be small for attaining laminar flow. This is the chief reason why a pouring gate should not be combined with a riser. For well-known reasons, risers must always be of large diameter.

It may also be said that the pouring gate must be designed on purely hydrodynamical principles, while the design of the riser is governed by the crystallisation properties of the cast material when at rest. The importance of the hydrodynamical design of the gating system will also be apparent from the following requirements which a good gating system should satisfy, for a small pouring gate diameter is not everything.

Fig. 4 shows the variation of the velocity of the metal flowing through the pouring gate with

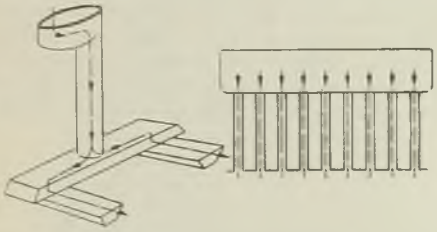


Fig. 5.—Common Gating System (left) and Suggested Improvement (right).

the pressure. Curves *a*, *b* and *c* show the loss of pressure, relative to the velocity of the liquid, which occurs when the molten metal undergoes a change in direction of 90 deg.

These curves were constructed on the following basis: If the resistance which the change in direction offers to the flow is equal to ζ (zeta), then

$$\zeta = \frac{\Delta p}{V_0^2 \cdot \frac{\rho}{2}}$$

where Δp [kg. m.$^{-2}$] = loss in pressure caused by the change in direction.

V_0 [m. sec.$^{-1}$] = velocity of the flowing liquid.

ρ [kg. sec.^{2} m.$^{-4}$] = specific gravity.

For a sharp bend of 90 deg. with a rough surface, Kirchbach and Schubert found a value of 1.27 by measurement. For a bend with a radius of curvature equal to the diameter of the pipe (curve *b*), this value is 0.50. For a radius of curvature equal to six times the diameter of the pipe (curve *c*) the value is 0.18. Although it should be definitely stated that these figures are not applicable to the flow of molten metal through a much cooler pouring gate, it is permissible to employ the value *n* for purposes of comparison, especially since the comparisons developed in hydrodynamics are also substantially applicable to liquids such as molten metal, while no values are yet known in the literature for correcting the above-mentioned numerical values.

It will be gathered from Fig. 4 that, for example, at a velocity of 3 metres (9.8 ft.) per second, the loss in pressure head for a sharp bend (curve *a*) is about 60 cms. (24 in.). For a curvature such as that given by the curves *b* and *c*, this loss is reduced to 20 cms. (8 in.) and 8 cms. (3 in.) respectively. This clearly shows the significance of the gate known as the horn gate.

It is necessary to avoid not only a sudden

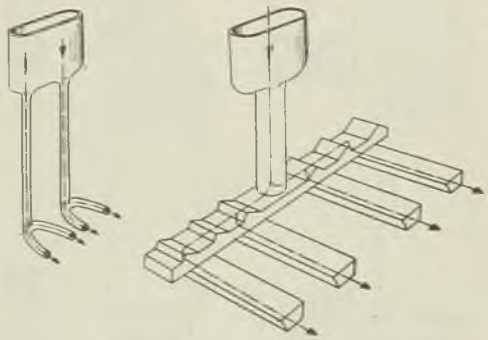


Fig. 6.—Gating System with Dirt Traps (right) and an Improved System (left).

change in direction of the flowing metal, but also abrupt changes in the cross-section of the gate, the loss in the case of a sudden increase in cross-section being particularly noticeable. Curve *d* shows the loss for a sudden increase in cross-section of one-quarter. The curve was plotted for a value of ζ of 0.7. Of course, the restricting condition mentioned above also applies in this case. Assuming now that there are two sudden changes in direction and a sudden increase in cross-section in a gating system (the example indicated in Fig. 4 shows the possibility of this condition), the losses may then be represented by the curve *e* and the actual velocity by the curve *f*. In the example cited, for a gate 100 cms. (40 in.) in height, for instance, the theoretical velocity as calculated from the equation $V = \sqrt{2gh}$ would be about 4.5 m. per sec. (18 ft. per sec.), while the actual velocity is only 2.2 m. per sec. (7.5 ft. per sec.),

giving a factor of usefulness of about 50 per cent. Compared with corresponding data in the literature, this figure appears quite possible.

Practical Examples

It will now be of interest to illustrate the application of the above theory with reference to some examples. The left-hand portion of Fig. 5 shows a gating system which is in common use. It will be seen that not only is there a repeated change in direction, but there are also sudden changes in cross-section. In the right-hand portion of Fig. 5, the single pouring gate has been replaced by a large number of thin gates. Changes in cross-section and direction are avoided as much as possible, while the gate diameter is also very small. The satisfactory effect of "pencil gates" employed in some quarters may thus be explained.

The right-hand portion of Fig. 6 shows a gating system provided with what are called

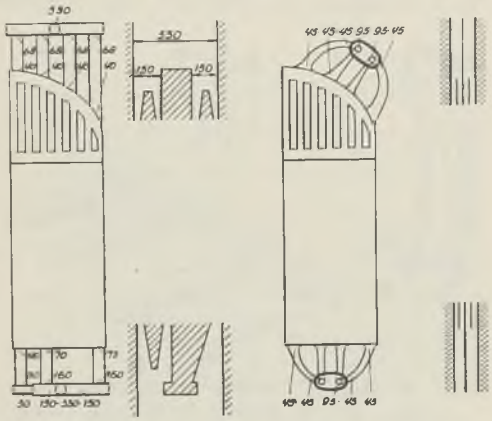


Fig. 7.—The Same Casting Provided with Conventional Gating System (left) and Improved System (right).

"dirt traps." From the foregoing, it will be clear that the writer is not an advocate of such dirt traps, which merely set up resistance and turbulence. This system can be very successfully replaced by the arrangement shown on the left in Fig. 6, which corresponds better to satisfactory flow conditions.

Fig. 7 shows two diagrams of the same casting. On the left, it is provided with the usual gating system, and on the right with a system of new design. The numerical values shown in the figure indicate the cross-sections of the various channels in square millimetres. The small diagram shows the variation in cross-section. Comparison of the two gating systems will clearly show that not only have sudden changes in direction been avoided as much as possible, but also sudden variations in cross-section, thus resulting not only in an improvement in the quality of the casting, but also in a considerable reduction in the weight of the gates and runners.

WRITTEN CONTRIBUTION

Mr. W. E. Styles in a written contribution wrote that he was in full agreement with Dr. Lips regarding the use of small downgates. In his opinion, the use of one or more small, instead of one large, downgate was the surest means of ensuring a clean casting. There were two points in the Paper, however, from which the writer found it preferable on occasion to

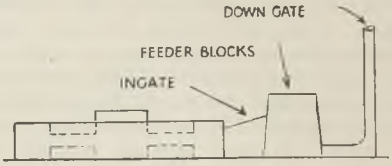


Fig. A.

differ:—(1) That a pouring gate should not be combined with a riser; and (2) that there should be no increase in the cross-section of the gate.

With reference to (1), a riser was added to the mould, chiefly for feeding purposes, and although the writer did not agree with the practice of pouring the metal through a riser, he

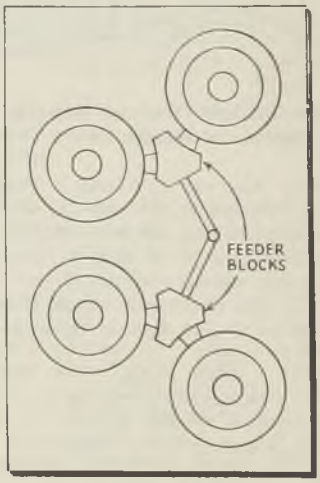


Fig. B.

had had considerable success by incorporating the feeder in the runner system.

The method employed would readily be understood by referring to Fig. A. The casting is a gear blank, and much trouble was experienced with sinking in the centre boss unless a riser

was added. This riser the writer wished to avoid, chiefly on account of extra dressing costs. Occasional trouble was also found with slight porosity at the root of the teeth after the castings had been machined. The application of the feeder block corrected both the above defects.

(2) Regarding the increase in the cross-section of the gate, this was an essential part of the feeder block principle. The downgate and channel *must* be of a smaller cross-section than the ingate from the feeder block to the casting. The reason for this was that the channel must solidify before the ingate to enable the molten metal in the block to feed into the casting and not back into the channel. Although only one casting had been described, the method had been applied to numerous others with excellent results.

Fig. B illustrated a typical pattern-plate layout.

Mr. Styles concluded his comments by tendering his thanks to Dr. Lips for the opportunity provided of reading a very interesting and instructive Paper.

Dr. E. M. H. Lips, in reply, wrote that to comply with the hydrodynamic theory, the downgate must be of a thin and regular cross-section. One would like to subject even the shape of a casting to the same reservations. This latter would be impossible in many cases, of course, which caused an ungovernable flow of the metal from the moment it entered the mould proper.

Referring to Figs. A and B, he suggested that one should look upon the riser as an integral part of the actual casting, thereby showing that there was no real contradiction in Mr. Styles' explanation of the phenomena and the author's. The same applied with reference to a sudden change in the cross-section. It stood to reason that full advantage of the application of the hydrodynamic laws could only be had when one bore in mind this principle in the design of the casting.

Paper No. 662

Some Iron Castings for Steelworks Plant

By JOHN ROXBURGH (Member)

Introduction

Machin and Oldham in a Paper* entitled "Castings," presented some years ago before this Institute, made the following statement:—"So many variables are associated with the manufacture of castings that the degree of success depends mainly on the decisions made by those responsible for the methods of procedure."

That statement, although brief, contains a wealth of truth. If one proceeded to amplify it in detail, one would be confronted with a tremendous task. A story would have to be unfolded, crammed full of experiences, containing descriptions of successful and unsuccessful experiments and endeavour, and detailing the various data collected, in order to lead up to the main theme, that of success depending on decision.

Year by year, the responsibility attached to the foundry executive becomes more and more important and, indeed, more exacting. It must be acknowledged that tremendous strides have been made in foundry practice during the past twenty years, mainly technical and metallurgical, and this progress has made possible the improved standard and wider application of the products emanating from the foundry. At the same time, however, the skilled operative must continue to play his part, particularly where the human element is all-important, and his contribution to the finished article must receive due recognition. Decisions respecting all phases of manufacture having been made by the responsible officials, organisation effected, technical and practical details considered, suitable tackle and materials provided—undoubtedly the chief considerations as they are—yet, without the skill and co-operation of the operative, their schemes, plans and

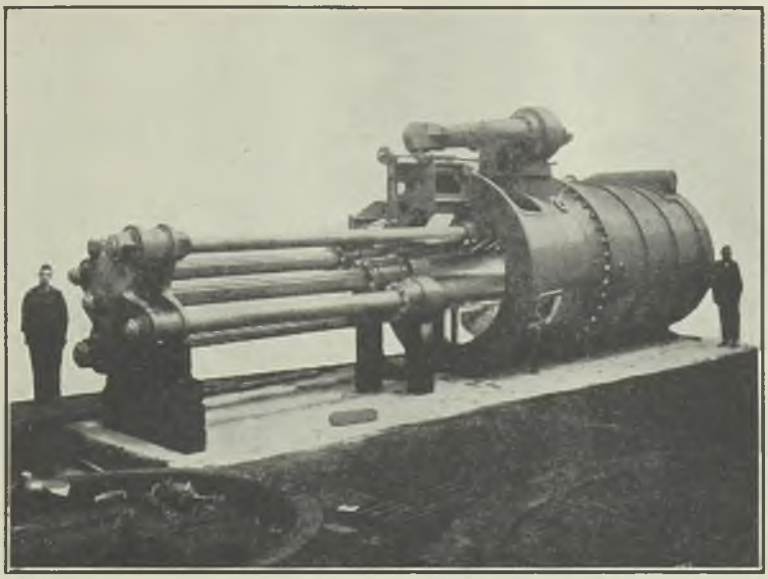


Fig. 1.—Hydraulic Intensifier for Press.

* W. Machin and M. C. Oldham, "Castings." Proc. I.B.F., 1934-5, Vol. XXVIII.

ideas would fail. Happy is the foundry executive who has skilled men upon whom he can depend to follow his instructions.

It is obvious, then, that a combination of practice and technique, in which latter undoubtedly the greatest progress has been and is being made, is necessary to ensure the production of a satisfactory casting, and a casting can only be termed satisfactory after it has passed through the stages of manufacture, has fulfilled all the required tests, been submitted to inspection, finally to give a reasonable service life, according to some considered standard of the user. Thus the foundry executive must, before the commencement of manufacture, be aware of the precise service conditions demanded. At the same time he must produce a sound casting in every sense of the term, and one of good appearance, true to shape and size, to say nothing of the economic aspect of production.

After having given the necessary consideration to all the practical details, he must, of necessity, place great importance on the metallurgical aspect. He knows that, until recent years, the analysis of a casting appears to have been the chief consideration, although he has been aware, from his experience, that two irons of the same composition can give very widely differing physical properties. He has also learnt that, in the main, properties of cast iron can be attributed to the quantity and condition of the graphite, and that by the latter's refinement, dispersion and reduction in amount, great improvements can be effected. Recently, therefore, in his deliberations regarding the most suitable metal for some particular casting, it has become essential for him first and foremost to decide the ultimate structure he desires, and, in contemplating the manufacture of any high-grade casting or one to withstand special service conditions, his first thought has had to be the attainment of a suitable structure in the metal of the casting. In order to obtain such a structure, the analysis of the metal is naturally a good guide, as, for instance, a low total carbon will help first of all in the refinement and quantity of graphite. The materials comprising the mixture, steel mixtures, the addition of alloys, the furnace in which the melting is carried out, the amount of superheat, the inoculation of the metal by some well-known process, artificial means of accelerating or prolonging the cooling rate, heat-treatment—these all have their effects on the ultimate structure to be found in a casting, and on the physical properties of the resultant metal. Thus the foundry executive must, initially, be able to visualise the casting to be produced, so that he can determine his practical methods of procedure and, at the same time, be aware of the possible defects and troubles he must try to avoid, and must simultaneously decide upon the metallurgical aspects

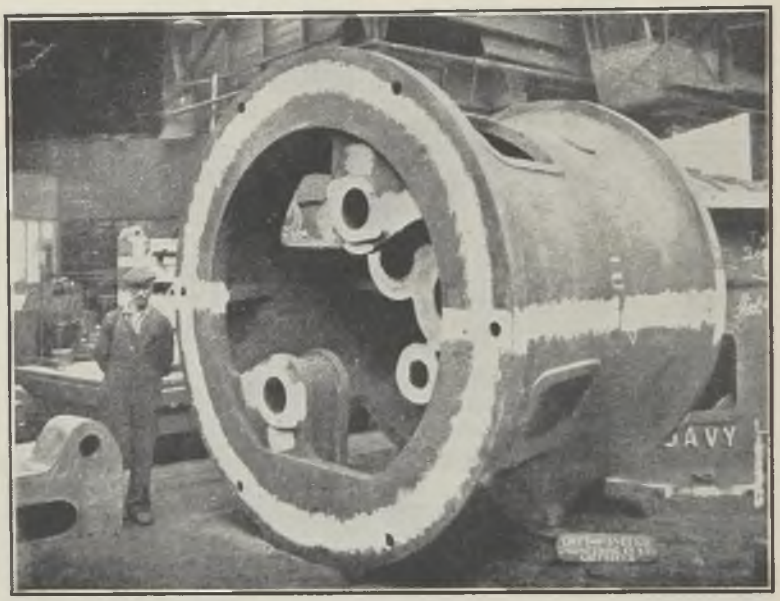


Fig. 2.—A 27-ton Stool Casting.

in order that the service conditions of the casting can be successfully met.

Control by Chills

In a previous Paper,* entitled "The Technique of Chilling," the author makes reference, based on his personal experience of roll manufacture, to the use of a chill test as applied to grey iron castings as apart from actual chilled castings. For all his special mixtures of iron, the author continues to make use of a chill test-piece 6 in. by 6 in. by $1\frac{1}{8}$ in., which has proved very helpful in practice.

Great attention is paid, naturally, to the selection of materials used for all metal mixtures,

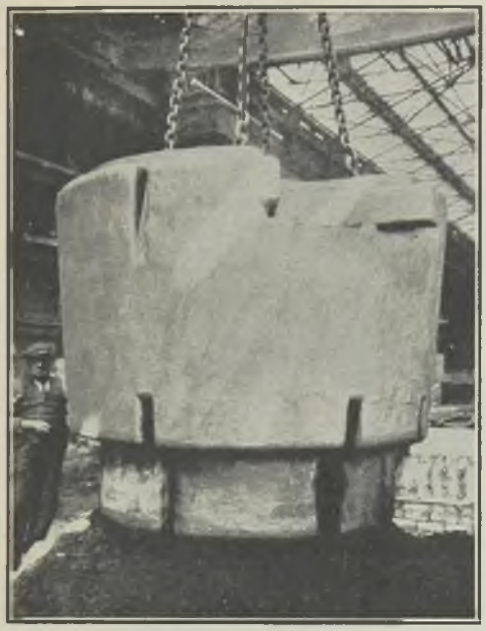


Fig. 3.—Main Core for Stool Casting.

and the scrap resulting from such is kept apart. Variation, however, is bound to creep in due to the use of such scrap, as it can only be given a general term, *e.g.*, cylinder scrap, and its structure and composition may differ slightly. Conditions of melting in the cupola, too, may vary from day to day.

With similar mixtures of iron, in attempting to obtain suitable structures, a chill test readily indicates, before casting, any great irregularities in the foregoing and gives the executive, by viewing the test-piece before casting, the opportunity of deciding whether the metal is satisfactory or not for the particular job.

By experience, data can be collected of metal mixtures used, compositions and structures obtained and the depth of chill on the test-piece correlated with the weight and section of the

Fig. 4.—Finished Outside Mould for Stool Casting.

casting, the machinability, physical and pressure tests. A cylinder metal analysing, for instance, 2.9 T.C; 0.8 Si; 0.5 Mn; 0.12 S; and 0.2 per cent. P would probably show $1\frac{1}{2}$ in. depth of chill on a test-piece, whilst a similar

Fig. 5.—Intensifier Cylinder Casting.

mixture but with higher silicon, say 1 per cent., would give approximately 1-in. chill.

With alloy irons containing hardening elements, *e.g.*, chromium, a limit for depth of chill on a test-piece can be determined to permit

* J. Roxburgh, "Technique of Chilling." Proc. I.B.F., 1934-5 Vol. XXVIII, pp. 586-603.

ease of machining. The test is viewed before casting, and, if above this limit, ferro-silicon may be added to soften the iron, to bring the casting within the bounds of machinability.

The engineering company with which the author is associated enjoys a high reputation for rolling mills and forging presses, and so the author is called upon to make castings for these, in addition to other steelworks plant. He hopes, as fully as possible in the space available, to describe the manufacture of certain of these typical castings.

Forging and Bending Presses

At the present moment his company is well forward with the manufacture of two of the largest

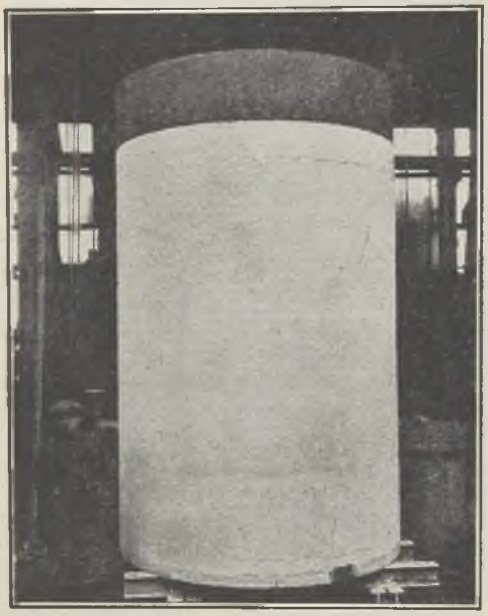


Fig. 6.—Centre Core for Intensifier Cylinder.

presses ever made in England. The presses comprise a 15,000-ton bending press and a high-speed forging press to operate at 12,000, 8,000 and 4,750 tons. The latter press will forge hollow drums up to 18 ft. dia. by 19 ft. long and is served by four steam hydraulic intensifiers, with hydraulic cylinders, 95 in. dia. by 10 ft. 4 in. stroke, with steam pressure of 150 lbs. per sq. in. and hydraulic pressure of 3 tons per sq. in. in the main press cylinder.

The total weight of the 12,000-ton forging press, including valves and intensifiers, but no other auxiliaries, is approximately 3,000 tons, whilst the total weight of the four intensifiers approximates 400 tons. Incidentally some of the steel castings required for these two presses weigh 120 tons each when finished and have actually been made in Sheffield.

Intensifier Castings

In the first batch of examples, reference will be made to some of the iron castings made for the above presses. Fig. 1 is a view of one of the four intensifiers, completely erected, showing the stool, the cylinder and cover—inside of which, of course, is the piston body and junk ring, together with the valves and other accessories.

The stool casting is approximately 10 ft. dia. and 8 ft. deep, weighing 27 tons, and Fig. 2 well illustrates its size and intricacy. Loam boards are provided for both mould and main core, together with the loose pieces for the branches, windows and internal bosses. The machining allowance is 1 in. on the top flange.

Fig. 3 depicts the finished main core. This is

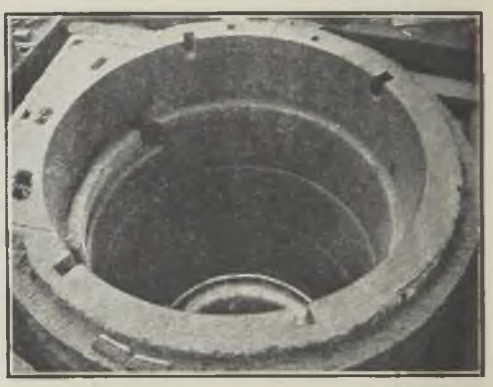


Fig. 7.—Mould for Intensifier Cylinder.

built-up in a trough, which had been previously swept, and in which the internal bosses and ribs had been set accurately. Grids were placed in the pockets formed between the bosses and rammed up, and these were bolted to a main grid, the core then being bricked to the top, with further binders built in, and the top bosses and brackets were located. The core was dried in the trough and then lifted out to be finished.

Fig. 4 shows the finished outside mould, which calls for no explanatory remarks except that it is split at the bottom flange. The segment cores are first bolted down in the bottom, then the branch cores located, and next the main centre core is placed on cast-iron screwed studs, and finally the top plate is added. Incidentally, between the bottom and top plate all cores are packed iron to iron to avoid any movement. The method of running adopted is by using two ladles on opposite sides. On one side are three

downgates, $2\frac{1}{2}$ in. dia., two of which enter tangentially on the bottom flange. The metal flows through 16 holes in the segment cores, two in each, as shown, in order to fill the centre of the mould. The third downgate is released when the metal is judged to have covered the segment cores. On the opposite side, three top gates, $1\frac{1}{2}$ in. dia., are opened when the mould is three-quarters filled. A casting such as this is apt to crack at the windows and to obviate this possibility, two matters require attention:—(1) A flash is carried across each window; and (2) the mixture of metal is arranged accordingly. A steel-mix iron, containing a percentage of hematite, was used, and the average analysis of the four castings made was:—T.C, 3.19; Si, 1.27; Mn, 0.64; S, 0.096; and P, 0.40 per cent.

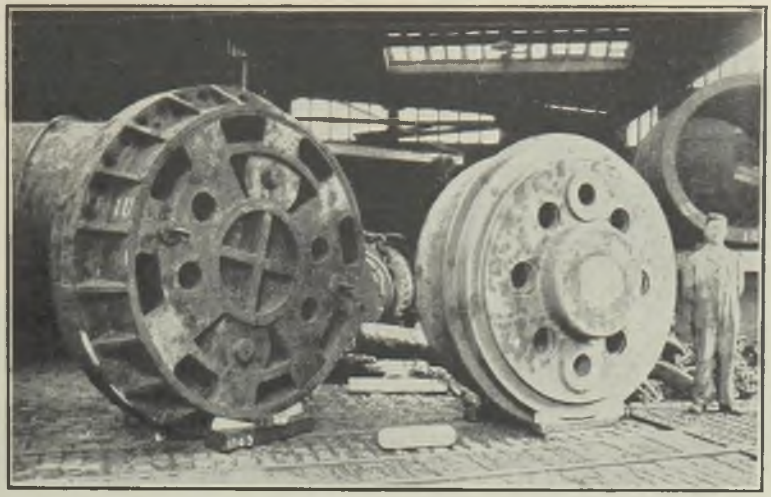


Fig. 8.—Cylinder Cover and Piston Body.

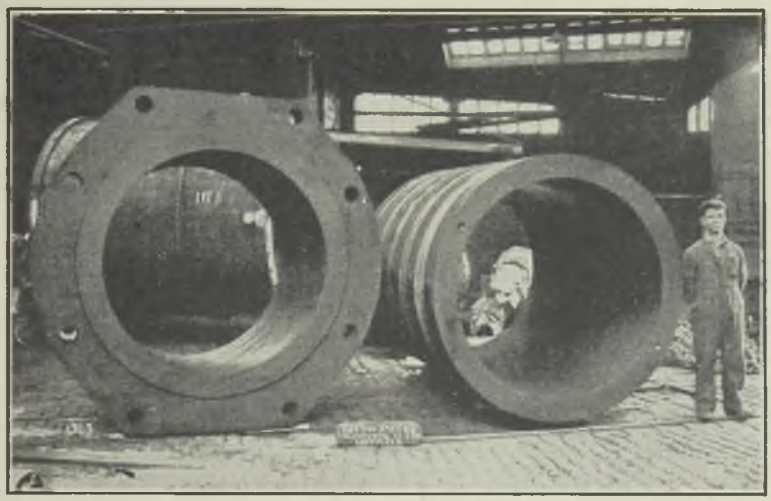


Fig. 9.—Guide Cylinder and Bush.

Intensifier Cylinder Casting

The intensifier cylinder shown in Fig. 5 is 95 in. dia. in the bore and 10 ft. 4 in. long, and it is necessary to incorporate 2 ft. of head on the top flange to ensure soundness, the total

weight of the casting being $35\frac{1}{2}$ tons. The machining allowance was $\frac{5}{8}$ in. in the bore, the average section of metal being 5 in. This casting again is a loam job, boards being provided together with loose branch and bosses.

The centre core (Fig. 6) is built up on a core plate, binders being inserted every 18 in., and

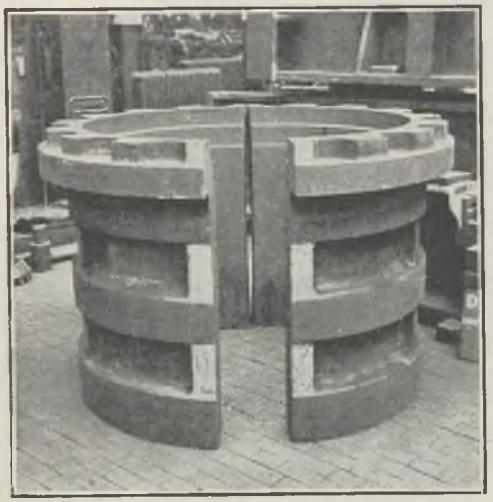


Fig. 10.—Half-Bushes for Press Column.

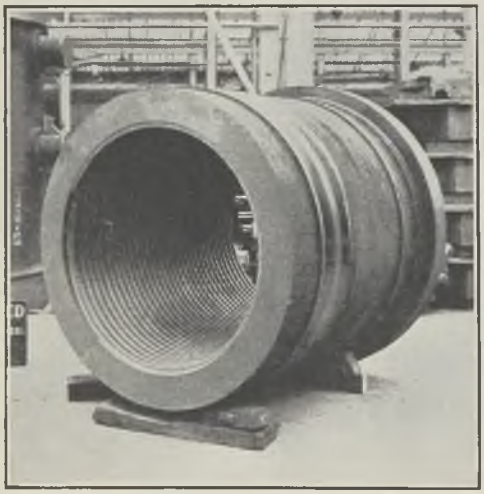


Fig. 11.—Column Nut in which the Thread is Machined from the Solid.

the core is finally bolted top to bottom. The outside, shown in Fig. 7, is built up in rings, 2 in. thick, and a drawback made above the branch in order to insert the branch core. The method of running employed was as follows. Two ladles were used to fill the runner dish, when two $2\frac{1}{2}$ in. dia. downgates were released first, which entered tangentially the bottom flange. When about 6 tons had entered the mould, to form a cushion and avoid splashing, fourteen top gates, $2\frac{1}{2}$ in. by $\frac{1}{8}$ in., were liberated, for top running ensured the cleanliness desired. For high-pressure cylinders, a phosphorus content of 0.2 per cent. is usually aimed at, but for low-pressure work this may with safety be raised to 0.4 per cent.

The average analysis obtained from the four cylinders made was:—T.C, 3.22; Si, 1.20; Mn, 0.65; S, 0.090; and P, 0.40 per cent.; but, in this case, no steel was used in the mixture, which consisted of 30 per cent. mottled iron, 10 per cent. hematite containing 1 to 1.25 per

Fig. 12.—Slabbing Stool Casting.

cent. silicon and 1 per cent. manganese, 20 per cent. cylinder iron, 25 per cent. cylinder scrap and 15 per cent. machinery scrap.

Cylinder Cover and Piston Body

Both the cylinder cover and piston body are shown in Fig. 8. The cylinder cover on the left weighs $11\frac{1}{2}$ tons, and was struck up in loam. The outside is lifted off, carried by a joint plate, whilst the top side of the casting, which is shown, is lightened out by cores bolted in prints on the top plate. One inch machining is allowed on the top surfaces of the casting to ensure cleanliness. A combination of top and bottom pouring was again employed, one downgate $2\frac{1}{2}$ in. dia. entering first tangentially in the bottom; later, at a predetermined time,

three top gates $1\frac{1}{2}$ in. dia. were released from the top. A cylinder mixture was used, giving as an average analysis for the four castings made:—T.C, 3.25; Si, 1.30; Mn, 0.63; S, 0.092; and P, 0.40 per cent.

The piston body, on the right, weighs $12\frac{3}{4}$ tons, and a ring head, 1 ft. deep, was incorporated to ensure soundness. This is also a loam job, and, when closing, the lightening cores were placed on wooden thickness pieces in the mould and then bolted up to the top plate through the 8-in. dia. $\frac{7}{8}$ in. were released when the bottom flange was completely filled.

The right-hand casting is a bush, weight 23 tons, 5 ft. 3 in. dia. bore by 8 ft. long, with 2 ft. of head and an average thickness of $6\frac{1}{2}$ in. One $2\frac{1}{2}$ in. dia. downgate was employed for running, and after 4 tons of metal had entered the mould, eight top gates $2\frac{1}{2}$ in. by $\frac{7}{8}$ in. were liberated.

For both these castings a steel mix was used containing steel, mottled iron, cylinder iron, cold-

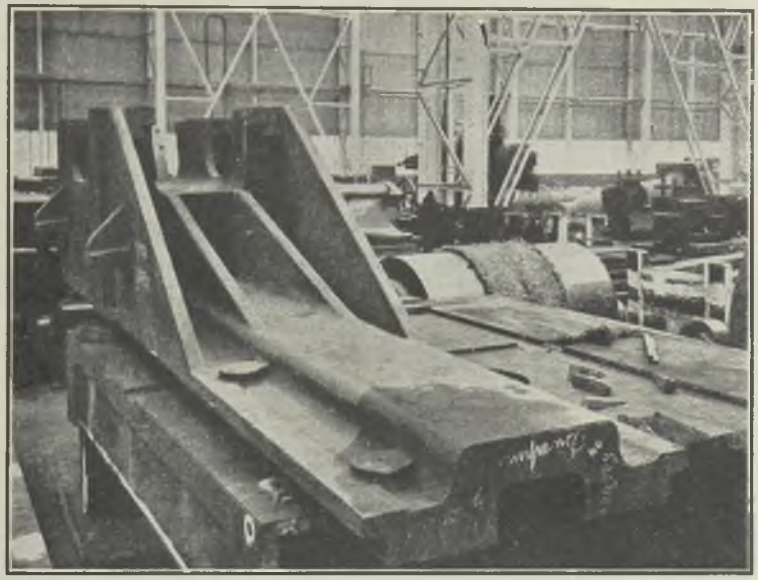


Fig. 13.—Offside Bracket Weighing 20 Tons.

cores shown, advantage also being taken of these latter cores in order to take off the vent. In this way, all studs on the important bottom machined face were eliminated. A very similar analysis was obtained as for the large cylinders previously mentioned.

Guide Cylinder and Bush

Fig. 9 illustrates two large castings which present probably more of a metallurgical problem from the point of view of soundness and suitable structure, than one of moulding, due to their unusual thickness of metal. The casting on the left is a guide cylinder; it weighs 16 tons, has a 5 ft. 3 in. dia. bore and is 5 ft. long with a head 1 ft. 6 in. long, whilst the metal round the bore is 7 in. thick. The flange cast at the bottom is 10 in. thick as finished. This casting was run with two $2\frac{1}{2}$ in. dia. downgates entering in the bottom flange and seven top gates $2\frac{1}{2}$ in. by blast, cylinder scrap and machinery scrap, and analysing as follows:—

Bush.—T.C, 3.04; Si, 1.12; Mn, 0.60; S, 0.122, and P 0.42 per cent.

Guide Cylinder.—T.C, 3.17; Si, 1.08; Mn, 0.54; S, 0.119, and P 0.41 per cent.

Half-Bushes for Press Columns

The half-bushes (Fig. 10) for the press columns weigh $2\frac{1}{2}$ tons each and, in this case, as there were sixteen to make, a full half-pattern was provided. The bottom flange was loose, rammed up separately, and turned over to receive the top part of the pattern, which was dowelled on. A joint was made above the bottom flange and a joint plate used to lift off the mould above this flange. The bore was formed by a core. A head 15 in. high was incorporated on the casting, and the job was cast open, five top gates 1 in. dia. alone being used to fill the mould. A low-

Fig. 14.—Mould for the Casting shown in Fig. 13.

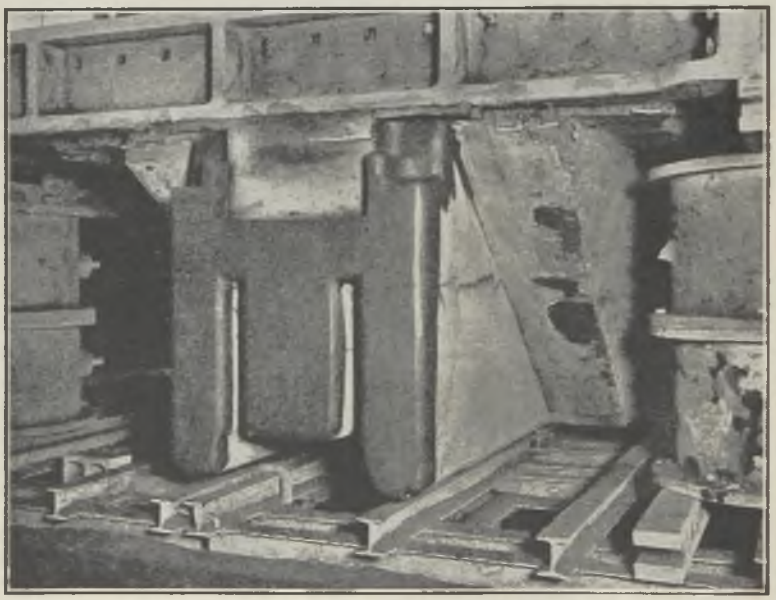


Fig. 15.—Bolting Arrangements for the Offside Bracket Mould.

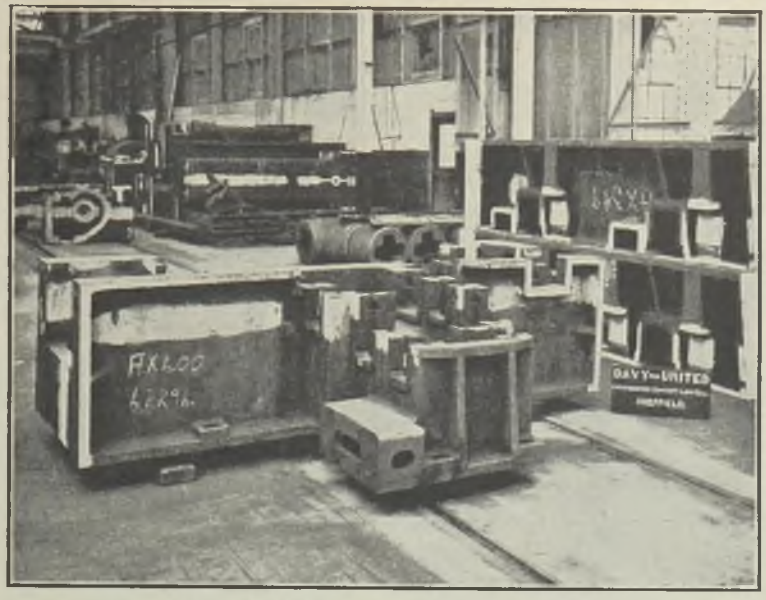


Fig. 16.—Reduction Drive Frame.

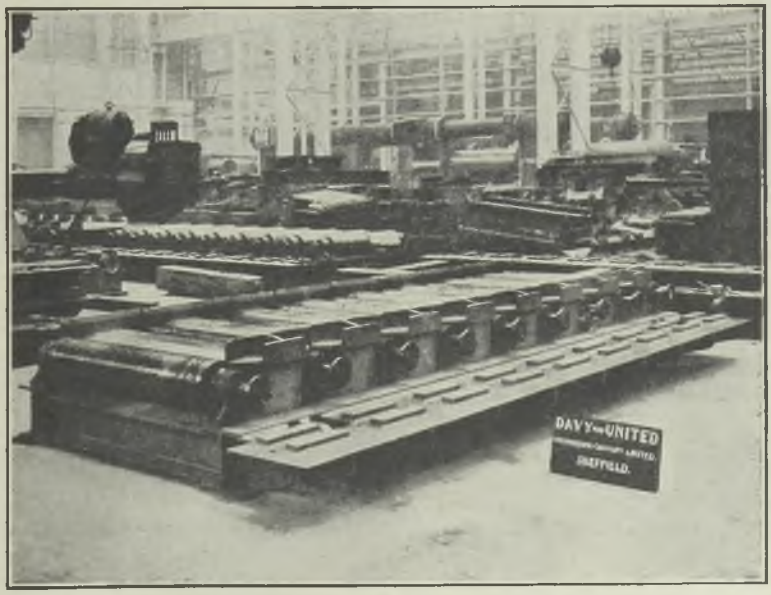


Fig. 17.—Rollers Assembled in Mill Table.

carbon, low-silicon, low-phosphorus iron was again used to ensure a close-grained material.

Column Nut

The column nut (Fig. 11), of which four have been made, has a finished weight of 5 tons. It is a particularly interesting casting, as a heavy duty is demanded of it and a tensile strength of at least 16 tons per sq. in. for the material was required. The mould and core were struck up in loam, with 2 ft. head on the top end of the casting, and the bore was cast plain, the deep thread being subsequently machined out of the solid. A combination of top and bottom running was employed, six gates being dropped from the top. A steel-mix iron was used to give an average analysis of:— T.C, 2.92; Si, 0.98; Mn, 0.54; S, 0.105, and P 0.35 per cent., again emphasising the importance of low contents of carbon, silicon and phosphorus. In the root of the thread, the metal was perfectly sound, close-grained and free from any sponginess.

Slabbing Stool and Offside Bracket

Another press casting, a slabbing stool weighing 16 tons, is shown in Fig. 12. A full pattern, completely blocked, was provided, the job being moulded on its side with two sets of cores, with metal between them. Iron studs and packings were used throughout to counteract any lifting. This casting is bulky, with fairly heavy sections of metal, and in order to withstand service conditions a steel-mix iron was used.

A final example of a press casting, an offside bracket, is illustrated in Fig. 13. It weighed 20 tons, is 20 ft. long and 5 ft. at the deepest part. As the slides on this casting are very important, these surfaces, of necessity, were moulded in the bottom. This naturally increased the difficulties of moulding, and Fig. 14 gives a view of the mould showing the awkward jointing involved. This necessitated a large volume and weight of sand being carried on the top part, grids being used and bolted with strong bolts to the top part. Fig. 15 depicts this feature quite well. Actually, two separate top parts were used in order to facilitate coring up, as will be obvious. The top part carrying the deep cods was placed in position first, and the coring up of the deep end was then carried out, and in this way studs could be placed between the cores and the deep cods of sands to secure the cores in position. Owing to the deep cods carried on the top part, it was necessary to put 90 tons of weights on the top to counteract the lift when casting.

This casting was run from both ends, with one ladle holding 8 tons of metal at the shallow end of the casting and one carrying 15 tons at the deep end. Both ladles were poured simultaneously, ingates entering at the bottom of the mould. By previous calculation, it was ensured

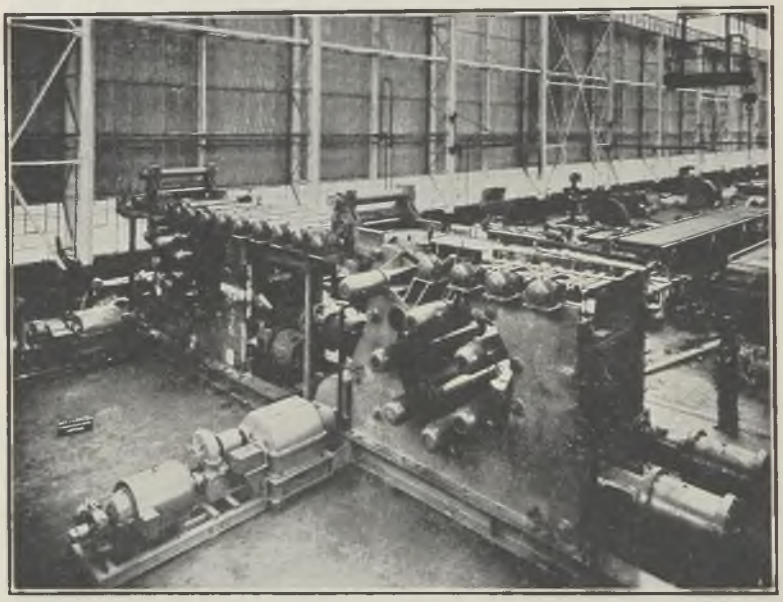


Fig. 18.—Coiler for Hot Reels.

that the slides had been completely covered with metal when the 8-ton ladle was empty, and the 15-ton ladle, with additional ingates higher up, completed the filling of the mould. This method was adopted to relieve the strain on the job; relief was also given by the location of dummy risers off the shallow part of the casting. A steel-mix iron was necessary to give an analysis of T.C, 3.15; Si, 1.20; Mn, 0.60; S, 0.095, and P, 0.40 per cent.

Actually, for all the above castings, a Brinell number of 160 to 180 was insisted upon, and despite the large sections of metal involved this figure was invariably obtained. It was essential, in view of the rigid requirements regarding cleanliness and soundness of the castings, that all the metal used should be melted at the highest possible temperature from the cupolas and cast as hot as possible, that is, above 1,300 deg. C. In order to achieve this, no time was lost in skimming off and conveying the metal to the jobs to enable them to be cast with the minimum delay. This applies to all high-class castings on which a great deal of machining is to be done. Some people would point out that, by following this procedure, the refractory materials of the moulds would suffer. Therefore, high-quality refractories must be employed in order to cater for the high-temperature metal, which is of primary importance.

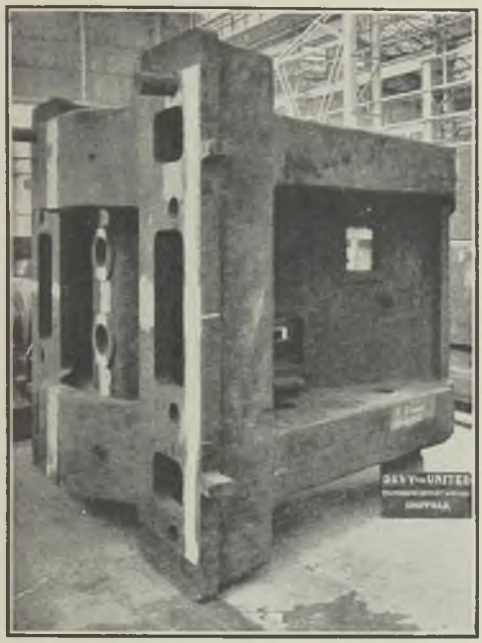


Fig. 19.—Pinion Housing Casting.

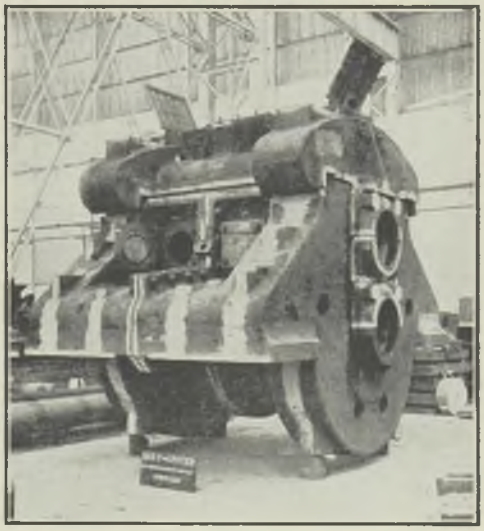


Fig. 20.—Pinion Housing and Cap.

Rolling-Mill Castings

As mentioned at the beginning of the Paper, the foundry with which the author is associated is called upon to manufacture many types of castings, large and small, in connection with rolling-mill plant, and he is only able to consider a few examples of such castings.

A number of the castings can be made from ordinary engineering iron, with the approximate analysis of:—T.C, 3.30; Si, 1.8; Mn, 0.7; S, 0.07; and P, 0.7 per cent., where the strength and structure of the metal are adequate for the service conditions. An example of a casting made from such material is a reduction drive frame, weighing 6 tons, which is shown in Fig. 16. The main feature of this casting, from the moulding point of view, is the accurate location of the bearing and other cores.

On the other hand, with a continuous hot strip and sheet mill, there are many applications where high-duty cast irons are essential. For instance a considerable number of table rollers were manufactured, 10 in. dia. and 4 ft. 8 in. long, the metal thickness being 1 in., and each weighing 5 cwts. A Brinell hardness number of 275 to 300 was demanded of the non-heat-treated castings, and to obtain this figure an alloy cast iron was employed, having the following composition:—T.C, 2.8 to 3.0; Si, 1.6 to 2.0; Mn,

0.7; S, 0.08; P, 0.15; Ni, 1.75; Cr, 0.4, and Mo, 0.35 per cent.

As these rollers were cast vertically, the moulding technique involved the use of only two $\frac{5}{8}$ in. dia. top runners, covered with perforated plates, and a 9-in. tapered head on the castings. Subsequently the castings were machined and ground on the barrel and fitted with shafts, and Fig. 17 shows some of the rollers in position in the table.

Rollers for Hot Reel Coilers

In connection with the coilers for the hot reels (Fig. 18) certain rollers 15 in. dia., 6 ft. long, $1\frac{1}{2}$ in. thick, and weighing 12 cwts. were called for, and a Brinell hardness range of from 450 to 500 was demanded. To obtain this a heat-treatment of the castings was carried out, by heating at 850 to 900 deg. C., quenching in oil and tempering at 180 to 260 deg. C. in order to relieve stresses. The metal used gave an analysis of:—T.C, 2.8 to 3.0; Si, 1.5 to 1.8; Mn, 0.7; S, 0.08; P, 0.15; Ni, 2.5 to 3.5, and Cr, 0.4 per cent.

The castings were machined all over and ground. In the foundry they were cast vertically, with 1 ft. of tapered head, and two top runners $\frac{7}{8}$ in. dia., covered with perforated plates, were used. Excellent results were obtained in both types of rollers described, by top running with the two small runners, and by pouring the metal at the highest possible temperature.

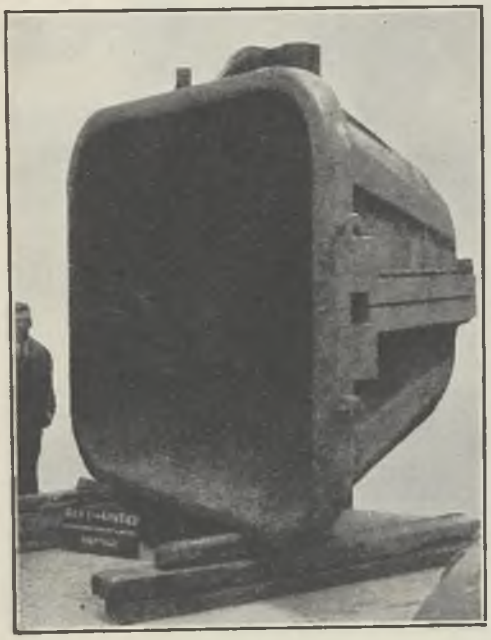


Fig. 21.—A 20-Ton Slag Ladle.

Pinion Housing

Other types of castings, owing to their size and the service required of them, necessitate the use of steel-mix irons. Such a casting, shown in Fig. 19, is a pinion housing, 36 tons in weight, cast in one piece and with the bedplate at the top. It is a job requiring very great skill in moulding and coremaking. The chief cores are the main body core, lightening cores in the arms and the cores for the bedplate portion. It is quite unnecessary, for all the large castings mentioned in this Paper, to emphasise the importance of the attention which should be paid to all details of manufacture and to the strength of any tackle used on the jobs. A usual analysis for this type of casting is T.C, 3.25; Si, 1.20; Mn, 0.7; S, 0.09, and P, 0.4 per cent., while a 25 per cent. steel addition is customary.

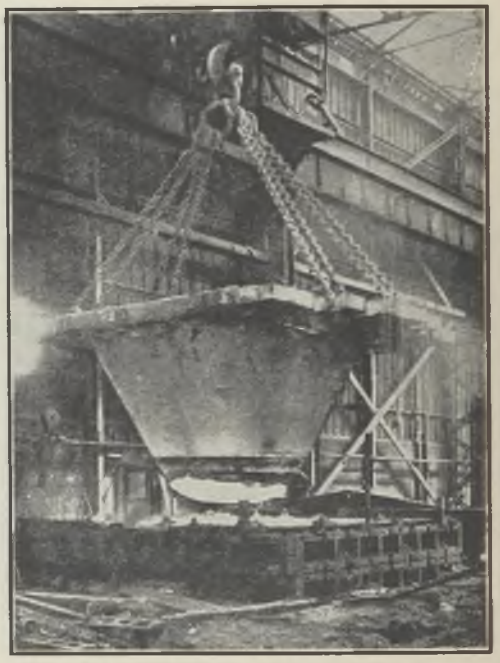


Fig. 22.—Lifting the Top Plate and Core from the Cast-up Mould.

Another type of pinion housing, consisting of two halves bolted together, is shown in Fig. 20, as is also the housing cap. The pinion housing weighs 46 tons and the cap 13 tons. Each half of the housing is moulded separately, joint-flange down, and the cores in the arm have to be held

down with chaplets, suitably packed, to avoid lifting. The housing cap was moulded in the position as shown with the joint-flange down, necessitating drawbacks at each side. For these castings a similar steel-mix iron was employed. In large castings particularly, the question of "feeding" is very important and, although a great deal depends on the skill of the moulder, the first consideration is the provision of hot metal for "feeding," which latter the author supplies in his foundry from a cupolette, specially operated for this purpose.

Slag Ladles

Other types of castings are manufactured for steelworks, and Fig. 21 shows a 20-ton slag ladle, in halves, which presents an interesting moulding job, as a number of these castings have been made from a semi-permanent mould and core. A skeleton pattern was provided with a splitting

Fig. 23.—Core for Slag Ladle.

core print, and for the first casting the mould was bricked to the pattern, the thickness made up and the core built up inside with specially designed tackle and bolted to a strong top plate, weighing itself 18 tons. At a suitable time after casting, the top plate and core are lifted out (Fig. 22) and for all subsequent castings it is only necessary to redaub both the mould and the core with loam, all the brickwork in both cases being retained. The only parts of the mould to be remade each time are the two drawbacks over the trunnions. Fig. 23 illustrates the core; when redaubing it, the skeleton pattern is simply lowered over the brickwork so that the core is dead accurate in shape. This casting is made from a hematite mixture, analysing usually as T.C, 3.60; Si, 1.60; Mn, 0.65; S, 0.07, and P 0.07 per cent.

Steam-Hammer Cylinder

A final example, Fig. 24, is that of a steam-hammer cylinder, weighing 6 tons, which is moulded horizontally in special boxparts and then cast vertically. A 2-ft. head was incorporated on this casting, which was run completely from the bottom, a runner entering the bottom flange. A cylinder metal was employed, the actual analysis of the castings being T.C, 3.15; Si, 1.22; Mn, 0.65; S, 0.115, and P 0.38 per cent. A special feature of the job is the port cores, which are very slender and surrounded by bulky metal; they require to be made from a special refractory in order that they may be removed without difficulty. The chief constituents of the refractory material are steel moulder's composition, blacking and plumbago, and loose low-

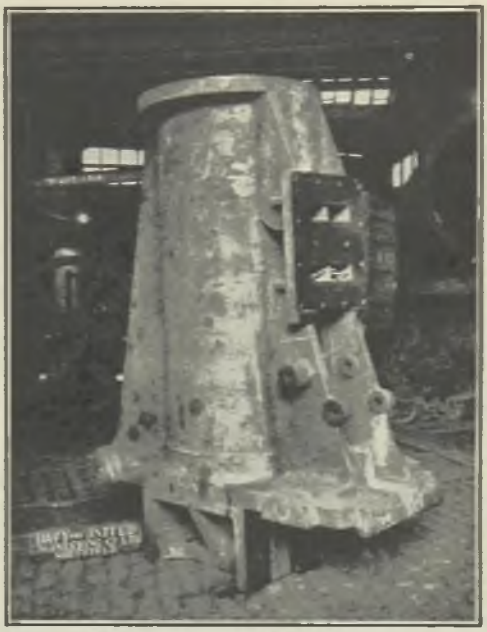


Fig. 24.—Steam-Hammer Cylinder.

carbon iron rods are used for reinforcing the cores, thus facilitating their removal.

In conclusion, the author would take the opportunity of thanking his directors, and particularly Mr. W. Reid, for their kind permission to publish this Paper.

DISCUSSION

Composition and Section

Mr. A. E. McRae Smith commented first on the composition of the metal used, and said it had occurred to him that in most cases the aggregate of total carbon content plus silicon was rather higher than he would have expected in cast irons used for castings of heavy section

in some cases apparently 7 in. and over. He wondered whether the figures, especially those for silicon, were average figures, or were minima or maxima.

A factor which appealed to him was that in most of the cases quoted the sulphur content was remarkably low, and he asked whether that result was achieved by the selection of low-sulphur raw materials or by any de-sulphurising process.

Brinell Hardness of Alloyed Cast Irons

Referring to two alloy cast irons mentioned in Mr. Roxburgh's Paper, in the sections dealing with rolling-mill castings and rollers for hot reel coilers, he had noted that in the iron which had attained a Brinell hardness number of 275 to 300, part of the chromium was replaced by molybdenum; that hardness was attained in the non-heat-treated castings. In the second iron, however, which was heat-treated, there was no molybdenum, according to the figures given. He asked if that were really so.

Further, he was rather doubtful that, in sections such as those referred to, one would be able to achieve regularly the high hardness figure of 300 Brinell. He knew that, with 1-in. or 2-in. sections in the composition mentioned, one might expect to attain a Brinell hardness of 260 to 280, but he did not wish it to be assumed, particularly by those who bought castings, that one could always achieve a minimum Brinell hardness of 300 with that composition.

Running Methods

Mr. A. J. Shore, dealing with Mr. Roxburgh's description of the casting of rollers, 1½-in. thick, for hot reel coilers, asked whether, if the rollers had been, say, 4 in. thick, Mr. Roxburgh would still have used the two rather small top runners of ⅞-in. diameter, with 12 in. of tapered head? Would he, in making what amounted to a cylinder on end, lean towards the small pencil type of runner, or would he use a much larger diameter runner, in casting a thick section cylinder? Presumably, the job was a dry sand job.

AUTHOR'S REPLY

Mr. Roxburgh, replying to Mr. McRae Smith, said that the practice at his works was always to time the running of the bigger jobs, and in that respect they were able to build up data which they had found to be very useful indeed.

Dealing with the question concerning the analysis of the metal used in some of the bigger castings, where the total carbon plus silicon figures seemed to be high, he said that the figures given were average figures. When dealing however with very large quantities of metal, of anything from 20 to 40 tons, although in his opinion it was perfectly right in theory to aim at very low carbons and silicons, yet in practice it created a lot of difficulties in the actual casting operations. Therefore, he had selected very carefully the materials used in the mixtures, in order to get a close-grained material; in some cases the carbon was from 2.92 to 3.2 per cent. in the final castings, and with the silicon at 1.1 or 1.2 per cent., the structures obtained, and the castings when machined, came out very well indeed.

As to the fairly low sulphur content of the irons, he said that in that connection again the selection of the materials was important, and in some of the refined irons he had used he had specified low sulphur content—0.03 to 0.04 per cent.—in order to allow for the pick-up in the cupola melting.

With regard to the alloy cast iron rollers which had attained a Brinell hardness of from 275 to 300, he said that in the main they were within those limits; some were 280, some 290 and some had Brinell hardness figures up to 300. The metal for the smaller rollers had a nickel content of 1.75, whereas in the larger rollers the nickel content was 2.5 to 3.5, and that was why the molybdenum was omitted in the latter.

Dealing with Mr. Shore's question as to the type of runners he would have adopted if the rollers had been 4-in. thick instead of 1½-in. thick, he said he would still run the castings from the top. Quite a number of castings of that nature, 4-in. thick, were made at his works, and he would simply increase the number of top gates, having 4 or 3 instead of 2, and he would keep them as small as possible. In the casting of all the special irons he had found that the head was a very important factor. One might find that for ordinary irons 1-ft. of head was quite sufficient, whereas for some of the special irons a head of 18-in. or 2-ft. might be necessary. So that, for the castings under consideration, if they were 4-in. thick, he might manage with a head of 12-in., because the section was fairly uniform, or, on the other hand, he might increase the head.

Paper No. 664

Position of the Development of Centrifugal Casting in Germany

By W. A. GEISLER (Member)

Historical

In Germany, centrifugal casting is, as elsewhere, still a recent art which only reached its present state of development after the Great War. No other branch of foundry practice, not even if moulding machines are included, has undergone in the last 20 years such an intensive and exhaustive treatment as centrifugal casting, which, unlike the work on the improvement of steel and cast iron—a province reserved rather for the scientists—has been primarily a matter for the practical man. The first experiments on centrifugal casting which were made in Germany date back to the middle of the last century, although not so far back as the experiments of the Englishmen, A. C. Eckhardt (1809) and A. Shanks (1849).

Up to the year 1894, there were nine German patents relating to centrifugal casting, but these are not all of German origin. A. C. Eckhardt's British patent of 1809 included all possible constructions regarding the spindle arrangement, and all the subsequent patents relate merely to constructional details or special purposes. A consideration of these early German patents shows that development often goes in circles with frequent repetition. Thus, in 1899,[1] G. Hoper took out a patent for a process of centrifugal casting for making slabs or billets to be worked up into wire or sheet. From time to time, this process is to be found again in later patents, but with slight modifications. To-day, the process is again being successfully applied to the manufacture of bronze wire. The process of G. Walz[2] of 1893 has also been repeated. In this process (Figs 1A and 1B), the tubular body is formed by first introducing the molten metal into the vertical or inclined mould, which is set in rotation before the metal is poured, so that a funnel-shaped depression is formed on the sur-

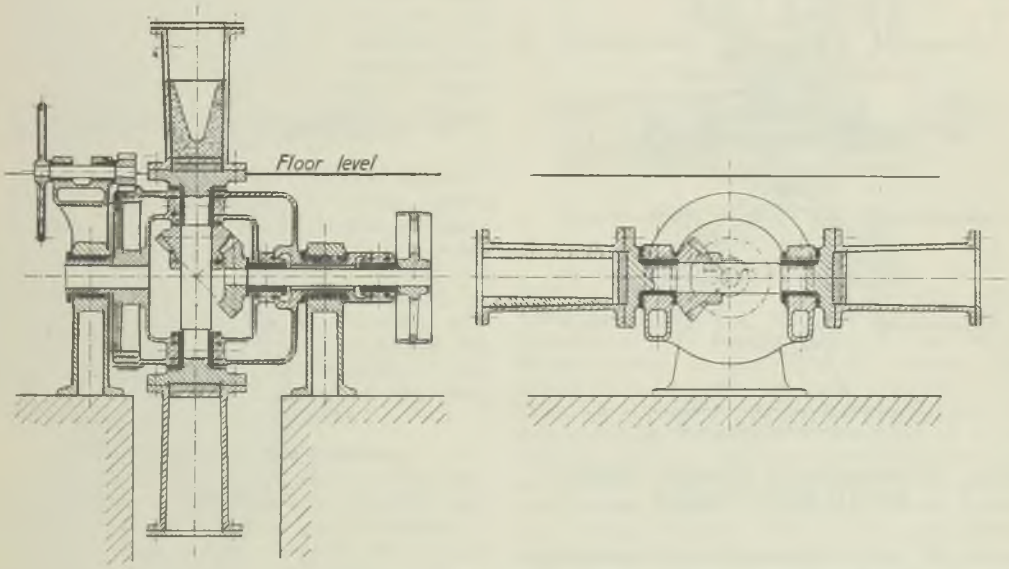


Fig. 1A.—Centrifugal Casting Process of Walz. German Patent 72,478.

face of the metal. The mould is then slowly brought into a horizontal position, the funnel-shaped depression extending deeper into the ingot until a tube or pipe has been formed, the wall thickness of which becomes more uniform with increasing horizontal position of the mould, until finally, when the position is quite horizontal, a perfectly cylindrical cavity is produced.

A process of the Vereinigte Stahlwerke A.-G., Düsseldorf,[3] is based on this idea, for in this process, also, preliminary centrifuging is effected with the mould vertical, final centrifuging being effected with the mould horizontal.

The machine patented by Hundt & Weber[4] for producing tubular bodies by centrifugal casting is also very reminiscent of the centrifugal casting machine patented 40 years previously, except that in the more recent machine, the two moulds can be disconnected independently from the common driving means.

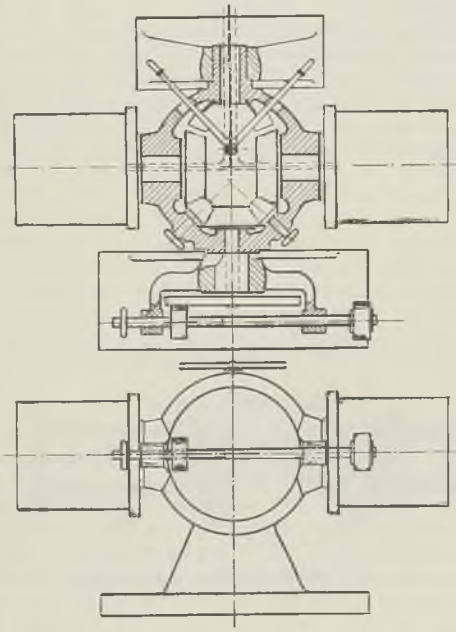


Fig. 1b.—Centrifugal Casting Machine. German Patent 589,350.

P. Huth,[5] in 1894, was the first to secure a patent for a process of centrifugal casting for producing compound castings. In the inventor's words,[6] the process is intended to provide certain machine parts, such as track wheels, rolls, gear-wheels and hard-nosed shells and so forth, with correspondingly hard and soft parts in one casting operation.

Fig. 2 shows examples of a track wheel and shell. In the case of the track wheel (Fig. 2a), the harder metal forming the circumference is poured in while the mould is being suitably rotated. The softer metal poured in afterwards forms the underneath part of the tyre, the spokes or disc and the hub.

In the case of the shell (Fig. 2b) the harder metal is poured in while the vertical mould is rotating. In this case, a surface having a paraboloid concavity is formed, on which suitable metal for the remainder of the shell is cast.

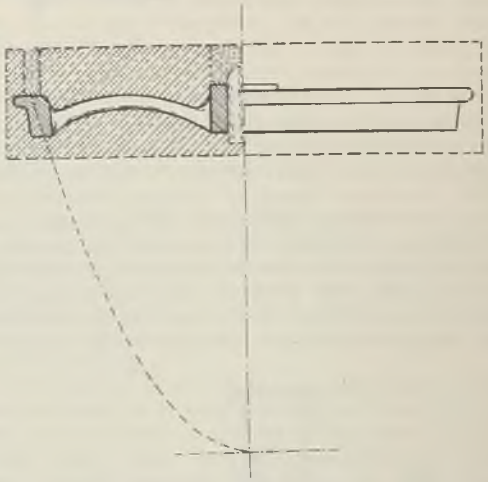


Fig. 2a.—Track Wheel. German Patent 78,532.

Fig. 2b.—Shell. German Patent 78,532.

In a later publication,[7] the inventor shows the intimate union between the two metals, and considers his process to be suitable, *inter alia*, also for the production of crusher rings, armour plating having a hard surface of any desired

depth on one side, guide rolls, cutting tools, roll collars and so forth. Now, 45 years after the grant of Huth's patent, this sphere of work is again being given special attention and detailed treatment.

In a Paper read in 1898 in Dresden, E. Lewicki[8] stated that although centrifugal casting had been in the course of development for half a century, it had not left the experimental stage. He referred to P. Huth's patent[5] of May 10, 1894, and believed that this process would provide really useful results. Even though this hope, like those of many inventors in this field, was not realised, the general principles as set forth by Lewicki showed that the theory of vertical and horizontal centrifugal casting processes had already been thoroughly mastered. The fact that centrifugal casting has become established only in the last twenty years is based on technical and economic grounds. In the early years, the problem of the means for driving the rapidly rotating moulds was by no means simple, and only the introduction of the electric motor enabled it to be solved satisfactorily. Thus, C. Irresberger[9] writes that the early machines failed on account of the cost of rotation. The purchase of expensive centrifugal casting machines can only be economical when they are employed for mass-production. In the development years the strongest motive for any technical development was lacking, namely, the demand.

Centrifugal Casting of Iron and Iron Alloys

Although large quantities of bushes, gear-wheels, rings, brake-drums and the like are made to-day by the centrifugal casting process, some years ago the object of centrifugal casting was mainly for casting long pipes. As a matter of fact, the ever-increasing demand for water and gas pipes stimulated endeavours to simplify the process of manufacture, especially since it was possible to eliminate the making of the core, pouring gates, runners and ingates.

The Briede-de Lavaud Process

The development of the processes for the centrifugal casting of long pipes has already been dealt with in a large number of publications.[10] In the early years, these processes were faced with almost insurmountable difficulties, such as the problem of the means for driving the rapidly rotating moulds and the material for the dies. In the early stages, an Englishman, Whitley,[11] was probably the most successful. His tilting spout, which he introduced in collaboration with S. Fox[12] in 1881 formed the basis for the subsequent successful application of the process by de Lavaud since 1912. After lengthy experiments in Brazil, de Lavaud succeeded in establishing the centrifugal casting of pipes on a large scale in America during the World War. Whitley's tilting spout, which was at first also used by de Lavaud in America and by others, had, however, disadvantages. It is not sufficiently well known that the pioneer invention which first set the centrifugal casting process for pipes properly on its feet should be ascribed to the German, Otto Briede,[13] namely, the introduction of the moving spout in 1910 (Fig. 3). At the commencement of the operation, the pouring spout *b* is introduced into the rotating mould *a*, so that its outlet end reaches close up to the socket part. Metal is then allowed to flow through the spout from the ladle *c* of measured contents arranged at the opposite end of the spout, the stopper of the ladle being lifted for this purpose. As soon as the socket part is filled with metal, the spout is withdrawn from the mould at a certain speed in the direction of the arrow. As a result of the two movements, rotation of the mould and backward movement of the spout, the stream of metal issuing from the outlet end of the spout is applied helically to the inner surface of the mould. Briede effected his invention in a purely theoretical manner, and not until after the Great War, after lengthy and costly experiments, was the invention embodied in the form of a serviceable machine. Briede himself, however, was not to live to see the conversion of his process into modern foundry production. As de Lavaud also utilised Briede's idea of the longitudinal movement of mould and feed device, the process is known in Germany as the Briede-de Lavaud process.

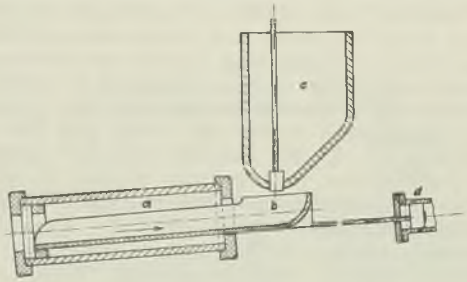


Fig. 3.—Otto Briede's Process. German Patent 242,307.

Process of the Vereinigte Stahlwerke and Buderus

In Germany, cast-iron pipes are made by the Briede-de Lavaud process, that is to say in water-cooled moulds, in two large plants, in the Vereinigte Stahlwerke at Gelsenkirchen and at Buderus, Wetzlar. The stress on the steel moulds caused by the heat and oxidation of the surface is considerable. Originally, nickel-

chromium steel was employed for the mould, but later this was replaced by chromium-molybdenum steel, the surface of which was found to be much more resistant. Steel moulds for making pipes and other tubular bodies by the centrifugal casting process are subjected to considerable strain on account of thermal stresses. When the castings are being taken out of the moulds, grooves and fine notches are formed on the inner surface of the moulds. These grooves and notches promote the formation of cracks and fissures at the high thermal stresses and hence reduce the life of the moulds. In a process patented by Fried. Krupp A.-G.[14], the formation of thermal stress cracks on centrifugal casting moulds is reduced by subjecting the inner surface of the moulds to treatment by nitriding.

Making Grey-Iron Pipes in Water-Cooled Moulds

Cast-iron pipes made in water-cooled moulds have to be subjected to a heat-treatment with the object of eliminating stresses and removing hard outer zones. This treatment is effected immediately after withdrawal from the mould, the temperature of the pipe being still 700 to 750 deg. C. In the last few years a number of patents have been granted relating to processes for producing unchilled castings in water-cooled centrifugal casting moulds. The considerable number of these patents leads one to believe, however, that this problem has not yet been solved completely.

For producing soft pipes, the moulds were at first lined with powdered graphite, aluminium, ferro-silicon, ferro-phosphorus, zinc dust or powdered facings made from similar metal alloys. These linings, however, had the disadvantage that when the molten metal was poured into the mould, the metal slid on them and was not carried round by the rotating mould. Once such slipping occurs, the molten metal is inadequately accelerated in the direction of rotation; it does not therefore rotate at the same speed as the mould and the pipes produced are defective. By employing lining materials of different degrees of fineness,[15] it is said that the tendency for the molten metal to slip on the surface of the lining is reduced. The Deutsche Eisenwerke[16] proposed to secure a reduction in the flow of heat, that is to say, effect a longer rate of cooling and hence avoidance of hard outer zones, by the fact that the lining layer is not applied directly to the inner surface of the mould, but is spaced away slightly from the latter, for example by means of a wire gauze or the like applied to the surface of the mould. According to another process of the same firm,[17] for producing centrifugally cast pipes having a soft outer skin in chill moulds, the lining material which is to retard the flow of heat and is to be applied in liquid form to the inner surface of the mould, is made of substances, mixtures of substances and alloys which, when the molten cast iron impinges on them, are completely absorbed by the outer layer of the pipe in course of formation, have a graphitising effect on the centrifugally cast iron and impede the flow of heat. In this case also, the liquid lining material may be applied to a support covering the inner surface of the mould and maintaining the lining layer at such a distance from the inner surface of the mould that the flow of heat from the solidifying lining layer and from the centrifugally-cast iron is diminished. According to another process,[18] in order to produce unchilled castings in cooled centrifugal casting moulds, the portion of the inner surface of the mould to which the molten metal is applied is subjected to local limited heating in such a manner as to prevent or at least considerably diminish the formation of hard outer layers. This process has been extended by the fact that the local, limited heating of the mould is produced by the radiation of an electrically-heated resistance.[19]

An apparatus has been patented for lining centrifugal casting moulds.[20] A spout or trough combined with the pouring spout is provided for feeding the lining materials, the latter being moved forward in the trough by swinging, shaking or rotary movements of the trough. A process[21] recently disclosed for making centrifugally cast pipes with a soft outer skin in moulds, employs crushed slag in powder or granular form. Cupola or blast-furnace slag is said to be eminently suitable. On account of its weight being less than that of the material of the pipe, the powdered slag passes into the outermost surface of the pipe in course of formation, and produces there a rough, slightly porous surface, to which subsequent coatings of paint adhere most intimately, and which forms an excellent corrosion-resistant outer layer, according to the composition of the slag. In addition to the manufacture of cast-iron pipes, the invention is said to be advantageously applicable to the production of centrifugally cast tubular members of steel or other metals.

Halbergerhütte Process

The necessity to anneal the pipes is obviated altogether in the centrifugal casting process employing sand moulds. In Germany, the Halbergerhütte[22] of Brebach a.d. Saar are employing this process. Briefly, the operation is as follows:—

Circular mould boxes with evenly distributed axial and radial vents and fully balanced masses are placed in a vertical position and mounted on rotary seats. After insertion of an iron pat-

tern corresponding to the external diameter of the pipe, an automatic, accurately regulated sand-feeding device is started, and the sand running in is rammed by long-shafted rammers. After ramming, the moulds are blacked with graphite, set horizontal by tilting tables, and taken away on roller conveyors to be dried, which is effected by means of hot gases. After the insertion of the socket core at the socket end, the mould is ready for the casting machine. For ensuring uniform wall formation of the

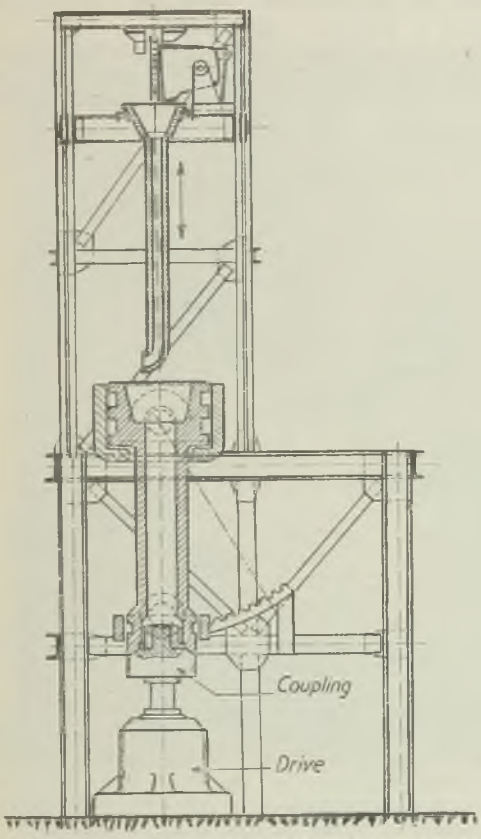


Fig. 4.—Billand's Process.

pipe, the mould boxes have to be rotated with absolute uniformity. Casting is carried out as follows:—

The mould boxes coming from the drying plant are set down by means of a jib crane by the side of the casting machine, and after removal of the cover of the machine are placed in the latter. The necessary weight of molten iron is poured into a tilting ladle and the mould box is set in preliminary slow rotation. The tilting ladle is then tipped so as to discharge its contents into the rotating mould, the iron being evenly distributed over the entire length of the bottom of the mould. Rapid rotation of the mould immediately commences, the molten iron under the action of the centrifugal force being projected against the rammed sand wall and being applied with absolute uniformity against the cylindrical surface. The rapid rotary motion is continued until the iron is solidified. After lifting off the cover of the casting machine, the mould is taken out and is laid on a roller conveyor by means of the jib crane. As in the earlier casting process, the cast pipe can now cool slowly in the sand mould. The result of this gradual cooling is that the iron of the finished pipe remains soft and therefore does not require any subsequent heat-treatment.

Ardelt Process

The combined ramming and centrifugal casting process known as the "Ardelt" system[23] likewise employs sand moulds for making long pipes.

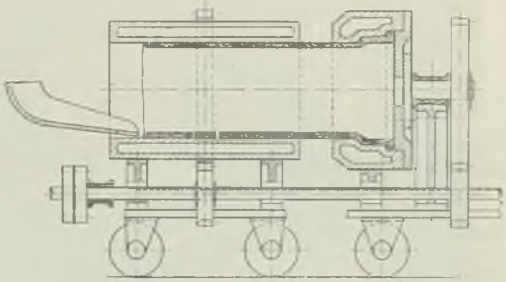


Fig. 5.—Process for Manufacture of Pipes of Any Desired Length. German Patent 417,227.

Billand Process

In Germany, attempts have also been made to effect the centrifugal casting of socket pipes in the vertical position. The principle of the Billand process will be immediately gathered from Fig. 4.[24] The molten iron is introduced into a vertical mould through a movable pouring pipe which is moved upward in the mould during casting. At the commencement of pouring, the socket core is placed on the fully retracted coupling and the tilting ladle is then filled with iron. The coupling is then moved upward by switching on the motor and when the coupling has engaged the mould, the latter commences to rotate. The ladle is then tilted. The pouring tube remains stationary until the socket has been completely filled, whereupon the pouring spout is moved upward in a uniform manner, the pipe being formed by the centrifugal action exactly as in the Briede-de Lavaud process. The

excess of iron is then taken up by the feeder head. For removing the pipe from the mould, the latter is set at an inclination. The difference from the earlier centrifugal process in a vertical mould is that the iron is no longer obliged to ascend the walls of the mould by the action of the centrifugal force but is introduced spirally by the pouring spout.

Process for Making Pipes of Any Desired Length

The Arensröhren A.-G. in 1924 patented a process for producing pipes of any desired length by centrifugal casting.[25] According to the invention, for making pipes of any desired length, the molten metal is fed from a stationary casting device. The metal flows directly into the mould and is continuously removed in the form of a pipe from the other end of the mould (Fig. 5.) It is stated that by this means a substantially simpler construction of the machine is possible, and that the feeding of the metal can be continuously supervised and consequently made uniform. As far as the writer is aware, however, the last two processes have not yet acquired any particular industrial significance.

Liners

After the casting of long pipes from cast iron, the centrifugal casting process has acquired considerable importance in Germany for the production of cylinder liners of internal-combustion engines, compressors and pumps. Such liners are relatively short parts, rarely longer than 50 cm. (20 ins.), which, unlike the socket pipes referred to above, have to be not only compact but also extremely resistant to wear. Although some firms prefer to cast centrifugally in sand moulds in order to secure the desired structure, by far the greater number of centrifugally-cast liners are cast in iron moulds. The well-known Hurst-Stokes process is employed, a process which, originating in England, has become established not only in Germany but also in Italy and France. The moulds are air-cooled and in order to ensure a sufficiently slow rate of cooling for the formation of a fine grey structure, the moulds are maintained at suitably elevated temperatures. Soft annealing of these liners is therefore unnecessary.

Apart from constructional details, the Hurst-Stokes process,[26] [27] which has already been frequently described, has not undergone any further development, but progress has been made more in the metallurgical field.[28] Table I gives the mechanical properties of the alloys most frequently employed in Germany for liners, and Fig. 6 shows a portion of the centrifugal casting foundry of Fried. Krupp A.-G., of Essen.

TABLE I.—*Properties of Various Centrifugally Cast Alloys.*[28]

Material.	Strength according to British ring test (B.S.I.).			Strength of tensile stress specimens made from the liners.		
	Ring strength,* $\frac{1.87\ P.D}{b\ .\ d^2}$. Tons per sq. in.	Permanent deformation. Per cent.	Modulus of elasticity. Tons per sq. in.	Tensile strength. Tons per sq. in.	Modulus of elasticity (range of stress, 2–14). Tons per sq. in.	Brinell hardness in the bore. Kg. per sq. mm.
Unalloyed centrifugal casting	21.0	7.5	7,260	17.1	7,300	240–285
Alloyed centrifugal casting (1 per cent. Mo, 0.4 per cent. Cr)	22.2	6.5	8,255	19.0	7,937	260–300
Hardened, unalloyed centrifugal casting	21.6	4.0	7,620	16.5–19.0	7,620	350–500
Nitrided casting	25.4	2.0	10,795	26.0	10,950	280–320 (Surface 700–900 Vickers).

* P = Force in kilograms, D = External diameter of ring, b = Width of ring, d = Thickness of ring, 1.87 = Conversion factor.

Valve Seats

A large number of bushes for valve seats are also being made by the centrifugal casting process. Casting alloys having a high content of chromium or molybdenum are generally employed. In some alloys, the chromium content attains 28 per cent., and the molybdenum content a maximum of 5 per cent. On account of the coefficient of expansion, that is to say for insertion in light-metal cylinders, Fried. Krupp A.-G. have developed an austenitic alloy with only 5 per cent. nickel and without added copper. This alloy has been found to be very efficient.

Brake-Drums

The centrifugal casting process has found an interesting development in Germany in the manufacture of brake-drums[29] for motor vehicles. The outstanding suitability of cast-iron brake-drums in respect of rigidity and wear is sufficiently well known. Cast drums, however, have the great disadvantage that if sufficient strength is to be attained, they must be made considerably heavier than sheet-steel drums of the same size. Certain types of brake-drums* combine the advantages of sheet steel with those of cast iron. Substantially, the drum comprises two parts, the sheet steel back, the flange of which is provided with dove-tail recesses for facilitating intimate welding and for increasing the security, and also a centrifugally cast-on iron rim. The union between the cast iron and steel is definitely intimate; fusion welding taking place as has been previously shown,† the carbon of the cast iron penetrates to a considerable depth into the steel. It is noteworthy that this welding occurs without pre-heating of the sheet steel, the necessary heating of the latter being ensured by the stream of hot cast iron. This stream is directed so as to sweep continuously the edge of the rotating sheet metal back.

Composite Castings

As stated at the commencement of this Paper, P. Huth[5] as long ago as 1894 took out a patent for a "centrifugal casting process for casting together two different metals, metal alloys, or a metal of different hardnesses, in which a separate deposition of the metals in the mould is effected by rotating the latter." In a publication made in 1897,[7] illustrations of fractured pieces show the intimate union of the different metals attained at that time.

In 1928, W. Raym[80] obtained a patent for a process of producing solid ingots made of two or more kinds of metal. According to the invention, the centrifugal casting mould is mounted for tilting about a pivot, so that pouring can be effected at first with the rotating shaft horizontal and later with the rotating shaft vertical (Fig. 7). The process is carried out by first pouring the metal forming the shell

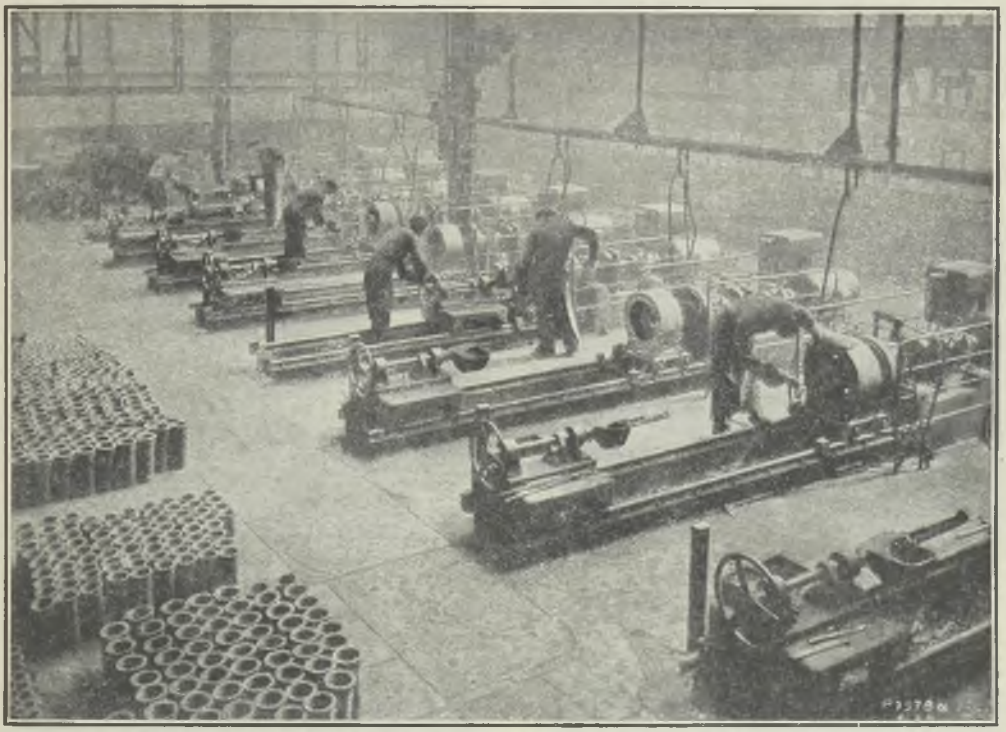


Fig. 6.—Portion of the Centrifugal Casting Foundry of Fried. Krupp A.-G., Essen.

* See illustration on page 307, Proc. Inst. Brit. F., 1934–5.
† See illustration on page 306, *loc. cit.*

into the horizontal rotating mould and then erecting the entire mould so that its shaft is now vertical. The material forming the core is then poured in, while the mould continues to be rotated, the rotary motion being gradually retarded until it finally ceases, in order to ensure a compact structure of the core.

The firm of Hundt & Weber[31] in 1932 worked out a process for making tubular bodies consisting of one or more metals, or solid bodies, more especially solid rolls, consisting of different sorts of metal, in centrifugal casting moulds rotating about the vertical axis. When employing two different materials in a roll, the outer shell (Fig. 8) is first cast centrifugally in a specially

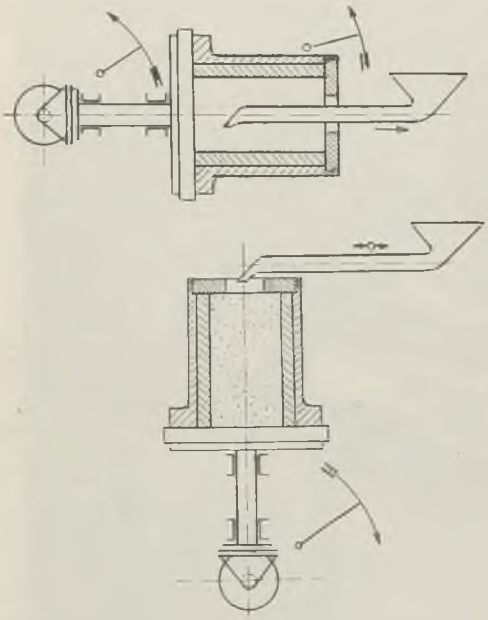


Fig. 7.—Process for Manufacture of Articles from Two or More Kinds of Metal by Centrifugal Casting. German Patent 459,965.

suitable composition, the shell being cast in any thickness according to the quantity poured into the mould. The machine continues to rotate in the same position. By means of a second pouring ladle, held in readiness, the inner core of softer material is poured in and centrifuged at the instant the inner surface of the shell previously cast and already solidified on its outer surface is still so liquid or pasty as to ensure a perfectly homogeneous union between the hard outer shell and the soft inner core.

To eliminate the disadvantage of the inner part of the tubular body first cast having a surface of a paraboloid of revolution, according to the invention, by a special method of regulating the speed in accordance with the dimensions of the centrifugal casting mould, and taking into consideration the properties of the kind of metal cast, a practically rectilinear boundary of the inner wall is ensured, and as desired this wall may be "cylindrical" or even conical. This problem is solved by pouring the metal of the shell at the maximum speed of rotation, which is determined by calculation, and thereupon, taking into account the rate of solidification and the other physical properties of the cast metal which enter into consideration, the speed is re-

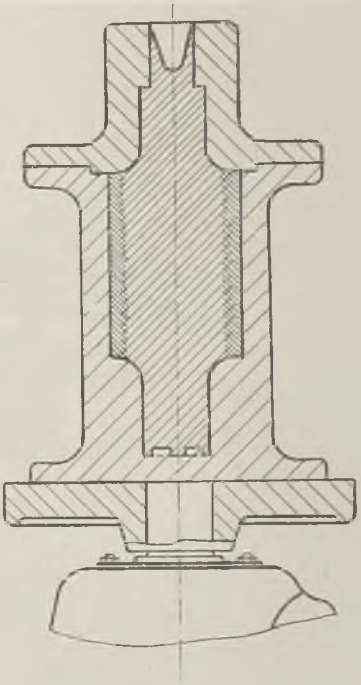


Fig. 8.—Centrifugal Casting Process. German Patent 603,243.

duced by a certain amount. For example, in the case of a roll of 600 mm. diameter and a length of body of 1,000 mm., a speed of 800 r.p.m. would be necessary. Upon pouring the core, the speed is reduced in proportion, and in this case is brought to a final speed of 200 r.p.m.

By means of this process, it is possible to cast centrifugally either chill rolls or steel rolls, or, of course, rolls made of non-ferrous metals, of one or more different materials. In the case of the first-mentioned, the outer shell preferably has the hardest possible composition, while in the case of the next-mentioned (steel rolls) it preferably consists of chromium-nickel steel, while the inner core, as a safeguard against the

Fig. 9a.—Sand Casting. × 100.

Fig. 9b.—Centrifugal Casting. × 100.

60/40 Brass.

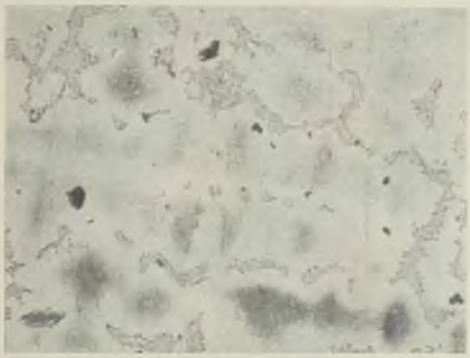


Fig. 10a.—Sand Casting. × 100.

Fig. 10b.—Centrifugal Casting. × 100.

86/10/4 Red Brass.

Fig. 11a.—Sand Casting. × 100

Fig. 11b.—Centrifugal Casting. × 100.

90/10 Aluminium Bronze.

danger of fracture, in the case of chill rolls consists of a softer grey iron, or better still cast steel, and in the case of steel rolls, the core consists of a soft tough cast steel.

Centrifugal Casting of Non-Ferrous Metals

The successful introduction of the centrifugal casting process in the case of cast-iron pipes also led non-ferrous foundries to make exhaustive experiments with this process. It was very soon found that quite considerable improvements in quality were possible, as compared with sand casting. These improvements are all due to the exceptional refinement of structure which the material undergoes through the twofold effect of the centrifugal force and the rapid, uniform cooling (Figs. 9, 10 and 11). This refinement of structure, in the first place, results in a considerable increase in the tensile strength and hardness.

Table II gives a summary of the physical properties of various red brass and bronze alloys, the mean values and the minimum values for centrifugally cast alloys being compared with the DIN (German Industrial Standard) values for sand cast alloys. In order to secure the best possible mechanical properties in the case of non-ferrous metals, usually cold or slightly preheated or even water-cooled metal moulds are employed. The rapid cooling in the centrifugal mould has a substantial influence on the attainment of a fine-grained and compact structure which is consequently resistant to corrosion and wear.

In the case of non-ferrous metals, centrifugal casting in sand moulds results in a much coarser grain and hence a deterioration in the physical properties. In the centrifugal casting of non-ferrous metals, maintenance of the correct speed is of great importance. If the mould is rotating too slowly, the inner surface of hollow cylinders is very rough and the entire cross-section of the casting is often permeated by blow-holes. At the optimum speed, however, the inner surface is smooth and less machining is subsequently required.

In the case of alloys having components of a widely different character, as soon as the molten material has assumed the speed of the mould, the specifically heavier components are forced outwardly against the wall of the mould on account of their greater centrifugal force, and thus the specifically lighter components are situated more in the inner parts. Such liquation becomes more pronounced, the greater the solidification range of an alloy, the more dissimilar are its components, the lower the rate of cooling, the greater the centrifugal pressure and the thicker the wall of the castings. By regulating these working conditions, *i.e.*, therefore by maintaining suitable speeds of the moulds, a suitable pouring temperature, regulating the cooling and so forth, however, liquation can in most cases be kept within such limits that it does not cause any trouble.

TABLE II.—*Properties of Various Non-ferrous Metals Centrifugally Cast compared with Standard Specification Requirements for Sand Castings.*[35]

Material according to D.I.N. 1705.	Centrifugal casting.						D.I.N. requirements for sand castings.		
	Mean values.			Minimum values.					
	Tensile strength. Tons per sq. in.	Elongation. Per cent.	Brinell hardness. Kg. per sq. mm.	Tensile strength. Tons per sq. in.	Elongation. Per cent.	Brinell hardness. Kg. per sq. mm.	Tensile strength. Tons per sq. in.	Elongation. Per cent.	Brinell hardness. Kg. per sq. mm.
Rg 5 ..	16.5	13	80	15.9	12	75	10.5	10	60
Rg 9 ..	17.1	9	90	15.9	7	85	12.7	12	60
Rg 10 ..	19.0	9	95	17.1	8	90	12.7	10	65
GBz 10 ..	19.6	12	90	17.8	8	80	12.7	15	60
GBz 14 ..	20.3	3	115	17.8	2	105	12.7	3	90
GBz 20 ..	21.6	0	220	19.0	0	190	10.5	0	180
BlBz 10 ..	19.0	12	80	17.8	8	75	11.4	15	70

NON-FERROUS PIPES

Osnabrücker Kupfer- und Drahtwerk Process

In Germany, pipes of considerable size are made of non-ferrous metals. The works application of the centrifugal casting process for the manufacture of non-ferrous pipes was first carried out in Germany in 1926/27 by the Cologne firm of Ostermann & Flüs. The chief reason for this was the severer demands made on the mechanical properties of non-ferrous metal alloys in connection with the increased section thickness.[32] The centrifugal process employed was very simple. The mould was mounted horizontally and there was no movement between the pouring spout and mould during the casting operation. The process was later taken over and developed by the Osnabrücker Kupfer- und Drahtwerk.

In Osnabrück, at first only alloys of special brasses were cast centrifugally. These were brass alloys containing 54 to 62 per cent. copper, and sometimes more. In addition to zinc, such alloys also contain mainly nickel, manganese, aluminium and iron, which together may amount to about 7 per cent. The mechanical properties attained with this alloy by centrifugal casting clearly showed the fundamental superiority of this process over sand casting. Table III shows an increase in tensile strength of about 20 per cent., and an increase in elongation of about 25 to 50 per cent., as compared with normal sand casting. In addition to this increase in the tensile strength, the perfect homogeneity and freedom from porosity are of particular and even greater importance.

Subsequent development of the centrifugal casting process was effected by the same firm in connection with red brass and bronze alloys. Centrifugal castings of these alloys exhibited over the greater part of their periphery crater-like cavities rendering the pipes useless. The cause of this phenomenon was quite apparent to the foundryman, as it was well known that "splashing" of the walls of the mould in ordinary metal mould casting resulted in similar phenomena caused by evolution of gas on solidification.

Of the various possible methods of avoiding these defects, two were mainly found to be feasible after lengthy experiments. In the first place, contact of the metal with the material of the mould could be prevented by a lining of sand, as employed in America. This, however, would result in a deterioration of the physical properties on account of the changed conditions of solidification. The second method finally adopted consisted in selecting the material of the mould in such a manner that the dangerous absorption of gas upon the entry of the metal, *i.e.*, upon splashing, did not occur. Such a mould material was found in copper and various copper alloys.

For economic reasons, however, it was out of the question to make the moulds of solid copper or copper alloys, since all dimensions up to 1,500 mm. diameter and 10 metres in length occur. An appropriate solution to the problem was found by lining the actual cast-iron mould with relatively thin copper sheets of 1 to 3 mm. in thickness.[33] For this purpose, the copper sheets are bent approximately to the requisite diameter and pushed into the mould. Close application of the copper sheets to the wall of the mould is effected automatically by means of the centrifugal force as soon as the mould has been brought to the high speed usual for centrifugal casting. In this way, it is possible to cast centrifugally all the metal alloys used to-day for various purposes, such as bronze, red brass, nickel-copper, Monel metal, etc., in a satisfactory manner, quite free from porosity, because all contact of the molten metal with the cast-iron or steel mould is avoided.

Figs. 12 and 13 show some of the centrifugally-cast pipes made by the Osnabrücker Kupferwerk. The finished castings weigh up to 6 tons, and for such castings melts of about 10 tons, that is to say, considerable weights, are centrifugally cast. From the point of view of size, the centrifugal castings of the Osnabrücker Kupferwerk are not surpassed in any country. The pipes shown in Fig. 12 are 10,050 mm. long with an external diameter of 500 mm. and a wall thickness of 25 mm. The centrifugal casting with cast-on flange shown in Fig. 13 has a length of 3,620 mm., an external diameter of 1,500 mm. and an internal diameter of 1,460 mm.

TABLE III.—*Showing the Superior Properties of Centrifugally Cast Brass.*[32]

Special brass no.		I.	II.	III.
Tensile strength. Tons per sq. in...	Centrifugal casting ..	24.0	31.1	45.9
	Sand casting	20.3	25.6	39.0
Elongation. Per cent.	Centrifugal casting ..	40.2	29.0	13.3
	Sand casting	33.3	22.0	8.5
Brinell hardness	Centrifugal casting ..	105.0	138.0	175.0
	Sand casting	91.0	115.0	150.0

In the centrifugal casting of such tubular bodies, there is formed on the inner surface of the material a fissured and strongly oxidised zone which, even though relatively thin, has generally to be removed mechanically before the pipe can be used or treated further. The following is the explanation of the formation of this inner zone:—

When the molten metal is poured into the mould, the air present in the mould is strongly heated, so that it escapes at a considerable velocity, while cold air continuously flows in, cooling the metal from the interior. The metal solidified on the inner surface cannot, of course, participate wholly in the reduction in volume which occurs upon the complete cooling of the casting. The consequence is that the metal cracks. The entrance of cooler air naturally exercises a strong oxidising action on the material, particularly at the fissured places.

The new small fissures which are continually being formed are immediately oxidised.

The Osnabrücker Kupferwerk eliminates these harmful effects[34] by providing a curtain of hot gas in front of the aperture of the mould. This curtain of hot gas prevents the escape of hot air from the mould and corresponding entrance of cold air into the mould, and displaces all the oxygen of the air, so that, even if gases are drawn into the mould, only neutral or reducing gases come into contact with the metal, and on account of their high temperature, these gases do not produce any undesirable chilling. The pipes produced in this way have a perfectly smooth, metallically clean inner surface without appreciable oxidation.

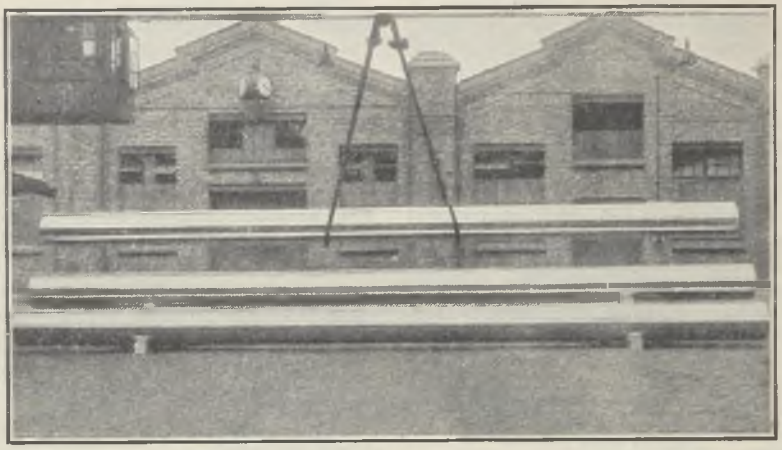


Fig. 12.—Centrifugally-Cast Pipes by the Osnabrücker Kupferwerk, 10,050 mm. Long, and 25 mm. Wall Thickness.

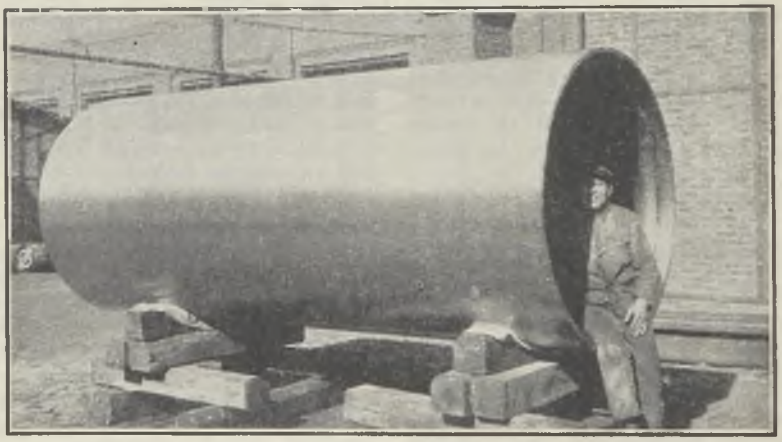


Fig. 13.—Centrifugal Casting with Cast-on Flange (Osnabrücker Kupferwerk), 3,620 mm. Long, and 1,500 mm. External Diameter.

The Schwietzke Process

The firm of I.G. Schwietzke, of Düsseldorf, adopted the manufacture of centrifugal castings early in 1930,[35] the Briede-de Lavaud system being employed. For ensuring uniformly good properties in the centrifugally-cast products, it is considered that uniform cooling conditions are essential, and intensely water-cooled moulds are therefore employed. The casting process

corresponds to the casting of sewer pipes. The casting machine is movable by means of a mechanical contrivance. The quantity of metal corresponding exactly to the weight of the pipe to be cast is run into the tilting ladle and from the latter it is poured through the pouring spout into the mould. At the instant the issuing metal comes into contact with the wall of the mould, the machine carrying the mould is set in movement. The stream of metal is now applied helically to the mould, being pressed uniformly against the inner surface of the latter by the centrifugal force and thus forming the pipe. Apparently, the helical application of the metal eliminates the above-mentioned difficulties connected with "splashing."

The provisional manufacturing installations of I.G. Schwietzke permit the production of pipes having external diameters of 50 to 160 mm. with internal diameters of at least 30 to 50 mm. in lengths of 1 to 1.25 metres, and pipes with external diameters 150 to 270 mm. and wall thicknesses up to 60 mm. in lengths of 3 metres. Special machines are actually provided for the centrifugal casting of worm wheels and spur wheels. In these machines, rings of up to 540 mm. external diameter and heights of up to 200 mm. can be made. The following materials are being cast successfully by the centrifugal process:—Copper, bronze, red brass, brass, special brass, nickel bronze, aluminium bronze, Monel metal, Silumin and other alloys.

In addition to tensile strength, hardness, elongation, soundness and uniformity, resistance to wear and the bearing and running properties of a material are of considerable importance in many fields of application. Centrifugal castings made in cooled moulds possess these properties to such a degree that this process must be considered as being of revolutionary significance in connection with the production of plain bearings. Wear tests carried out in the Kaiser-Wilhelm Institute in Düsseldorf showed that centrifugally cast red brass 5 has approximately three times the resistance to wear of sand-cast red brass 5.

Vertical Centrifugal Casting

(*For rings, plates, double-walled tubular bodies, etc.*)

The firm of Hundt & Weber, of Geisweid, have made a speciality of centrifugal casting with a vertical axis of rotation and have developed their own centrifugal machines for vertical casting.[4, 36] In centrifugal casting with vertical axis of rotation, the molten metal is poured directly into the rotating mould. It then ascends, being driven up by the centrifugal force. A uniformly thick pipe, however, is not formed, but the wall thickness diminishes upwardly in the form of a parabola. The inner shape of the casting is therefore formed by a paraboloid of revolution. This is steeper, the higher the peripheral speed. Calculations of the speed necessary for vertical centrifugal casting moulds were given as long ago as 1898 by E. Lewicki, as mentioned earlier in this Paper.[5]

In vertical centrifugal casting, gravity acts against the ascent of the metal, and as compared with horizontal centrifugal casting, a higher centrifugal pressure and hence also a higher speed are necessary. Vertical centrifugal casting is therefore generally employed for castings of small height relatively to their diameter, for instance the rims of worm-wheels, spur wheels and bevel wheels.

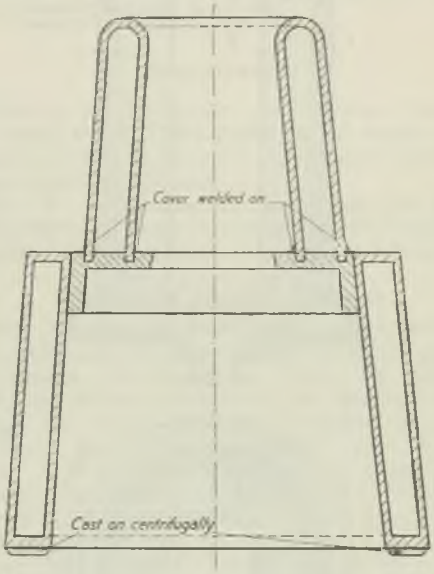


Fig. 14.—Centrifugally-Cast Tuyere, by Hundt & Weber, Geisweid.

An excellent application of vertical centrifugal casting is the process developed by the firm of Hundt & Weber for the production of double-walled tubular bodies,[37] more particularly blast-furnace tuyeres (Fig. 14). These are conical tubular bodies with double, closed side walls, through which cooling water is passed when in use for protecting the tuyeres against the attack of the hot blast-furnace gases. Formerly, these highly-stressed elements were made by forging from electrolytic copper. Production is much quicker to-day in heights of up to 1,000 mm. and individual weights of up to 300 kilograms. In addition, it is stated that the mechanical properties attained in centrifugal casting are substantially better than those attained by forging.

In recent years, an extraordinarily large number of patents have been granted for centrifugal casting, and to discuss them would be to go far beyond the scope of this Paper. Reference may be made, however, to a further process of the firm of Hundt & Weber[38] for the production of hollow cylinders having internal and external flanges, as well as bodies of any shape by centrifugal casting. The process, which, of course, also concerns the centrifugal casting of iron and steel, although up to the present it has only

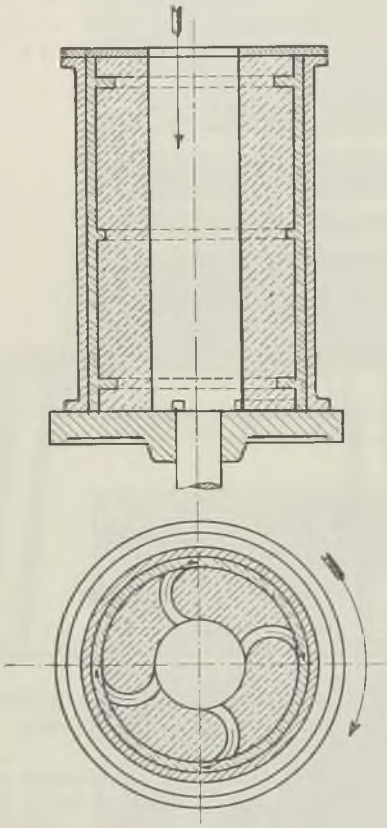


Fig. 15.—Process for Manufacture of Hollow Cylinders with Inner Flanges. German Patent 578,928.

been used for casting non-ferrous metals, in the production of hollow cylinders having internal flanges, employs a core for forming the inner surface of the casting (Fig. 15).

This method of centrifugal casting, as well as centrifugal casting in mould boxes, where the inner surfaces of the castings are not formed by centrifugal force alone and the speeds employed are low, cannot be regarded as true centrifugal casting. Cooling of the castings progressively from the outside to the interior only occurs in the case of true centrifugal casting. In the case of profiled centrifugal castings, where cooling must occur in different directions, the resulting shrinkage, cavity formation and porosity make their appearance. The real purpose of centrifugal casting, namely, the absolute guarantee of soundness and freedom from cavities is, however, not attained in profiled centrifugal casting. The centrifugal casting of billets or bars (Fig. 16) in sand moulds with central pouring gate may produce good, sound castings, but this can also be done in simple metal moulds which also ensure a better yield. If complicated moulds with cores are used, it is to be expected that both the mould and also the cores will be damaged and the consequence will be much waste.

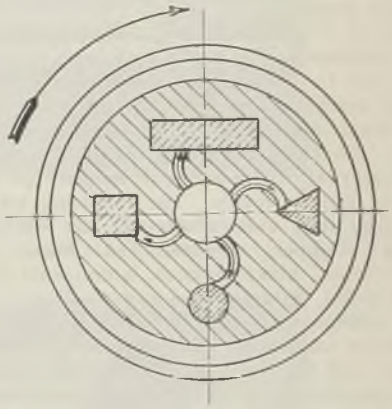


Fig. 16.—Centrifugal Casting of Billets or Bars, according to German Patent 578,928.

The production of blanks in the form of plates or rings of non-ferrous metals by centrifugal casting is a considerable field of application for this process. For example, metal wire plates are made in dimensions of about 450 mm. diameter and 20 to 40 mm. thickness (G. Schmadt & Company, Letmathe). The metal is poured slowly into the mould and is suddenly chilled, producing a fine-grained structure. The plate is annealed and formed into wires.[39] Besides these thick plates or slabs, thin plates are also cast with a thickness of only 8 mm. and a diameter of 700 mm.[40] The casting of these thin plates eliminates annealing and rolling work.

It is nowadays possible, without difficulty, to cast centrifugally rings, for example, for worm rings, weighing 4 to 5 tons, satisfactorily in aluminium bronze. To cast such a large worm ring in sand, it would be necessary to employ

a metal charge of about 10 tons and to eliminate shrinkage effects by means of extensive risers. The centrifugally cast ring is satisfactorily sound and, in addition, has a high tensile strength.[41]

Casting and Lining of Bearings

Bronzes and red brasses centrifugally cast in tubular form in cooled moulds form excellent bearing metals. An example of the advantageous application of liquation phenomena is obtained in the centrifugal casting of bearing metal on a lead basis. The hard, specifically lighter zinc crystals are forced on to the inner surface, and as supporting elements are embedded in the lead. The bearing properties of a bearing made in such a way, and hence its life, are considerably increased. In practice, such bearings have been cast centrifugally in weights of up to 500 kilograms and have given excellent service.[42]

The lining of bearings by centrifugal casting has nowadays become customary in most factories employing the mass production of bearings, such as, for example, in motor-car factories. Fundamentally, the processes resemble the centrifugal casting processes described. Numerous machines have been constructed for this purpose and they are continually being improved with the object of rendering automatic the operations of heating the bearings, cleaning the surfaces, applying a flux and pouring in the metal to the exclusion of all oxidising influences, so that the lining of the bearings can proceed on the travelling band.

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DISCUSSION

Opening the Discussion, the CHAIRMAN (Major R. Miles) asked if Mr. Geisler would confirm the lengths and diameters of the largest cast-iron pipes made in Germany.

MR. W. A. GEISLER said the largest iron pipe in Germany cast centrifugally had the standard length of 5 metres and a diameter of 500 mm.

Influence of Speed of Rotation

MR. MALCOLM BROWN, after complimenting Mr. Geisler on his Paper, referred to the speed of rotation. If rotated too slowly, Mr. Geisler said, the inner surfaces of the castings were rough, the cross-section was irregular, and the castings were often permeated with blowholes. It was interesting to hear of centrifugal castings exhibiting blowholes. Was there a reason for that which the author could give?

Later in the Paper the introduction of a curtain of hot gas to prevent the formation of oxidation cracks in the finished casting was mentioned. Had the author any experience of pouring in finely ground charcoal to generate a carbonaceous atmosphere after casting, and thus prevent the cold air entering the rotor during cooling?

Replying to this question, MR. GEISLER invited his hearers to start centrifugal casting. They would find that the first thing they would produce would be, not dense castings but something like Gruyère cheese—full of blowholes. In centrifugal casting they used mainly steel or cast-iron moulds. In sand moulds the gases always had an opportunity of leaving the iron through the sand. In an iron mould it was not so easy to get rid of the gases because they had to pass through the liquid metal.

If the speed of rotation was too slow when they were casting, the iron would not remain on the outside of the mould, but would contract

inwards on itself, and they would get a laminated structure in the finished casting. On the other hand, if the speed was too high, then they might apply too much pressure. Then the casting could not contract and the centrifugal force would break it while it was in the soft state. It was important always to have the correct speed, which could very easily be determined experimentally.

Referring to charcoal in order to get a smooth outside surface, for ordinary castings, such as cylinder liners, it was very important to get the correct kind of charcoal or graphite to get a smooth surface. If there was none used, they would always get blowholes. It seemed that charcoal would take care of some of the gas, or at any rate lead it away from the inside of the mould.

Manganese in Austenitic Irons

Mr. T. R. Twigger asked, concerning an austenitic iron with only 5 per cent. nickel and no added copper mentioned in the Paper, how it could be austenitic. Was there not an appreciable amount of some other element, such as manganese? An illustration was given of a large roll made centrifugally and which rotated at 800 r.p.m. From a rough calculation the weight appeared to be at least two tons, to say nothing of the weight of the mould. That was rather a large lump to start rotating at 800 r.p.m. even though, as was mentioned, the speed was later reduced as the core metal was poured in. Were such castings made centrifugally on a production scale?

With regard to moulds lined with copper for non-ferrous work it would be interesting to know if Mr. Geisler had tried that for cast irons, and if any success had been obtained; for example, would copper-lined moulds minimise the difficulty of keeping the casting free from the blowholes which had already been mentioned, and would the moulds be more durable?

Copper-Lined Moulds

Mr. Geisler said they had to use manganese to replace the copper in their cast iron and the nickel content was about 5 per cent. Nickel was scarce in Germany and they made up for it with 12 per cent. manganese. They made, in that way, a very good austenitic iron, which was a very much cheaper iron than one with 12 to 14 per cent. nickel and 5 to 6 per cent. copper.

As to the rolls, it was a fact that they went to 2 tons in weight. Very often they had gone up to 15 tons and more; it was only a matter of building the machinery sufficiently heavy.

With reference to moulds lined with copper, that only applied to non-ferrous work. No attempt had been made to use copper in cast-iron moulds since there seemed to be no necessity for it. They used ordinary blacking and secured a very smooth casting without pinholes or other deleterious defect. Actually they achieved a smooth surface.

Tuyere Castings

Mr. J. Blakiston asked about the advances that had been made in the centrifugal casting of copper, particularly in reference to the tuyeres and coolers. They had to be cast from a metal which had to be as near 100 per cent. purity as possible on account of the conductivity properties which were required of them. Cast copper, when passing through its freezing range, was very friable, and, on account of this, presented considerable difficulties to obtain a sound casting. He wondered if the author could enlighten him at all as to whether the centrifugal casting of copper had become a definite commercial proposition and was being adopted where applicable.

Mr. Geisler said tuyeres used to be made by forging for they had to be very dense. They were now being made by the centrifugal process as a matter of everyday production and they were at least as good as the forged ones, and very much cheaper. The forging plant had been scrapped. That was a real development.

On this point the Chairman (Major Miles) mentioned that some time ago his firm had produced in this country copper tuyeres by the centrifugal casting process mentioned in the Paper, but the difficulty was that one had to have continuous production. In this country the demand had not been found sufficient to keep such a plant going.

Blowholes in Centrifugal Castings

Mr. S. E. Dawson suggested that blowholes in castings were due to a chemical reaction between the graphite in the iron and an oxide. This was supported by the fact that if a mould was coated with an easily reducible oxide such as lead oxide, a large number of blowholes were produced and a deposit of lead pellets resulted. Dissolved gases which may be several times the volume of molten iron were eliminated by the centrifugal action at an early stage, but gases produced on the outside of the casting may be trapped if formed after the metal solidified.

With regard to the question of austenitic cast iron raised by Mr. Twigger, it was necessary to have a manganese equivalent of about 12 per cent., obtainable by the use partly of manganese itself together with sufficient nickel to produce suitable softness. In steel where relatively little carbon was present, the equivalent manganese required to retain the austenitic condition was about 16 per cent. Copper which hardened cast iron could be used in place of nickel to a limited

amount, say 5 per cent. maximum. This was the basis of his original patent for non-magnetic cast iron taken out in 1920.

Mr. Geisler said the causes of pinholes and blowholes were so numerous that they could talk about them for hours. As to the austenitic iron, it was a fact that with about 3 per cent. carbon in iron from 12 to 14 per cent. manganese was needed to get the desired result.

Mr. Dawson further amplified his point about blowholes by saying that the amount of gas dissolved in cast iron was very great; one could have four or five times the volume of gas to that of the metal dissolved in it. If blowholes were due to that gas they would never be able to cast a pipe. The gas in solution, he claimed, was eliminated by the centrifugal process, and the formation of blowholes was due to the chemical reaction he had mentioned.

Speed played an important part, and the increased speed to which reference had been made gave a thinner layer of metal which set quicker, and, therefore, tended to cause blowholes from the fact that the metal setting trapped the chemically-produced gases, and gave them less chance of being brought to the inside.

Mould Dressings and Blowhole Elimination

Mr. F. C. Pearce, speaking on the same subject, suggested Mr. Dawson's contention could be disproved. One could always get rid of blowholes by making the casting thicker. Mr. Geisler had left speeds where they were—he understood the best speed was still about 1,800 ft. a min.—and he also left dressings where they were. Had he no information about better dressings, cheaper and easier to apply? What was the highest speed he had used? What also was the minimum section thickness of cylinder liners in Germany, and what was the minimum phosphorus content of the casting which should be not more than 0.3 in. in section thickness?

Mr. Geisler replied that the cheapest coating they had was ordinary blacking, and that worked very nicely. As a matter of fact it was not necessary to apply a coating after every casting, since there was always some material left when the mould was stripped. As graphite was very cheap and satisfactory they had not troubled to try anything else.

As to eliminating blowholes by making castings thicker, that was possibly the case, but customers would not always be satisfied with such a remedy. They did not want castings heavier than they need be. The thinnest castings made had been from $\frac{3}{16}$ in. to $\frac{1}{4}$ in. thick, and they had made iron castings, to be hardened subsequently by the nitrogen process, with below 0.1 per cent. of phosphorus.

Paper No. 665

Specially-Hard Alloy Cast Irons for Resistance to Abrasion

By M. M. HALLETT, B.Sc., and A. B. EVEREST, Ph.D. (Member)

Martensitic white cast iron is widely used in applications involving resistance to abrasion, particularly in such severe service as in grinding and crushing equipment or for parts of plant handling abrasive solids. Cast irons of this type have found wide application in the mining and metallurgical industries and in public utility companies, offering marked increases in service in nearly all cases where a plain white or chilled iron was previously used. These applications cover a wide variety of castings, from small parts such as Sandslinger cups up to castings weighing several tons, such as rolls for metal-working or for crushing applications.

The question of alloyed chilled cast iron is an extremely wide one. Characteristics of some of the alloyed irons for chilled castings such as rolls have already been discussed.* In the present Paper, however, attention is given rather to the smaller types of castings which would be made in a sand mould and which are of such section that they would cool quickly to room temperature.

In the case of chilled rolls, it is necessary that the depth of chill should be carefully controlled, and to effect this a balance must be maintained between elements promoting the formation of graphite and those forming stable carbides. The martensitic white cast iron known as Ni-Hard usually contains, for roll production, about 3 per cent. carbon, 4½ per cent. nickel, and 1 to 1½ per cent. chromium, depending on the silicon content.

Chilling is applied mainly for the purpose of developing a white iron structure at least for part of the section thickness of heavy castings, where normally, due to the slow cooling of such castings, it would be impossible or difficult to obtain the white iron structure. Sand casting, however, may successfully be employed for lighter castings in white iron. Due to the more rapid cooling of such castings, certain changes in the alloy content may be desirable to obtain the best results. Furthermore, it is not necessary to maintain the strict balance between graphitising and carbide-forming elements in the case of sand castings, as these are merely required to solidify with a structure as completely white as possible. The purpose of the present Paper is to deal with the characteristics of white iron sand castings in order to obtain a clearer picture of the factors governing the choice of correct composition.

Fig. 1 shows the microstructure of an unalloyed white cast iron; it is seen to consist of two major constituents, iron carbide or cementite showing as the light component and the duplex constituent—pearlite. The carbide is of course hard, whereas the pearlite is comparatively soft. The hardness of the final casting can be raised by increasing the carbon content of the iron, thus increasing the proportion of the hard carbide. In practice, such an increase cannot be carried very far, as the carbide tends to be brittle and the properties of the iron suffer accordingly. Nor is it possible to alter the hardness of the carbide very greatly by means of alloy additions. In order to raise the hardness of the whole mass and thereby to secure the maximum resistance to abrasion, attention must be concentrated on the pearlite constituent.

By means of suitable alloy additions, the hard constituent, martensite, may be substituted for the pearlite. The structure of Ni-Hard "as cast" is illustrated in Fig. 2, where the martensite is shown as a needle-like constituent. If the alloy content is on the low side, a black-etching product of intermediate hardness known as troostite is liable to appear. This is shown in Fig. 3, where the black nodules of troostite may be seen, apparently growing from the carbide phase. If, on the other hand, the alloy content is too high, the proportion of martensite will decrease and a light etching soft constituent, austenite, will take its place, as seen in Fig. 4. The object of the foundryman producing castings for resistance to abrasion is, therefore, to obtain a well-balanced structure entirely composed of the hard constituents martensite and carbide.

It will be convenient first to consider the changes which may occur in a white iron casting during solidification and subsequent cooling, and, secondly, to discuss the effect of alloy elements on these changes. The changes themselves may be divided as occurring in three stages:—

(1) Solidification of the molten metal. Here the iron separates itself into two main con-

* W. T. Griffiths. "The Production of Specially-Hard Cast Irons by Alloying and Heat-Treatment." Proc. Inst. Brit. Foundrymen, 1933–34. Vol. XXVII, pp. 563–587.

stituents, the carbide and the solid solution of other elements in iron known as austenite.

(2) Changes in composition of the austenite. Certain elements are less soluble in austenite at low temperatures than at high, and may, therefore, be precipitated from the austenite during cooling.

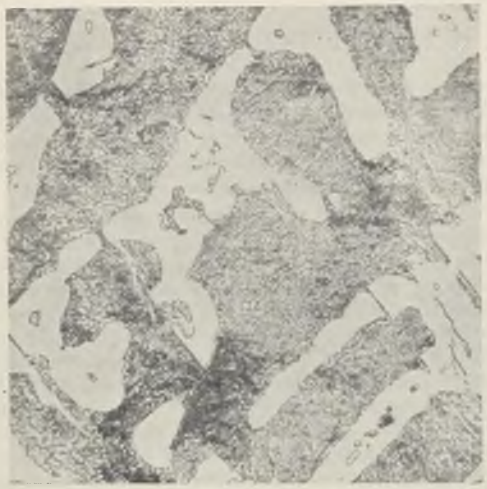

Fig. 1.—Unalloyed White Cast Iron. × 500.

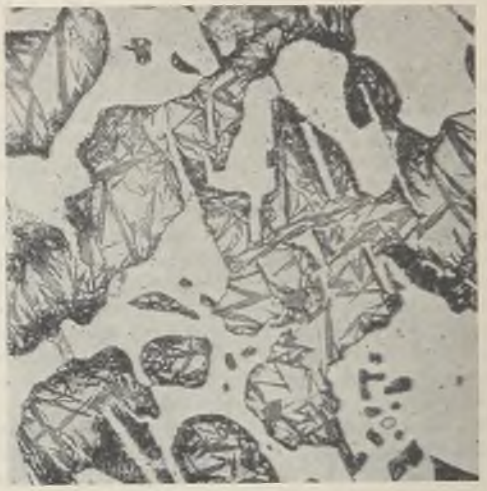

Fig. 2.—Sand-Cast Ni-Hard. × 500.

Fig. 3.—Low-Alloy Ni-Hard showing Troostite and Martensite. × 500.

Fig. 4.—High-Alloy Ni-Hard showing Martensite and Austenite. × 500.

(3) Decomposition of the austenite. Below a temperature of about 700 deg. C., the austenite in a white iron becomes unstable and tends to break down. Briefly, it may be stated that the decomposition may proceed at a relatively high temperature, say, above 600 deg. C., or at a low temperature, say below 250 deg. C. If the decomposition is allowed to proceed at a high temperature, then the result of the breakdown will be the comparatively soft product, pearlite, illustrated in Fig. 1, whereas if the reaction occurs at a low temperature, then the product will be the hard needle-like constituent, martensite, shown in Fig. 2.

It should be borne in mind that these changes will be modified by the speed of cooling and by the composition. Of all the controlling elements,

carbon itself is probably the most important, and in the detailed description of the changes to follow, the effect of carbon will be considered along with the discussion of the phenomena, as the two are so closely inter-related as to make it inconvenient to consider them apart. It is perhaps desirable to stress here that the point under consideration is not the total carbon content of the iron, nor even the combined carbon content, but the carbon in solution in the austenitic matrix.

Consideration of Changes During Cooling

On cooling a molten alloy iron, solidification commences by the formation and growth of dendrites of austenite in the melt. When a certain definite temperature has been reached, the remaining liquid, which has now attained eutectic composition, solidifies around the growing dendrites. At this point the structure of the casting will consist of a mixture of austenite dendrites surrounded by eutectic. The eutectic itself consists of a fine mixture of carbide and austenite. In irons of rather low carbon content, the austenite particles composing one phase of the eutectic tend to deposit on the pre-existing austenite dendrites, and the carbide is left in a massive form, so that when examined under the microscope, the characteristic appearance of a eutectic is not evident.

At the eutectic temperature, the carbon content of the austenite is in the order of 1.7 per cent., varying to some extent, of course, with the composition of the iron. As the temperature falls, the solubility of carbon in the matrix decreases, and the carbide thrown out of solution is deposited not only preferentially on the pre-existing eutectic carbide masses (particularly at high temperatures), but also and especially at the lower temperatures, as needles or nodules within the austenite. The inoculating effect of the carbide masses on withdrawal of carbon from solution at higher temperatures is sufficiently high to permit the rapid deposition of carbide. It is necessary to note here that, in the alloyed irons under consideration, the austenitic matrix will not normally undergo a transformation at temperatures in the region of 700 deg. C., as would happen in the case of unalloyed cast iron. The presence of alloying elements slows down the rate at which austenite decomposes in this temperature range and, as has been clearly demonstrated in the case of steels, when sufficient alloying elements are present, austenite may be cooled at slow rates down to temperatures in the order of 250 deg. C. without transformation setting in.

When the austenite matrix of iron is retained undecomposed down to temperatures in the order of 250 deg. C., further cooling leads to its transformation into hard martensite. The temperature at which the transformation sets in during cooling is primarily determined by the amount of carbon in solution in the austenite. The more carbon in solution in the austenite, the lower is the temperature at which the change

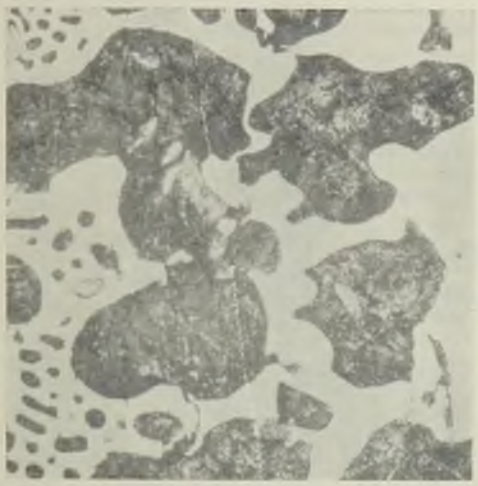

Fig. 5.—5 per cent. Chromium Iron, cast in $\frac{3}{8}$-in. dia. Bar. × 1,000.

Fig. 6.—Ni-Hard after Retarded Cooling at 550 deg. C. × 500.

(All specimens etched in alcoholic nitric picric acid.)

sets in and the less complete the reaction. Each step in the cooling leads to the instantaneous formation of a certain quantity of martensite. The material may be held at a constant temperature without the reaction continuing appreciably, and further cooling is necessary to cause a further step in the decomposition.* Even by the time room temperature is reached, the breakdown of the austenitic matrix to martensite is seldom complete, and the end product is generally a mixture of martensite and retained austenite.

In order to obtain maximum hardness, conditions must be so adjusted that the whole of the matrix decomposes to martensite, and this involves the taking of steps to control the amount of carbon in solution in the austenite. One such step is to adjust the rate of cooling. By doing this, the correct degree of carbide deposition may be caused to occur at elevated temperatures. In general, this will necessitate delaying the natural rate of cooling of all but the largest castings. It is necessary, however, to guard against the decomposition of the austenite into pearlite, troostite, and similar products formed at the higher temperatures. This is done by so adjusting the alloy content as to render the high-temperature transformations so slow that they are for practical purposes eliminated.

Summarising, the properties of a white iron casting will be determined mainly by the following factors:—

(1) The quantity of massive carbide, which is, of course, determined by the carbon content of the iron and its chilling characteristics.

(2) The degree to which the higher temperature transformations producing soft pearlitic and similar products are eliminated. This depends on rate of cooling and alloy content.

(3) The relative proportions of martensite and retained austenite in the matrix of the iron. These are determined by the carbon content of the austenite, which in turn depends on the rate of cooling through the intermediate temperature range of 650 deg. C. to 400 deg. C.

TABLE I.—*Relation between Composition, Size of Section, and Hardness.*

Mark.	Composition. Per cent.				Vickers diamond hardness values.		
					Size of section.		
	T.C.	Si.	Ni.	Cr.	¾ in.	1 in.	2 in.
A	3.20 to 3.23	0.55 to 0.61	2.21	0.97 to 1.01	724	576	581
B			2.47		707	650	595
C			2.68		689	710	640
D			2.96		707	627	740
E			3.33		—	—	772
F	3.23 to 3.34	0.48 to 0.53	1.10	1.80 to 1.85	650	599	560
G			1.76		720	650	596
H			2.24		681	715	627
I			2.51		686	759	662
J			2.75		693	743	765
K			2.93		653	746	759
L			3.09		627	760	792
M			3.29		654	743	772
N			3.46		640	743	762
O			3.79		681	733	727
P			4.27		650	678	697
Q			4.51		627	710	700
R	2.81 to 2.84	0.40 to 0.45	2.34	1.47 to 1.50	733	670	558
S			2.49		762	750	616
T			2.83		654	762	762
U			3.05		—	724	—
V	3.30	0.55	Nil	4.91	620	585	560

Effect of Alloy Elements

Each of the alloy elements has an effect on the phenomena described above and requires individual consideration.

Nickel is the most important of the alloy elements added to suppress the high-temperature transitions of the austenite, and it is essential that sufficient should be present to ensure com-

* There is evidence to show that in high-carbon alloy materials breakdown of the austenite may continue to some extent during holding at room temperature, but the effect cannot be detected above about 50 deg. C.

plete suppression with the result that the austenite breaks down only at low temperatures to form hard martensite. The amount of nickel required will depend on the rate of cooling, or, in other words, on the size of the cast section. In Table I are shown the hardness values of sections $\frac{3}{8}$, 1 and 2 in. in diameter, cast in sand and cooled in the mould to room temperature, and some of the results are illustrated in Fig. 7. In the Table the irons are arranged in three main groups. The first group is of medium carbon content and a low chromium content, while the second contains the same amount of carbon at a high chromium level. The third group covers low carbon irons.

It will be seen that, in the case of the first group, maximum hardness is already attained at 2.2 per cent. nickel in the section $\frac{3}{8}$ in. thick, while 2.7 per cent. and 3 per cent. nickel are required for 1-in. and 2-in. sections respectively. These nickel contents are lowered by about 0.2 per cent. if the chromium is raised by 0.8 per cent. (compare the first and second groups), but are not appreciably affected by changes in carbon content over the range 2.8 to 3.3 per cent. The microstructures of the irons in this table confirm the hardness values. Thus, in the first material quoted, A, the $\frac{3}{8}$-in. bar was martensitic like the iron illustrated in Fig. 2, and the 1-in. bar was sorbitic. With further additions of nickel, B, the 1-in. bar showed a mixture of troostite and martensite as in Fig. 3 and became fully martensitic with 2.7 per cent. nickel, C.

The hardness results of the series containing 3.25 per cent. carbon and 1.8 per cent. chromium fall on curves of the type shown in Fig. 7. The maximum hardness obtained is greater, the larger the section of the casting. In the large section, due to the slower rate of cooling, more time is spent in the temperature range in which deposition of carbide from the austenite occurs. Consequently more carbide is precipitated and the austenite rendered poorer in carbon. As shown earlier, the impoverished austenite is able to decompose more completely to martensite on further cooling. Small castings tend to be soft on account of high proportions of retained austenite. It should also be noted that the decrease in hardness when the nickel content is raised beyond that required for maximum hardness is not as rapid as the increase in hardness on approaching the maximum from lower nickel contents.

The predominant effect of carbon on the low-temperature transition to martensite has already been described, and note has been taken of the effect of carbide masses in impoverishing the neighbouring austenite, by accelerating the withdrawal from it at higher temperatures of carbon in solution. The result of this is shown in Fig. 3, where a high-temperature reaction product, troostite, has started to form in the austenite immediately adjacent to the carbide masses. Graphite is sometimes present in castings which are nominally white and will have an inoculating effect differing slightly from that of carbide. Carbon will similarly be withdrawn from solid solution in the neighbouring austenite but will deposit as graphite.

Carbide requires for its formation both carbon and iron, but graphite, of course, does not. Hence, when graphite precipitates, the iron which might have been required is left behind to dilute the austenite solution, and the impoverishment of the austenite in carbon may be more marked near a graphite flake than near massive carbide. It might be added that carbon also has a powerful effect in suppressing breakdown

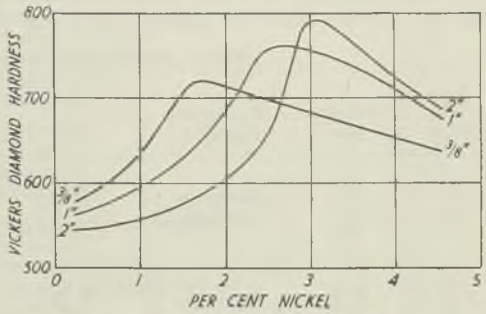

FIG. 7.—EFFECT OF NICKEL CONTENT AND SECTION THICKNESS ON HARDNESS OF WHITE CAST IRON CONTAINING T.C 3.2 AND CR 1.8 PER CENT.

of austenite at temperatures near 500 deg. C. Breakdown of this type to form an intermediate product is frequently encountered in alloy steels,* but, on account of the high carbon content, is not likely to be met with in continuously-cooled alloy white iron sand castings.

Silicon directly accelerates the tendency to form soft pearlite and also has a powerful indirect effect, in that it lowers the solubility of carbon in austenite. It may therefore usefully be added to castings with a wide range of wall-thickness, in which the alloy content is necessarily high enough to ensure the formation of martensite in the thick sections. Under these conditions, the thin sections will retain much austenite, but silicon reduces the amount of retained austenite by precipitating carbon from it at high temperatures, hence permitting it to invert more readily at low temperatures. Great

* This has recently been studied by W. T. Griffiths, L. B. Pfeil and N. P. Allen, "Second Report of the Alloy Steels Research Committee." Section XII, p. 343. Iron and Steel Institute, 1939. Special Report No. 24.

care must be taken not to add too much silicon, and, at the same time, to maintain a high chromium content, or graphite will be formed and the hardness of the casting suffer.

Chromium markedly decreases the speed of diffusion of carbon in iron and thereby stabilises the austenite, preventing its transformation at high temperature. As the chromium tends to enter into combination with the carbide, it will be found concentrated in the massive carbides, and a relatively small proportion of it will be present in the austenite. Its effect on the breakdown of the austenite in white iron is much less than its effect on the breakdown of austenite in steel. An example is furnished by the cast iron, V, in Table I. This contained 4.91 per cent. chromium with no nickel, and was comparatively soft in all sections. Even the ⅜-in. bar had a sorbitic structure, which is illustrated in Fig. 5 at a magnification of 1,000 diameters. It will also be recalled that the amount of nickel required to form martensite was only slightly affected by the chromium content of the material.

Manganese promotes the stability of austenite and, therefore, assists in suppressing its transformation at high temperature; but, as in the case of chromium, it forms stable carbides and its efficacy in retarding decomposition of austenite is thus reduced. Furthermore, its use is limited, as, apart from foundry difficulties, the manganese-containing carbide is softer than iron carbide, with the result that the hardness of the casting is lower.

Molybdenum behaves in a manner similar to that of chromium in that it forms stable carbides and retards diffusion. It does not appear to form such stable carbides as does chromium, and probably more of it enters into solution in the austenite with the result that it is approximately as effective as nickel in promoting the formation of martensite.

TABLE II.—*Typical Compositions of Ni-Hard Sand Castings.*

Ref. letter.	Section. Ins.	Properties required.	Composition. Per cent. T.C.	Si.	Ni.	Cr.	
A	¼–½	Maximum hardness	3.3–3.6	0.8	2.5	1.5	In all cases manganese should be between 0.3 and 0.5 per cent., sulphur about 0.1 per cent., phosphorus 0.4 per cent. maximum. Molybdenum may also be present, if desired.
B	½–2		3.3–3.6	0.6	3.2	1.7	
C	2–4		3.3–3.6	0.5	4.5	2.0	
D	¼–½	Maximum toughness	2.7–3.2	0.5	3.0	1.5	
E	½–2		2.7–3.2	0.5	4.0	1.7	
F	2–4		2.7–3.2	0.5	5.0	2.0	

Heat-Treatment

In some cases, improvements in the properties of chilled alloy iron castings may be effected by heat-treatment. A useful purpose may be served by summarising the effects of such heat-treatment, which it will be convenient to consider under three headings:—

(*a*) Tempering at low temperatures in the order of 250 deg. C.

(*b*) Tempering at intermediate temperatures in the range 400 to 650 deg. C.

(*c*) Reheating to temperatures above 750 deg. C., followed by cooling at controlled rates and possibly by a final tempering.

The first type of heat-treatment, *viz.*, tempering at about 250 deg. C., is particularly useful in reducing internal stresses which are likely to be caused by the expansion which accompanies the transformation of austenite to martensite. A tempering operation tends to increase the toughness of the material by permitting release of the stresses. As the temperature is low, the hardness of the iron will not be affected.

Tempering between 400 and 650 deg. C. has more profound effects than low-temperature tempering. The hard martensite will be softened somewhat and some of the retained austenite may decompose to form a comparatively soft constituent. The chief result of the operation, however, is to bring the austenite to a temperature at which it can reject carbide retained in supersaturated solution during the first cooling in the mould. The austenite is thereby impoverished and enabled to invert to hard martensite during the cooling from the tempering temperature. It should be noted that austenite cannot invert directly to martensite during the heating to or soaking at the tempering temperature. This type of inversion occurs only during cooling below about 200 deg. C. Any direct inversion of austenite during tempering would be to a comparatively soft constituent. In fact, it is frequently the case that, after tempering at 500 deg. C., the hardness of the iron is greater than in the "as-cast" condition, as sufficient fresh martensite may be formed during cooling to counterbalance the drop in hardness due to tempering of the original martensite.

Reheating to temperatures above 750 deg. C. restores the iron to the austenitic condition. Breakdown of the austenite during cooling will be controlled, as before, by the amount of carbon redissolved in the austenite, the alloy content and the rate of cooling. At high temperatures, graphitisation may occur leading to permanent softening. Both after high-temperature and intermediate-temperature reheating, a final low-temperature tempering is desirable to relieve stresses.

reheat to 550 deg. C., but care must be taken not to allow the temperature to fall below 250 deg. C., or martensite will be formed and will subsequently soften during heating at 550 deg. C. The time required at 550 deg. C. must be determined by direct experiment, but normally will vary from 1 to 12 hrs.

As an example of the increase in hardness which can be induced by retarded cooling may be quoted the case of a cast containing 2.97 per cent. carbon, 0.56 per cent. silicon, 0.34 per cent. manganese, 4.89 per cent. nickel, and 1.13 per cent. chromium. Bars $\frac{7}{8}$ in. dia. were cast in sand moulds and cooled to a temperature of about 600 deg. C., when they were rapidly stripped and transferred to a furnace at 550 deg. C. After soaking at that temperature for progressively increasing lengths of time, the bars were removed and cooled slowly to room temperature. The control bar cooled in the mould had a Vickers diamond hardness of 678. After 2 hrs.' soaking at 550 deg. C. before cooling, the hardness rose to 739, and after 6 to 24 hrs.' soaking it was 782, an increase of over

TABLE III.—*Typical Applications of Ni-Hard Sand Castings with Recommended Compositions, as Shown in Table II*

Where alternative recommendations are made, they are to cover varying conditions of service, the maximum toughness grades, for instance, being required where shock loading or high stresses are imposed, and the maximum hardness grades being available where abrasion is the prime consideration. In other cases, alternatives are given to cover a wide range of section thickness, and the composition of iron must be selected from Table II in accordance with the general dimensions of the casting under consideration.

Application.	Composition.	Application.	Composition.
Ash discharge doors	B	Gravel pipes	B
Ash pump bodies	D or E	Grinding machine rests	D
Ash pump impellers	A	Grinding mill balls	C or F
Ash troughs	E	Grinding pan bottom	E
		Grinding plates	E
Ball-mill trunnions	C	Grizzley discs	B or E
Brakeblocks	F*		
Brick mould liners	B	Mill guides	E
		Mixer arms	E or F
Cable car pulleys	E	Muller tyre	C or F
Centreless grinder blades	D	Muller wheel	C*
Chute plates	B		
Clay pipe dies	C	Plough points and shares	D or E
Coal-breeze pit pumps	B or E	Pug knives	D
Coffee grinder plates	A or D	Pulveriser bull rings	F
Coke-quenching car sides and bottoms	E	Pulveriser hammers and plates	E or F
Concrete pump liners	E	Pump rams	F*
Concrete pump plungers	F*		
Conveyor plates	B or E	Sand-blast nozzle	A
Conveyor skidder bars	B or E	Sand-blast table segments	E
Conveyor sprockets	E	Sand ploughs	A or B
Crusher roll shell	B	Sandslinger cups	A or D
Crusher roll, small (for brickmaking, etc.)	B	Sandslinger wear plates	A or D
		Shot-slinger baffles	D
Dredger pump bodies and impellers	E or F	Shot-slinger vanes	D
Dust-collecting valves	B or E	Stamp mill heads and shoes	F*
		Tractor shoes	E
Fan blades for pulverised coal	D	Tumbler barrel ends	E
Feed screws	D	Water nozzles	B

* Castings may also be made in chills.

The precise heat-treatment applied will require adaption to each particular case. For maximum resistance to abrasion, the rate of cooling of the original casting should be adjusted so that the matrix will have decomposed entirely to martensite by the time room temperature is reached. In the case of small castings, which tend to cool too rapidly, this will entail checking the cooling for an hour or so at about 550 deg. C., to allow complete precipitation of carbide from the austenite to occur. It may be more convenient to allow the castings to cool in the mould to about 250 deg. C. and then to

100 Vickers hardness points over the bar cooled normally in the sand mould. The microstructure of the hard bar is shown in Fig. 6 at a magnification of 500 diameters. When compared with the normal structure of a sand-cast bar (Fig. 2), it is clear that there is a much greater amount of martensite present, and that the retained austenite has almost disappeared.

It is desirable to apply a stress-relief tempering operation after all types of heat-treatment of complicated castings.

Choice of Correct Composition

The above considerations indicate that the composition of any casting should be chosen bearing in mind both the rate of cooling and the service in which the final casting is to be placed. It may be required to possess the maximum resistance to abrasion or great toughness coupled with high abrasion resistance. It is often difficult to adjust the alloy content so as to hit the maximum on the hardness peak, particularly when a variety of castings is being poured. The best procedure is to work with a slight excess of nickel and to delay the cooling at a temperature of 500 to 550 deg. C. There is then no danger of having too low an alloy content with a consequent marked decrease in hardness and, furthermore, provided a certain minimum is present, there is no necessity to control the composition within fine limits, as slight variations will not cause great changes in hardness even if no delayed cooling treatment is adopted, though the latter treatment ensures the maximum hardness. The alloy content must always be adjusted in terms of the largest section involved, otherwise in these more slowly cooled parts, softer products such as pearlite and troostite will tend to form. A delayed cooling of higher alloy iron ensures that all sections harden equally.

Often maximum hardness is not desired so much as a combination of hardness and toughness. This is best reached by working at a higher nickel content so as to retain some austenite in the structure. The toughness of the casting will be enhanced and the wear resistance may suffer little as the austenite tends to decompose under severely abrasive conditions and will form hard martensite.

In Table II are given alloy compositions suitable for various types of castings, and in Table III are enumerated a number of applications of Ni-Hard sand castings. The compositions quoted should be regarded as approximate suggestions rather than as precise compositions calculated to give the optimum results. In a number of cases, such as crusher rolls for coal, cement or rock, car wheels and ball mill liners, the castings will normally be made in chills, and here it is difficult to make general recommendations, as the weight and temperature of the chills and the thickness of the coating will vary greatly from case to case and correspondingly affect the cooling rate. In general, chill castings require a lower chromium content than sand castings to maintain a white structure, but each case requires individual consideration.

Heat-treatment, such as delayed cooling at 550 deg. C., is sometimes desirable, as indicated above. It should perhaps be emphasised that the delaying of the cooling should not occur at temperatures higher than 550 deg. C. If solidification is slowed up, there is always danger of graphite forming, and fairly quick cooling from 700 to 550 deg. C. is desirable to suppress any high-temperature inversion of the austenite. In practice, it is best to allow the casting to cool in the mould until it is definitely below red-heat, say, 400 to 550 deg. C., and then to strip it and rapidly transfer to a furnace at 500 to 550 deg. C., soaking at that temperature and cooling in the furnace. If only a simple treatment such as slow cooling in the mould is possible, the alloy content must be kept high.

DISCUSSION

Mr. R. Chavy said the authors had drawn attention to the importance of the carbon content of the austenite in determining the structure of white irons of the Ni-Hard type. This factor was without doubt very important, and should be considered in conjunction with the effect of total carbon content, to which attention had been drawn in a Paper presented to the International Congress in 1935.[1]

The experiments reported in that Paper led to the conclusion that if it could be assumed that the constituent (austenite, martensite or troostite) which accompanied the carbides contained approximately the whole of the nickel, then the concentration of nickel in this constituent was progressively higher as the amount of combined carbon was increased. Thus, if for a certain section thickness of casting in a white iron containing about 2.5 per cent. carbon the nickel content necessary to obtain martensite was of the order of 4.5 to 5.0 per cent., then the nickel necessary would only be 3.5 to 4.0 per cent. if the carbon content was raised to 4.0 per cent. Under certain circumstances it might, therefore, be desirable in a casting of given section to take this factor into account and to adjust the content of nickel in proportion to the carbon present.

It was also interesting to note that one could harden some nickel-chromium white irons by air-quenching from 850 to 900 deg. C. in the same way as in quenching grey irons or air-hardening

[1] Ballay and Chavy. "Special White Cast Irons." Bull Assoc. Tech. Fond., 1935, ix, December, 366-380.

nickel-chromium steels. In this case the content of nickel and chromium was maintained at a lower level than that necessary for obtaining martensite in the "as-cast" state, and the maximum hardness (750 to 850 Vickers) was obtained by quenching in air. These irons should be interesting for castings which were required to be lightly machined, but which in service must possess the greatest possible hardness.

He had similarly studied, in association with Dr. M. Ballay, the oxy-acetylene hard surfacing of steel or iron specimens with a thin layer (0.08-0.2 in. thick) of white iron. A Paper on this subject was presented to the Foundry Congress in Paris in June, 1937.[2] Certain nickel-chromium white irons lent themselves particularly well to deposition. The adherence was excellent and the hardness was equal or even superior to that of certain more expensive alloys actually used for this application. Thus the surface deposited could attain a hardness of 650 to 750 Vickers Brinell, and sometimes one could increase this hardness by air-cooling from 850 to 900 deg. C. up to values of 800 to 850 Vickers.

For irons required for surface repairs, the nickel and chromium contents should be kept quite low (2 to 3 per cent., according to the carbon content), on account of the very high speed of cooling of the deposited metal.

Finally, during the course of these studies it had been found that with relatively low nickel contents (6 to 10 per cent.) and chromium contents of 4 to 6 per cent., one could obtain white irons with a cementite-austenite structure the hardness of which was approximately the same as those of the base irons of the same carbon content, but which had numerous advantages in relation to ordinary white irons:—(1) High resistance to shock, about three times higher than that of the ordinary base iron; (2) high resistance to corrosion by certain acids, in particular hydrochloric acid, and (3) resistance to heat and especially low sensitivity to thermal shock. This last property rendered it possible to envisage the use of these white austenitic irons for applications requiring resistance to wear at very high temperature, such as the cooling elements for cement clinker for example, where the metal must resist at the same time both high temperature and erosion.

Alloy Requirements to Form Martensite

In reply the Authors stated that they were aware of the interesting work carried out on white cast irons by Mr. Chavy and Dr. Ballay, in which it was concluded that the carbon content affected the alloy content required to form martensite. This work was, however, carried out over a much wider range of carbon than that studied in the present Paper. In their own work over the restricted carbon range of 2.8 to 3.2 per cent., the authors did not find any evidence of this effect.

They were very interested in Mr. Chavy's experiments with white austenitic cast iron. From their own experience with irons of this type, such as Ni-Resist with 5 per cent. chromium, they could confirm the valuable combination of hardness, corrosion and heat resistance which they possessed.

The authors were aware of the employment of these alloy white irons for hard surfacing, and of the useful contribution to this subject made by Mr. Chavy. While there were cases where a low alloy content was advisable, they believed that there were others where it would be advantageous to keep the nickel content somewhat higher, thus ensuring the presence of a small quantity of austenite which might assist in connection with toughness and wear resistance.

Mr. P. A. Russell, B.Sc., found the fact that thicker castings could have a lower alloy content to obtain optimum properties most interesting, for he had always assumed that at least 4 per cent. nickel was needed to produce martensite in a casting.

Did those properties extend to grey cast iron, because there were a large number of castings made with about $2\frac{1}{2}$ per cent. nickel which were produced not to be martensitic as cast, but for heat-treatable iron, and if $2\frac{1}{2}$ per cent. would produce martensite, it was rather surprising, because in his experience such irons were freely machinable.

Mass and Alloy Additions

The Authors agreed that it was not an unfamiliar idea that one required a lower alloy content when the castings were small. The formation of martensite was dependent on the alloy content and rate of cooling. The importance of the rate of cooling was well illustrated by a case in which extremely small single cast piston rings were made. These naturally cooled very quickly and showed appreciable contents of martensite even with $\frac{1}{2}$ per cent. of nickel. With 1 per cent. of nickel they were almost fully martensitic. This clearly showed that as the rate of cooling rose, the alloy content necessary was lowered. The point was possibly rather academic, as such very small castings were not often produced in the foundry. As regards the nickel content required to produce martensite in grey cast iron, that again depended partly on the thickness of section, or, in other words, on the rate of cooling. With the nickel content of 4 per cent., $\frac{1}{8}$-in. and $\frac{1}{4}$-in. sections

[2] "Special White Cast Irons and Cupro-Nickels Containing Tin for Building Up by Torch Welding." M. Ballay and R. Chavy, International Foundry Congress, Paris, 1937. Paper C.I. 28.

would be martensitic as cast, but sections of $\frac{1}{2}$ in. or thicker would not be martensitic. A 3 per cent. nickel grey iron was not martensitic in any section down to $\frac{1}{8}$ in. These observation confirmed those of Mr. Russell. The reason why a higher nickel content was required in grey iron was partly due to the higher silicon content of the grey iron as compared with that of a white iron, though it was possible that the effect of concentration of alloys in the dendrites mentioned by Mr. Chavy might play a part.

Tube Mill Liners

Mr. A. H. Guy (President, S.A. Branch) mentioned that his firm were large manufacturers of white iron, principally tube-mill liners. They had to wear down to $\frac{1}{4}$ in. before being taken out, having started at 4 in. They used a mixture of white iron and steel, and added 0.5 per cent. manganese merely as a flux which had no effect on the quality of the iron. From 0.4 to 0.7 per cent. of silicon was added to make the metal flow, and they found that if the addition went any higher than that, the metal became grey or mottled and the Brinell hardness dropped from 410 to 280. They also added 0.3 to 0.4 per cent. of chromium, and the result was that they got a Brinell hardness of 410. He mentioned these facts, because his firm had found that any white iron supplied from England for tube mill liners did not give the same life.

In reply to questions by the chairman, Mr. Guy mentioned several other irons and steels which had been tried, but as cost was a ruling factor, many had failed on that account in comparison with the iron mentioned.

The Authors expressed themselves as very interested in Mr. Guy's remarks concerning tube mill liners. Mr. Guy had stated, however, that his results were based principally on one test conducted at his works with an experimental set of Ni-Hard liners. Mr. Guy would, no doubt, be the first to admit that with a complicated alloy such as Ni-Hard one could not expect to get the best results from a first trial, and no doubt the record of 60 per cent. increase in life could be further raised. In fact, in service of this type Ni-Hard had in many cases proved an economical proposition, giving a greater life than necessary to compensate for the increased cost.

Mr. Guy added that conditions in tube mills were very severe, for liners had to stand up to attrition as well as impact, consequently if the metal was too hard it would crack before it was worn out.

Relative Conversion Power of Elements

Mr. S. E. Dawson asked whether nickel was the principal element in preventing the conversion of austenite to martensite as stated by Dr. Everest, since manganese was twice as strong as nickel, while chromium was one and a half times as effective in this respect. In steel one could use manganese, nickel or chromium in varying proportions, depending on the physical properties required, such as malleability, machinability and resistance to corrosion. This formed the basis of his patent taken out in 1928. In cast iron the higher carbon limited the amount of chromium permissible.

Application to Grey and White Irons

The Authors thought that Mr. Dawson was neglecting the difference between white iron and grey iron. In a grey iron carbon was present as graphite. In the white iron, it was there as carbide, and when one had carbides present the carbide-forming elements were concentrated in those carbides. That applied particularly to chromium and to a lesser extent to manganese. Therefore, as the elements in question were in the carbide they could not be present in the austenite as well, and so had very little effect on the breakdown of the austenite. The effect of chromium might be seen in Table I of the Paper where it was shown that increasing the chromium content from about 1 to 1.8 per cent. (maintaining all conditions the same) had very little effect on the amount of nickel required to form martensite. Attention might also be drawn to the iron containing 4.91 per cent. of chromium and no nickel. This material was sorbitic even in the small $\frac{3}{8}$ in. dia. rod, and the hardness of the 2-in. section was hardly any higher than that of a plain iron. It was clear that contrary to the ratio of $1\frac{1}{2}$ to 1 which Mr. Dawson quoted as the relative potency of chromium and of nickel, chromium was actually less than a quarter as powerful as nickel in promoting the formation of martensite in white iron. Similar reasoning could be applied in the case of manganese.

Paper No. 666

The Thermal Conductivity of High-Duty and Alloy Cast Irons

By J. W. DONALDSON, D.Sc. (Associate Member)

1. Introduction

The thermal conductivity of grey cast iron was determined by the author[1] some ten years ago in a series of investigations covering a wide range of cast irons. Experiments were also made to determine the influence on the thermal conductivity of grey cast iron of certain alloy additions. All the determinations were carried out over a range of temperature from 50 to 500 deg. C. As a result of these investigations, it was shown that the thermal conductivity of grey cast iron varied from 0.110 to 0.137 cal. per cm. per sec. and decreased as the temperature increased. The values obtained for thermal conductivity depended not only on the composition but also, although to a much smaller extent, on structure, free ferrite being a much better conductor of heat than eutectoid pearlite. The influence of silicon was to lower the conductivity considerably, but with over 2 per cent. of silicon the falling-off in conductivity was reduced, owing to the formation of a ferrite structure. Phosphorus tended to produce a slight decrease in thermal conductivity, and manganese had a somewhat similar effect. As regards alloy additions, nickel produced a similar effect to silicon. Vanadium had little influence, while chromium and tungsten tended to raise the conductivity. Heat-treatment at 550 deg. C. at first increased the thermal conductivity due to pearlite decomposing to form ferrite and graphite, after which oxidation of iron in the vicinity of the graphite flakes caused a slight decrease.

TABLE I.—*Composition of Plain and Alloy Cast Irons*

Cast iron.	Plain 1.	Copper.	Plain 2.	Chromium molybdenum
	Per cent.	Per cent.	Per cent.	Per cent.
T.C ..	3.20	3.18	3.11	3.12
Si ..	1.56	1.58	2.26	2.31
Mn ..	0.72	0.69	0.39	0.38
Cr ..	—	—	—	0.54
Cu ..	—	1.58	—	—
Mo ..	—	—	—	0.77

Since these investigations were carried out, considerable advances have taken place in the metallurgy of cast iron, and have resulted in the development of the high-duty and alloy cast irons. As it had been found that alloy additions exerted an important influence on the heat-conductivity property of cast iron, it was considered of interest to investigate this property in those newly developed irons with a view not only of determining the effect of the combination of alloying elements already experimented with, but also to determine the effect of new alloying elements, while at the same time obtaining reliable data on the thermal conductivity of such irons.

2. Composition of Cast Irons Tested

The first series of cast irons tested consisted of two unalloyed or plain cast irons and two alloy cast irons. The former were cast from two hematite and steel base mixtures and contained varying amounts of silicon and manganese. To the lower silicon iron copper was added, and to the higher silicon iron additions of chromium and molybdenum were made. The compositions of the four irons are given in Table I. All the irons were cast in bars 20 in. long by 0.875 in. dia. and were poured in green-sand moulds.

TABLE II.—*Composition of High-Duty Cast Irons.*

Cast iron.	Plain.	Molybdenum.	Ni-Tensyl.	Manganese nickel.	Nickel chromium.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
T.C ..	2.61	2.56	2.80	3.10	3.41
Si ..	2.46	2.20	2.51	2.51	1.03
Mn ..	0.45	0.63	0.68	3.11	0.65
Ni ..	—	—	1.71	1.00	1.49
Cr ..	—	—	0.54	—	0.54
Mo ..	—	0.58	—	—	—
Tensile strength tons per sq. in. ..	22.7	25.4	25.0	24.7	21.5

The second series of cast irons tested are commercial high-duty cast irons, and include an unalloyed cast iron, a molybdenum iron, a manganese-nickel iron, a nickel-chromium iron, and a Ni-Tensyl iron. The compositions of these irons, which were cast in 1.2-in. dia. bars in dry-sand moulds, are given in Table II, together with their tensile strengths.

The heat-resisting cast irons Ni-Resist and Nicrosilal, together with an aluminium-chromium cast iron, formed the third series of irons tested, and their compositions are given in Table III.

3. Apparatus Used and Method of Manipulation

The apparatus used in determining the thermal conductivity, a sketch of which is given in Fig. 1, has already been described in various Papers, so that only a brief description is now necessary. It

TABLE III.—*Composition of Heat-Resisting Cast Irons.*

Cast iron.	Ni-Resist.	Aluminium-chromium.	Nicrosilal.
	Per cent.	Per cent.	Per cent.
T.C ..	2.41	2.70	1.81
Si	1.80	0.96	6.42
Mn	0.62	0.58	—
Ni	13.70	—	18.65
Cr	3.37	0.95	2.02
Cu	6.41	—	—
Al	—	7.00	—

is an apparatus based on the familiar guard-ring method of determining conductivity, designed for use in a commercial laboratory, and combines fair accuracy with fairly rapid manipulation. The flow of heat is measured by three thermocouples, placed 4 in. apart in a test-bar 15.5 in. long by 0.75 in. in diameter. The test-bar is heated by means of an electric heater, and the amount of heat flowing through the bar is measured by means of a continuous flow calorimeter. Lateral loss of heat is compensated for by an insulated guard-ring heated and cooled in a similar manner to the test-bar. Determinations were made over a range of temperature varying from 40 to 530 deg. C., copper-constantan thermocouples being used for the lower temperature measurements and platinum-rhodium for the higher temperatures. The thermometers used were standard ones reading to 0.05 deg. C.

The thermal conductivity K was calculated by the formula:

$$K = \frac{W\,(t_1 - t_2)\,l}{(T_1 - T_2)\,a}$$

Where

W = weight of water in grm. flowing through calorimeter C;
t_1 = temperature of outlet water from C in deg. C.;
t_2 = temperature of inlet water to C in deg. C.;
T_1 = temperature of the hotter thermocouple in deg. C.;
T_2 = temperature of the colder thermocouple in deg. C.;
l = distance between the thermocouples in cms.;
a = cross-sectional area of the bar in sq. cms.

Determinations for each iron were made over five varying temperature ranges, and a period of six hours was allowed at each range to obtain a heat balance and to establish equilibrium conditions. Three sets of readings were taken, and the average values obtained were used in calculating the thermal conductivities for the two different temperature ranges measured.

The various sources of error which may occur in using this apparatus have been very fully considered and a detailed description of the

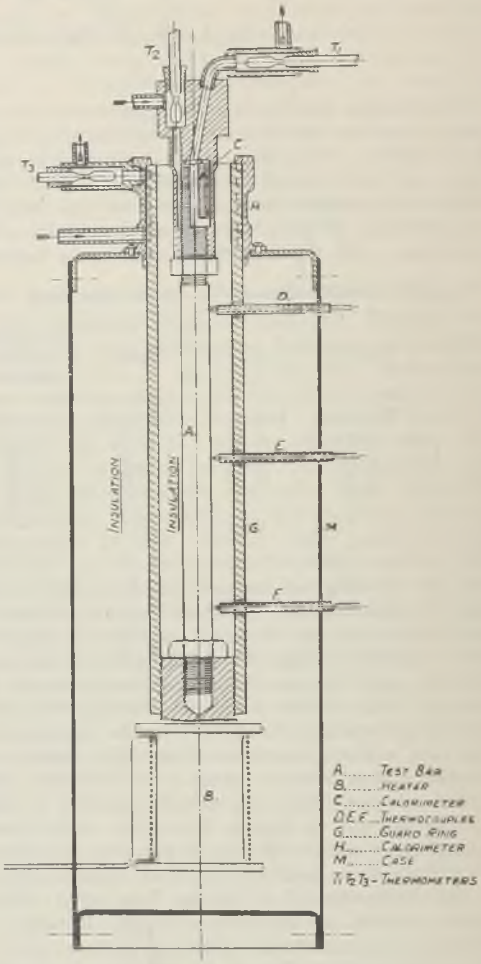

FIG. 1.—APPARATUS FOR DETERMINING THERMAL CONDUCTIVITIES.

methods adopted to check them has been published.[2] When such sources of error are considered, they show that, provided the test-bar is made to accurate dimensions and the apparatus is properly manipulated, the results obtained cannot vary by more than 2 per cent. As an additional check on the apparatus and the accuracy of the thermocouples and thermometers, a

commercially-pure aluminium test-bar, kept specially for calibration purposes, was tested before and after the determinations of each series of irons.

4. Consideration of Results

The results of the determinations for the various cast irons are given in Tables IV to XV. Curves plotted from these determinations showing the variation of thermal conductivity with the mean temperature for each of the three series of cast irons are given in Figs. 2 to 4. In Table XVI are given the thermal conductivity values at 100 and 400 deg. C. of unalloyed and alloyed cast irons determined in a previous investigation[1] and in Table XVII the thermal conductivity values at similar temperatures of all the irons experimented with in the present investigation.

TABLE IV.—*Plain Cast Iron.* I.

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	51–118	84.5	0.122
	118–187	152.5	0.118
2	74–154	114.0	0.121
	154–237	195.5	0.117
3	130–252	191.0	0.117
	252–382	317.0	0.111
4	144–306	225.0	0.115
	306–480	393.0	0.107
5	160–3 4	247.0	0.115
	334–5 0	427.0	0.107

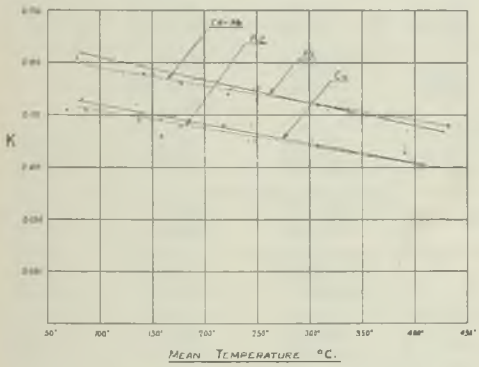

FIG. 2.—THERMAL CONDUCTIVITIES OF PLAIN AND ALLOY CAST IRONS.

Consideration of the data in these two tables and of the curves in Figs. 2 to 4 shows the unalloyed iron P1 to have a somewhat similar heat-conducting value to the unalloyed iron S8 previously determined which contained approximately the same amount of silicon. The addition of 1.58 per cent. of copper lowers the conductivity of the former iron from 0.121 to 0.112 at 100 deg. C. with a proportional decrease at 400 deg. C. The plain iron P, which is of lower carbon content and higher silicon content than P1, has a thermal conductivity of 0.110 at 100 deg. C., due to its higher silicon content, a value somewhat similar to that obtained with the plain iron P2, which contains slightly lower silicon but a higher carbon content. The thermal conductivity of P is increased to 0.118 by an addition of 0.58 per cent. of molybdenum, and that of P2 is raised to approximately the same value by an addition of 0.54 per cent. of chromium and 0.77 per cent. of molybdenum.

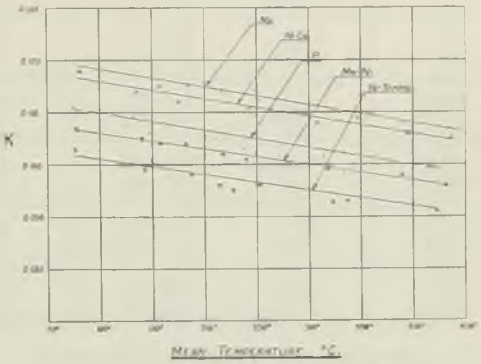

FIG. 3.—THERMAL CONDUCTIVITIES OF HIGH-DUTY CAST IRONS.

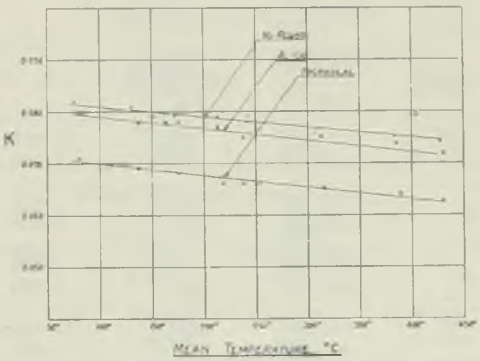

FIG. 4.—THERMAL CONDUCTIVITIES OF HEAT-RESISTING CAST IRONS.

The results obtained from these five cast irons show that copper lowers the thermal conductivity of cast iron in a similar manner to silicon and nickel. Its influence, however, is not so marked as that of silicon or nickel. In

Fig. 5 is shown the influence of silicon in lowering the thermal conductivity of cast iron, as determined by the author[3] in a previous investigation, where experiments were made on a series of cast irons containing 0.65 to 6.49 per cent. silicon. From this curve it appears that 0.8 per cent. of silicon lowers the thermal conductivity

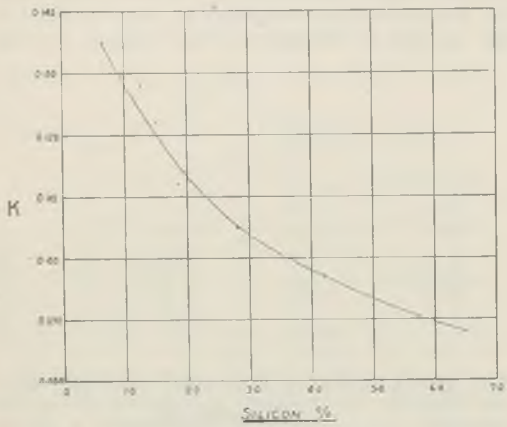

FIG. 5.—VARIATION OF THERMAL CONDUCTIVITY WITH SILICON.

approximately 0.01, while the present determination with copper shows that twice the amount of this element is required to produce the same effect. As regards the influence of nickel, reference to Table XVI shows that a nickel addition of 0.75 per cent. produces a fall in thermal con-

TABLE V.—*Copper Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	47–120	83.5	0.113
	120–195	157.5	0.109
2	80–189	134.5	0.112
	189–302	245.5	0.108
3	107–236	171.5	0.110
	236–368	302.0	0.105
4	136–304	220.0	0.108
	304–478	391.0	0.104
5	152–331	241.5	0.105
	331–518	424.5	0.100

ductivity of 0.013 or approximately 10.5 per cent. The influence of copper in lowering the heat-conducting properties of cast iron would therefore appear to be less than half that of silicon, while the influence of nickel is probably 30 per cent. more than that of silicon.

The influence of molybdenum is to raise the thermal conductivity of cast iron in a similar manner to chromium and tungsten. Its influence, however, is not so marked as in the case of these elements, for when the values given in Tables XVI and XVII are considered it is observed that a similar rise in thermal con-

TABLE VI.—*Plain Cast Iron.* 2.

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	51–122	86.5	0.110
	122–196	159.0	0.106
2	85–192	138.5	0.109
	192–303	247.5	0.105
3	114–242	178.0	0.108
	242–375	308.5	0.104
4	133–302	217.5	0.108
	302–478	390.0	0.103
5	143–327	235.0	0.105
	327–518	422.5	0.100

ductivity of approximately 7.3 per cent. is produced by 0.4 per cent. of chromium, 0.5 per cent. of tungsten, or 0.6 per cent. of molybdenum. Alloying of the two elements, chromium and molybdenum, in cast iron in proportions of 0.54 and 0.77 per cent. does not appear to produce a very much greater increase in conductivity, as the value obtained for the chromium-molybdenum iron at 100 deg. C. is only

TABLE VII.—*Chromium-Molybdenum Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	43–115	79.0	0.121
	115–189	152.0	0.118
2	87–197	142.0	0.118
	197–309	253.0	0.115
3	115–242	178.5	0.116
	242–374	308.0	0.112
4	139–307	223.0	0.114
	307–483	395.0	0.110
5	159–339	249.0	0.113
	339–528	433·5	0·108

8.2 per cent. higher than in the corresponding unalloyed iron.

The thermal conductivity values for the high duty irons, Ni-Tensyl, manganese-nickel, and nickel-chromium indicate the influence which the special element additions in combination with

silicon have on the heat-conducting property of these materials. The Ni-Tensyl and the manganese-nickel cast irons have similar silicon contents to the plain iron P. The thermal conductivity values of the three irons at 100 deg. C. are 0.101, 0.106, 0.110. The decrease in conductivity in the Ni-Tensyl iron is produced by the addition of 1.71 per cent. of nickel and in

TABLE VIII.—*Low-Carbon Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	40–111	75.5	0.110
	111–185	148.0	0.106
2	80–186	133.0	0.109
	186–296	241.0	0.105
3	117–246	181.5	0.107
	246–380	313.0	0.102
4	126–294	210.0	0.104
	294–468	381.0	0.101
5	146–330	238.0	0.103
	330–520	425.0	0.099

TABLE IX.—*Molybdenum Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	47–118	82.5	0.118
	118–191	154.5	0.115
2	84–191	137.5	0.118
	191–302	246.5	0.114
3	122–248	185.0	0.115
	248–380	314.0	0.110
4	134–302	218.0	0.114
	302–478	390.0	0.108
5	162–341	251.5	0.112
	341–530	435.5	0.107

TABLE X.—*Ni-Tensyl Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	38–114	76.0	0.103
	114–192	153.0	0.100
2	87–196	141.5	0.099
	196–308	252.0	0.096
3	120–254	187.0	0.098
	254–392	323.0	0.093
4	129–300	214.5	0.096
	300–476	388.0	0.093
5	133–324	228.5	0.095
	324–521	422.5	0.091

TABLE XI.—*Manganese-Nickel Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	45–120	82.5	0.107
	120–197	158.5	0.104
2	86–194	140.0	0.105
	194–305	249.5	0.102
3	116–248	182.0	0.104
	248–385	316.5	0.099
4	132–302	217.0	0.102
	302–477	389.5	0.098
5	146–335	240.5	0.101
	335–531	433.0	0.096

TABLE XII.—*Nickel-Chromium Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	44–119	81.5	0.118
	119–190	154.5	0.115
2	81–188	134.5	0.114
	188–298	243.0	0.111
3	110–241	175.5	0.112
	241–376	308.5	0.108
4	141–308	224.5	0.110
	308–481	394.5	0.106
5	153–340	246.5	0.109
	340–534	437.0	0.105

TABLE XIII.—*Ni-Resist Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	35–113	74.0	0.082
	113–194	153.5	0.079
2	76–186	131.0	0.081
	186–299	242.5	0.079
3	104–239	171.5	0.079
	239–379	309.0	0.076
4	129–297	213.0	0.079
	297–471	384.0	0.075
5	149–333	241.0	0.078
	333–524	428.5	0.074

the manganese-nickel iron by the 1.0 per cent. of nickel. In view of what has been indicated of the influence of nickel in lowering the thermal conductivity of cast iron a larger decrease might have been expected in both irons. The addition of chromium in the one iron and of manganese in the other appears to have had a beneficial effect in counteracting the full influence of the nickel. A somewhat similar result is obtained with the nickel-chromium iron. This iron on account of its lower silicon content cannot be compared with the unalloyed iron P, but if the value for an unalloyed iron containing 1 per cent. of silicon is derived from Fig. 5 and is taken as 0.127, the influence of the nickel addition of 1.49 per cent. in lowering the conductivity and the counteracting effect of the 0.54 per cent. of chromium are seen in the value of 0.116 obtained at 100 deg. C.

The influence of special elements in lowering the thermal conductivity of cast iron is also seen to a more marked degree when the values obtained for the three irons in the third series are considered. The Nicrosilal containing ap-

TABLE XIV.—*Aluminium-Chromium Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	44–123	83.5	0.080
	123–205	164.0	0.078
2	80–193	136.5	0.078
	193–307	250.0	0.077
3	106–242	174.0	0.078
	242–382	312.0	0.075
4	127–298	212.5	0.077
	298–474	386.0	0.074
5	144–333	238.5	0.075
	333–527	430.0	0.072

TABLE XV.—*Nicrosilal Cast Iron.*

Test.	Temperature range. Deg. C.	Mean temperature. Deg. C.	K.
1	40–119	79.5	0.071
	119–199	159.0	0.070
2	82–195	138.5	0.069
	195–310	252.5	0.068
3	107–244	175.5	0.068
	244–385	314.5	0.065
4	132–303	217.5	0.066
	303–479	391.0	0.064
5	143–333	238.0	0.066
	333–528	430.5	0.063

TABLE XVI.—*Thermal Conductivities of Plain and Alloy Cast Irons at* 100 *and* 400 *deg. C.*

Mark.	Composition.							K.	
	T.C.	Si.	Mn.	Ni.	Cr.	V.	W.	100 deg. C.	400 deg. C.
S.8	3.16	1.48	0.97	—	—	—	—	0.122	0.108
S.9	3.25	1.91	0.97	—	—	—	—	0.110	0.103
Mn	3.32	1.52	2.43	—	—	—	—	0.118	0.101
Ni	3.16	1.56	0.94	0.75	—	—	—	0.108	0.101
Cr	3.17	1.40	0.97	—	0.39	—	—	0.131	0.114
V	3.19	1.45	0.99	—	—	0.124	—	0.122	0.103
W	3.02	1.89	0.76	—	—	—	0.475	0.118	0.105

TABLE XVII.—*Thermal Conductivities of Plain and Alloy High-Duty Cast Irons and Heat-Resisting Cast Irons at* 100 *and* 400 *deg. C.*

Mark.	Composition.								K.	
	T.C.	Si.	Mn.	Ni.	Cr.	Mo.	Cu.	Al.	100 deg. C.	400 deg. C.
P.1	3.20	1.56	0.72	—	—	—	—	—	0.121	0.108
Cu	3.18	1.58	0.69	—	—	—	1.58	—	0.112	0.101
P.2	3.11	2.26	0.39	—	—	—	—	—	0.111	0.101
Cr–Mo ..	3.12	2.31	0.39	—	0.54	0.77	—	—	0.119	0.109
P	2.61	2.46	0.45	—	—	—	—	—	0.110	0.100
Mo	2.56	2.20	0.63	—	—	0.58	—	—	0.118	0.108
Ni-Tensyl ..	2.80	2.51	0.68	1.71	0.54	—	—	—	0.101	0.092
Mn–Ni ..	3.10	2.51	3.11	1.00	—	—	—	—	0.106	0.097
Ni–Cr ..	3.41	1.03	0.65	1.49	0.54	—	—	—	0.116	0.106
Ni-Resist ..	2.41	1.80	0.62	13.70	3.37	—	6.41	—	0.081	0.075
Al–Cr ..	2.70	0.96	0.58	—	0.95	—	—	7.00	0.079	0.072
Nicrosilal ..	1.81	6.42	—	18.65	2.02	—	—	—	0.070	0.063

proximately 18.5 per cent. of nickel and 6.5 per cent. of silicon has a value of 0.070 at 100 deg. C. Replacing part of the nickel by copper and reducing the silicon content, as is done in the Ni-Resist, raises the heat-conducting value of the iron by 15 per cent., a conductivity of 0.081 being obtained at 100 deg. C. A somewhat similar value of 0.079 at 100 deg. C. is obtained with the aluminium-chromium iron. This low value is produced in an iron containing a low percentage of silicon by the addition of 7.0 per cent. of aluminium, which would appear to indicate that aluminium has a very marked effect on the thermal conductivity of cast iron, an effect which is much greater than that produced by nickel.

5. Conclusions

The general conclusions to be formed from the above data may be summarised as follow:—

(1) The thermal conductivity of grey cast iron is lowered by copper in a similar manner to which it is lowered by silicon and nickel. The influence of copper, however, is approximately half that of silicon.

(2) Molybdenum tends to raise the thermal conductivity of grey cast iron, and in this respect acts in a similar manner to chromium and tungsten, although its influence is not so pronounced.

(3) Where nickel and chromium or nickel and manganese are alloyed together in cast iron, the influence of nickel in lowering the thermal conductivity is counteracted to a slight degree by the chromium or manganese.

(4) A large proportion of nickel has a pronounced influence in lowering the thermal conductivity of cast iron, but where part of the nickel is replaced by copper, the influence is not so marked.

(5) Aluminium, even in the presence of chromium, has a very pronounced influence in lowering the thermal conductivity of grey cast iron.

The author's thanks are due to Mr. J. Brown, C.B.E., and the other directors of Scotts' Shipbuilding & Engineering Company, Limited, of Greenock, for permission to carry out the above investigations. He also wishes to thank Mr. J. Arnott, F.I.C., of G. & J. Weir, Cathcart; Dr. A. B. Everest, of the Mond Nickel Company, Limited, London; and Mr. J. G. Pearce, M.Sc., of the British Cast Iron Research Association, for the samples of the various cast irons tested.

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DISCUSSION

Mr. F. J. Cook (Birmingham) said every foundryman was indebted to Dr. Donaldson for his work in that particular field. Did Dr. Donaldson agree that the amount of combined carbon—also the addition of graphite—had an effect on the results he had obtained of thermal conductivity, and would he include with his Paper, when it was printed, some particulars of these features?

Dr. J. W. Donaldson replied that such information had been given in previous Papers. Graphite did not appear to exert a marked influence except where it affected the denseness of the iron. Combined carbon certainly had an influence, as it had been previously shown that free ferrite was a much better conductor of heat than eutectoid pearlite, owing to the relative conductivities of ferrite and cementite which had been determined as 0.174 and 0.017 respectively.

The Lorenz Constant

Mr. M. M. Hallett said that, taken in conjunction with his earlier publications, the present Paper gave a clear idea of the effect of composition on the thermal conductivity of cast iron, a field of investigation which Dr. Donaldson had made his own. The value of the Paper would have been enhanced if measurements of the electrical conductivity of the bars under test had also been made, even if only at room temperature, as in most laboratories this property was much more convenient to determine, and reliable data regarding the Lorenz constant would enable a reasonably close estimate of the thermal conductivity to be made. Dr. Donaldson might actually have some data on this point which he had not incorporated in the Paper. The values of the Lorenz constant available in the literature could not be regarded as adequate.

One might comment on the presence of 0.54 per cent. chromium in the sample of Ni-Tensyl iron. This material did not normally contain chromium in any appreciable amount.

The Relationship with Carbon Affinity

An outstanding point, which must have struck all metallurgists familiar with the constitution of cast iron, was the manner in which the effect of alloy elements on thermal conductivity was related to their affinity for carbon. Thus chromium, tungsten and manganese raised the conductivity in almost exact proportion to the stability of their carbides, while the graphitising elements, nickel and silicon, lowered the conductivity. In the Paper presented by Dr. Everest and the speaker, an endeavour had been made to show the importance of the carbon con-

tent of the austenite on the properties of martensitic white iron. Might it be that those elements forming stable carbides raised the conductivity of an iron by causing the withdrawal of carbon from solution in the ferrite lamellæ of the pearlite, the ferrite presumably being the chief conducting structural phase, and therefore the phase in which one must look for changes to account for variations in conductivity? The relative effects of nickel and silicon, unexpected in view of the considerably greater graphitising power of silicon, might be explained by reference to the greater effect of silicon in precipitating carbon from solution in ferrite. This would raise the conductivity in opposition to the direct influence of silicon in decreasing conductivity as it entered into solution. Light might be thrown on this suggestion by an examination of oil-quenched samples where the degree of dispersion of the carbon would be the same in both cases. Under these conditions the chromium might even lower the conductivity.

In conclusion, he would like to congratulate Dr. Donaldson on adding another link to his interesting chain of investigations on the thermal conductivity of cast iron, a study which was yielding results both of practical and theoretical interest.

Dr. Donaldson said the determination of the Lorenz coefficient for cast iron was certainly very important. He had not made any electrical resistivity determinations on the various cast irons, but he appreciated the value that would be obtained from such work. The temperature range over which thermal conductivity values could be determined was limited due to heating conditions, but such limitations were not imposed on electrical resistivity determinations. If the Lorenz coefficient could be shown to hold for cast iron both at high and low temperatures, it would be possible to obtain the thermal conductivity at high temperatures by determining the electrical resistivity. Such work had still to be carried out on cast iron, and he hoped it would be done in the near future.

He agreed with Mr. Hallett's remarks on the affinity of carbon for such elements as chromium, molybdenum and tungsten, and their influence on thermal conductivity. He was also interested in what Mr. Hallett had said with regard to thermal conductivity determinations at low temperatures, and thought that it was possible such results might be obtained.

Industrial Application of Results

The Chairman (Major Miles) asked Dr. Donaldson if he could explain in general terms the desirable properties in thermal conductivity due to the advance from low-pressure steam to high-pressure steam and superheated steam and the internal-combustion engine.

Dr. Donaldson said the investigations were initiated many years ago in connection with the construction of large internal-combustion engines in order to determine which cast irons were most suitable for cylinder liners and piston heads. Aluminium alloys, which had high thermal conductivities and which were used in motor vehicle and aircraft engines, were not used in this type of construction to any marked extent. It was essential to use cast iron having good mechanical properties, high resistance to growth at elevated temperatures and as high a thermal conductivity as possible consistent with the other properties. There were also certain other applications, particularly in turbine and valve construction and in furnace construction, where the value of this constant for cast iron, and particularly for high-duty and heat-resisting cast irons, was of importance.

Paper No. 667

The Effect of Melting Conditions on Light Alloys

By A. J. MURPHY, M.Sc. (Member), S. A. E. WELLS and R. J. M. PAYNE, B.Sc.

There is a general recognition nowadays of the important *rôle* played by the conditions prevailing during melting in the production of aluminium and magnesium alloy castings of high quality. The present communication describes some observations on this aspect of metallurgical control which have come under the authors' notice and which it is hoped may be of interest in a discussion of melting conditions as they affect foundry processes.

Equipment

On comparing notes of the experience of different foundries, it is found that satisfactory results are obtained from a large variety of fuels, furnaces and crucibles, and the ultimate choice from among these is often governed by local conditions, such as the relative costs of oil, gas and coke or the maximum and minimum weights of castings to be produced. The plant with which the authors are concerned comprises separate foundries for sand-casting and die-casting and for aluminium alloys and magnesium alloys. Oil-burning crucible furnaces are used throughout; for aluminium alloys the crucibles in the stationary bale-out furnaces are of graphite-clay, and those in tilting furnaces are of cast iron; pressed steel crucibles are used for magnesium alloys both in tilting and stationary furnaces.

EFFECT OF MELTING CONDITIONS ON COMPOSITION

(a).—Contamination

The absorption of gases by molten metals is a form of contamination, but in ordinary foundry usage the term is limited to the entry into the metal of non-gaseous impurities. An obvious potential source of such impurities is the crucible. Since both aluminium and magnesium are strong reducing agents at elevated temperatures, they present the possibility of contamination by reduction of oxygen-containing refractory materials and the alloying of the reduced element, *e.g.*, silicon, with the light metal. In the case of cast-iron and steel crucibles, the danger of contamination by iron through direct alloying with the material of the crucible has also to be considered. In both these respects there is a sharp distinction between aluminium and magnesium-base alloys.

(I).—*Aluminium Alloys*

As far as the authors are aware, no case of contamination of the normal industrial aluminium alloys through reaction with graphite or silicon-carbide crucibles has been recorded, and certainly no instance of such contamination has occurred within their own experience. This is true both in the presence and absence of fluxes during the melting operation.

Cast iron presents advantages in certain respects over refractory clays as a material for crucibles in the aluminium foundry, notably in better thermal conductivity, superior strength, lower cost and greater facility of production. On the other hand, precautions which are unnecessary in the case of fireclay crucibles have to be observed constantly with iron melting vessels, if contamination of the aluminium alloy with iron is to be avoided. A wash consisting of whitening 10 lbs., water 5 galls. and sodium silicate 6 ozs., applied by brushing to the inside of the crucible, is found to be effective for furnaces which are completely emptied after each melt. It is necessary to renew the wash daily, and if this is carried out conscientiously no appreciable pick-up of iron occurs.

It is an undeniable criticism of the use of iron melting pots that the avoidance of this contamination is dependent upon the protective wash being applied and renewed with care by the fireman or other operator charged with this responsibility. Two instances may be cited to illustrate the serious consequences which may result from contamination of aluminium alloys by iron.

After suitable modification, aluminium-silicon alloy containing silicon 12 per cent. and iron 0.3 per cent., when cast into the usual 1-in. dia. dry-sand mould, shows a fine-grained fracture and mechanical properties of which the following are typical: maximum stress 11 to 12 tons per sq. in. and elongation on $4\sqrt{A}$ 10 to 15 per cent. If melted in a crucible of grey cast

iron without a suitable protective coating, the iron content may readily increase to 1 per cent. With this proportion of iron the alloy shows a bright "crystalline" fracture, with large lustrous facets, and the mechanical properties of a sand-cast test-bar become: maximum stress 9 to 10 tons per sq. in., and elongation on $4\sqrt{A}$ 2 per cent. The loss of ductility is a particularly undesirable feature.

The second case in which reference may be made to the effect of iron contamination is that of the aluminium alloy containing copper 4 per cent., with titanium up to 0.2 per cent. This has been introduced recently for aircraft applications under the provisions of specification D.T.D. 304. In order to attain the mechanical properties specified, namely, a maximum stress of not less than 18 tons per sq. in. and elongation no ess than 4 per cent., it is important that the iron content of the alloy shall not exceed about 0.2 per cent. This alloy is therefore very sensitive to contamination from iron crucibles, and experience in production has shown that if from this or any other cause the iron content rises to 0.35 per cent., the desired properties cannot be attained.

(II).—Magnesium Alloys

Molten magnesium reacts readily with siliceous materials such as fireclay, reducing silica and silicates, the silicon thus produced alloying immediately with the magnesium. No data are available regarding the quantity of silicon which can be absorbed in this way, since fireclay crucibles are never used for magnesium alloys, but it is a well-established fact that if adherent moulding sand is not thoroughly removed from runners and risers before they are remelted, the silicon content of the resulting metal will increase in extreme cases to as high as 1 per cent., as compared with an original value of about 0.1 per cent.

In complete contrast to aluminium, the normal magnesium alloys appear to be practically inert as regards any tendency to alloy with iron, at least up to a temperature of 900 deg. C. This permits crucibles of unlined steel to be used in the magnesium foundry, and the same material can be used for ladles and stirrers. The fluoride and chloride fluxes employed do not affect this reluctance to alloy with iron, and even after repeated fusions of the same charge in one steel crucible no increase of iron content can be detected. The presence of manganese—about 0.3 per cent.—in the magnesium alloy is considered to assist in preventing absorption of iron.

(b).—Change of Composition

Even when contamination, *i.e.*, invasion of the metal by foreign impurities, has been prevented, there remains the possibility of the composition of the charge being altered by the loss of one or more of the constituents during melting, just as phosphorus or zinc can be lost from bronzes and brasses. In general one does not have to contend with volatilisation in alloys of aluminium or magnesium, but the investigation now to be described briefly shows how a change of composition can occur, from other causes, in certain aluminium alloys.

The object of the experiments was to ascertain if any loss of magnesium occurred either when flux degasification treatment was applied to a melt or when the melt was subjected to ordinary melting only without fluxing. Alloy Ceralumin "B" (D.T.D. 287), having the original composition:—Copper, 1.3; silicon, 2.2; nickel, 1.3; magnesium, 0.1; iron, 1.0; niobium, 0.1 per cent., aluminium remainder, was chosen for the investigation, and the effect of repeated application of flux and the influence of remelting several times without flux were examined.

The fluxing experiments were carried out on a single 20-lb. melt, which was treated four times with a dry flux mixture of 2 parts sodium chloride and 1 part sodium fluoride, using 2 per cent. by weight of the salts mixture on each occasion. At each stage the temperature of the metal was raised to 750 deg. C. for fluxing, and after fluxing cooled to 700 deg. C. to enable two standard test-bars to be poured. The heads of the test-bars were cut off and returned to the crucible to maintain an approximately constant area of surface of metal exposed to the action of the flux. The quantity of the metal treated therefore only varied by a few ounces, the amount required for the test-bars.

The remelting experiments without flux were also made on a single 20-lb. melt. The procedure was to raise the temperature of the melt to 750 deg. C., cool to 700 deg. C. and cast two standard test-bars and then pour off the remainder into ingot moulds, the ingots and the heads cut from the test-bars being remelted at each stage. Three stages of remelting were carried out in all.

Samples consisting of turnings from the complete cross-section at the top of a test-bar representative of each stage of the experiments were taken for determination of the magnesium content in both the fluxed and non-fluxed series.

The normal heat-treatment for Ceralumin "B," consisting of heating for 11 hours at 165 deg. C., was applied to the test-bars before making mechanical tests. Brinell hardness determinations were also made on pieces in the "as-cast" condition, as it was thought that some difference might be observed even at this stage if any marked loss of magnesium had occurred. The results of the chemical analyses,

Brinell hardness determinations and tensile tests are given in Table I.

Tensile tests were not carried out on the "remelting series" as it was obvious from the chemical analysis and hardness tests that no loss of magnesium had occurred.

The first series of experiments show conclusively that a serious loss of magnesium can occur from a repetition of the fluxing treatment, resulting in a softening of the alloy, the effect being marked on all the mechanical properties examined. It is clear, therefore, that, if for any reason a melt of an aluminium alloy containing magnesium is treated more than once, or at the most twice, with a flux of the type described, an addition of magnesium should be made to compensate for the loss due to the action of the flux. The same consideration has to be borne in mind if remelted runners and risers constitute a large proportion of the charge, a condition which is likely to arise when the metal ratio on a job is high, *i.e.*, when the weight of the untrimmed casting is large compared with that of the finished casting.

The results of the second series of tests indicate that in the absence of flux, there is no loss of magnesium on repeated melting. Observations on aluminium-base alloys of higher magnesium content, such a Y-alloy containing 1.5 per cent. magnesium, show that they behave in the same way as Ceralumin "B," the actual loss of magnesium with repeated fluxing being greater, as would be expected.

It is a little surprising, in view of these results on aluminium-base alloys, to find that, with magnesium-base alloys containing 8 to 10 per cent. of aluminium, there is no change of composition even after many repetitions of melting under fluxes containing fluorides and chlorides. It is true that, although they contain chlorides and fluorides, the fluxes used for magnesium-rich alloys are not of the same composition as that applied to the aluminium alloys in the present investigation, and it is also conceivable that a more complex flux might be evolved which would not exert a preferential action on the magnesium in aluminium-rich alloys.

TABLE I.—*Effect of Repeated Melting—Ceralumin "B."*

	Repeated fluxing.						Repeated remelting without flux.			
	Mg per cent. by analysis.	"As cast."	Heat-treated.					Mg per cent. by analysis.	"As cast."	Heat-treated.
		Brinell hardness, 10/1000/15.	Brinell hardness, 10/1000/15.	0.1 per cent. proof stress. Tons per sq. in.	Ultimate stress. Tons per sq. in.	Elongation per cent. on 2 in.			Brinell hardness, 10/1000/15.	Brinell hardness, 10/1000/15.
1st fluxing	0.10	65	82	7.04 7.04	12.00 11.80	4 3.5	Original melting	0.12	63.5	79
2nd fluxing	0.08	61.5	78	6.88 6.60	11.40 11.40	3 3	1st remelt	0.12	63.5	81
3rd fluxing	0.08	58.5	75	5.92 5.24	10.92 10.32	4 4	2nd remelt	0.11	62	80
4th fluxing	0.06	58	67	4.64 4.93	10.32 10.53	5 5	3rd remelt	0.12	62	79

EFFECT OF TEMPERATURE ATTAINED BY THE MOLTEN METAL

Just as the alloys of aluminium and those of magnesium differ from each other in their requirements as regards melting vessels and in the effect of flux treatment, so it is also necessary to deal with them separately when considering the effect of the maximum temperature to which the melt is heated before casting.

(a).—Aluminium Alloys

It is generally accepted that when melting aluminium alloys in the foundry, the temperature should not be raised unduly beyond the level required to give a reasonable speed of working and to ensure the correct casting temperature in the metal after it has been removed from the furnace. The principal reasons for avoiding high melting temperatures are usually considered to be the reduction of melting losses through oxidation and the avoidance of gas absorption, the solubility of hydrogen in molten aluminium increasing rapidly with rise of temperature. Fuel consumption and crucible life are also adversely affected by excessive heating of the charge.

The authors have noticed that there is another consequence of high melting temperatures which may be of importance in certain circumstances and which is perhaps not generally realised. This is the effect of melting temperature on the grain size of sand castings.

Whereas with careful working aluminium alloys may be heated to as high a temperature as 800 deg. C., even in furnaces burning gas or oil, without absorbing a harmful amount of hydrogen, there is reason to believe that in many alloys the grain size of sand castings is considerably larger if the temperature of the melt has exceeded 750 deg. C. than if it has been maintained at a lower value. This effect is quite distinct from the influence of pouring temperature: in the alloys under consideration a coarse grain is produced if the temperature of the melt has exceeded the critical value of 750 deg. C., even though the actual casting temperature is about 720 deg. C.

A coarse-grain structure is undesirable for various reasons: it shows its influence first in causing a tendency for intercrystalline cracking

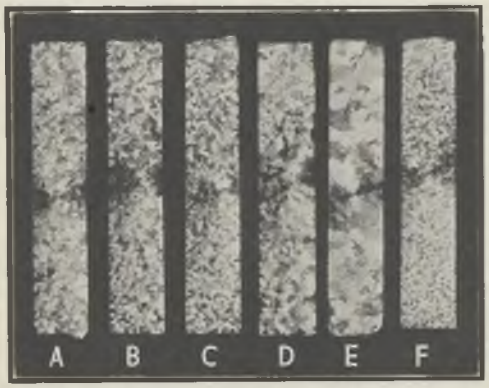

Fig. 1.

A=	Max. temp.	melt	720 deg. C.,	cast	720 deg. C.
B=	,,	,,	740 ,,	,,	,,
C=	,,	,,	750 ,,	,,	,,
D=	,,	,,	760 ,,	,,	,,
E=	,,	,,	800 ,,	,,	,,
F=	,,	,,	800 deg. C., ingotted, remelted 730 deg. C., cast 720 deg. C.		

to occur during the cooling of the casting in the mould, and possibly before solidification has been completed. This cracking is not to be confused with the weakness commonly known as "hot-shortness." Hot-shortness is more characteristic of a particular composition of alloy, and is present under all conditions of melting, whereas the feature now being described is avoided if the melting temperature is not allowed to exceed 750 deg. C.

Metal which has suffered a coarsening of grain through overheating during melting can be corrected by casting into chill moulds, *i.e.*, by ingotting and remelting below the critical temperature.

Fig. 1 illustrates the phenomenon in an alloy having the composition: Copper 2.5, nickel 1.5, iron 1.2, silicon 1.2, magnesium 0.8 per cent., and aluminium remainder. The macro-etched sections shown were taken from sand-cast plates 6 in. by 2 in. by $\frac{3}{8}$ in., all of which were cast at a temperature of 720 deg. C. after heating the melt to the various temperatures indicated. The sudden increase in grain size when the melting temperature passes 750 deg. C. is clearly seen. Precisely similar behaviour has been noted in the case of simple alloys of aluminium with 8 per cent. of copper, and it probably occurs also in other alloys.

Much more experimental evidence would be required before a satisfactory explanation of this effect could be formulated, but it is difficult to avoid the speculation that it may be connected with the formation of nuclei in the fluid metal below a temperature of 750 deg. C., and their disappearance at higher temperatures. It is a matter of conjecture whether these nuclei are particles of a solid phase which liquefies on heating above 750 deg. C. or whether they are merely centres formed by the grouping together of atoms in the liquid metal, but if either of these ideas be correct it still remains to account for the failure of the nuclei to re-form in the melt when the temperature falls below 750 deg. C. once more.

In any investigation of the relation between melting conditions and grain size, it is necessary to guard against the spurious effects which can be introduced by dissolved gas. The escape of gas from the cooling metal as it approaches the freezing point and during solidification causes agitation, which in itself produces a certain degree of grain refinement. It is therefore essential to eliminate this factor, by ensuring that the molten metal is substantially free from dissolved gas, when the influence of other variables is to be studied.

There are many occasions in the aluminium foundry when it is not convenient, or not possible, to operate under such conditions that the temperature of the molten metal does not exceed 750 deg. C. One need only mention the cases where a pouring temperature above this value is required for a casting having thin section in some parts. It is clearly necessary, therefore, to consider what alternative means there are of securing a fine grain in castings without seriously restricting the melting procedure.

Benefits of Fine Grain

It may be useful at this stage to review the benefits which follow from a fine grain size. The grain referred to here is the grain of the macro-structure, which is revealed by simple etching of

machined surfaces and is visible to the naked eye. The founding properties of aluminium alloys are improved when the metal is intrinsically fine-grained, since the risk of cracking in the mould and the tendency towards shrinkage porosity are reduced. The latter advantage appears to result from the greater facility with which metal solidifying with a fine grain " feeds down " from risers during the freezing of the casting. This is especially important in high-strength aluminium alloys, which are always characterised by a large contraction of volume in the transition from the molten to the solid state. In the same alloys heat-treatment by quenching from 500 to 530 deg. C. is often involved, and here again a small grain size reduces the danger of cracking.

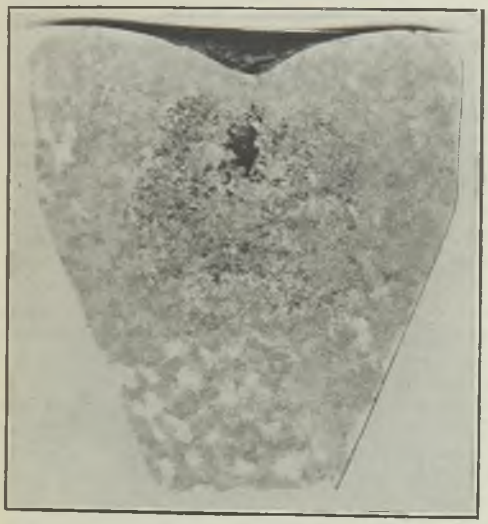

Fig. 2.—Unrefined. Cast 800 deg. C.

When considering the mechanical properties of actual castings, the most important effect of grain refinement is not in conferring high values of strength, but in the greater consistency of properties in the different parts and varying sections.

Although a number of different processes, of a more or less elaborate nature, have been proposed for ensuring a fine grain in aluminium-alloy castings, there is no doubt that the most easily applied method is that of incorporating in the alloy an element which by its presence produces a small size of macro-grain. From among a dozen elements which have been investigated from this point of view, niobium (or columbium) and titanium stand out as the most effective in their grain-refining action. During the past three or four years the authors have been largely concerned with the application of niobium, and the notes which follow refer to the grain-refining influence of this element in relation to melting conditions.

The efficiency of any grain-refining addition in aluminium alloys can be tested and demonstrated by casting the metal containing the addition from a high temperature into a mould which ensures slow solidification; these are the conditions best calculated to produce a coarse grain size if any tendency in this direction exists. For most aluminium alloys, suitable conditions for this test are obtained by pouring the metal at a temperature of 800 deg. C. into a dry-sand mould producing a cylindrical block 3 in. dia. and 3 in. high. In order to avoid too much dispersed unsoundness the mould may be tapered at

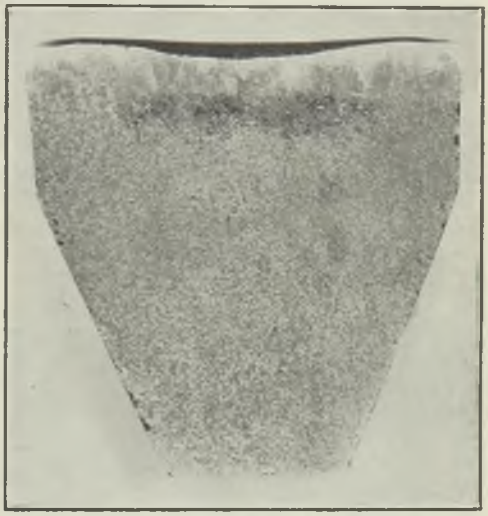

Fig. 3.—Refined. Cast 800 deg. C.

the base to have the form shown in Figs. 2 to 4. The grain size is revealed by sectioning the block along its central axis, machining one of the flat surfaces smooth in a lathe and etching in a suitable reagent.

As an illustration of this grain-refining action the effect of niobium on an alloy having the composition: Copper 2.5, nickel 1.5, magnesium 0.8, silicon 1.2, iron 1.2 per cent. and aluminium remainder, may be cited.

When a gas-free melt of this alloy is cast into the test mould under the conditions described above, grains of 2.5 to 5 mm. diameter are visible in the macro-structure. If, however, 0.1 per cent. of niobium is present in the alloy, the grain diameter is reduced to 0.2 to 1.0 mm. The effect is illustrated in Figs. 2 and 3.

Similar refinement results from the addition of 0.1 per cent. niobium to pure aluminium, simple alloys of aluminium containing up to 8 per cent. copper, the binary alloys of aluminium with magnesium contents up to 10 per cent., copper-free alloys of aluminium with magnesium and zinc, and a wide range of aluminium alloys containing copper, nickel and magnesium with various amounts of iron and silicon.

A grain-refining effect is noticeable with as little as 0.02 per cent. niobium, and the degree of refinement increases with increasing niobium additions until 0.10 per cent. is present. Raising the niobium content above this proportion does not produce any further refinement, so that in practice 0.1 per cent. is employed.

Fig. 4.—Refined. Maintained 900 deg. C. for 4 hrs., cast 900 deg. C.

The stability in relation to melting temperature of the grain refinement due to niobium has been investigated, and it has been found that not only can the alloy be heated to 900 deg. C. without impairing of the grain-refining effect, but it can also be held at this temperature for 4 hrs. and still maintain the fine grain-size. Fig. 4 shows a section of a test block which has been kept at 900 deg. C. for 4 hrs. before pouring at this temperature. It will be seen that it is still characteristically fine. A fair amount of dispersed shrinkage is shown in addition to the major cavity, but this is only to be expected considering the high pouring temperature and the fact that the block is entirely unfed.

It can be seen from the foregoing observations that when using an aluminium alloy which is intrinsically fine-grained, on account of the presence of a special element, the founder is relieved of one serious restriction in melting conditions, namely, the necessity for maintaining the temperature of the melt below the critical level above which grain-coarsening occurs. This is not to say that the other advantages of low melting temperatures, such as decreased gas absorption, do not remain, but a greater latitude in working conditions is certainly permitted.

(b).—Magnesium Alloys

Still another difference in melting technique as between aluminium and magnesium alloys has to be noted in discussion of the effect of the temperature attained by the melt. In aluminium alloys the physical characteristics of the castings are adversely affected if the molten metal is raised to a high temperature, unless special measures be taken to counteract this effect. As a complete contrast, in the case of all the normal magnesium alloys, it is necessary, in order to attain the best properties in the castings, to raise the temperature of the metal, shortly before casting, to a temperature of 850 to 900 deg. C. This is an essential process in the treatment of the Elektron series of magnesium alloys: it has no relation to the casting temperature, which is adjusted after superheating and is usually considerably lower.

The practical effect of the superheating treatment is to produce a marked refinement of the grain size in the castings, with a corresponding improvement in mechanical properties. The grain refinement can be seen in fractures, in the macro-structure of etched sections and also in the microstructure. An indication of the degree of refinement is given by a series of observations made on sand-cast Elektron A.Z. 91 alloy, having the composition: Aluminium, 9.7; zinc, 0.6; manganese, 0.3 per cent. and magnesium remainder.

Four samples of this alloy were drawn from a single original melt. Each of the samples was fluxed in the normal manner, but a different superheating temperature was applied in each case: the first was heated to 750 deg. C., the second to 800 deg. C., the third to 850 deg. C., and the fourth to 900 deg. C., the duration of superheating being the same throughout. Standard 1-in. dia. bars were cast at 680 deg. C. in sand moulds from each melt, and all the bars were finally heat-treated together in the same manner. The heat-treatment consisted of heating the bars for 20 hrs. at 420 deg. C., quenching in water, re-heating for 16 hrs. at 175 deg. C., and finally quenching again in water.

Figs. 5, 6, 7 and 8 show the microstructures of these bars at a magnification of 60 diameters, and demonstrate the reduction of crystal size which results from superheating the molten metal

to a temperature of 850 deg. C. or higher. Table II summarises the mechanical properties, each result given being the average from four test-bars.

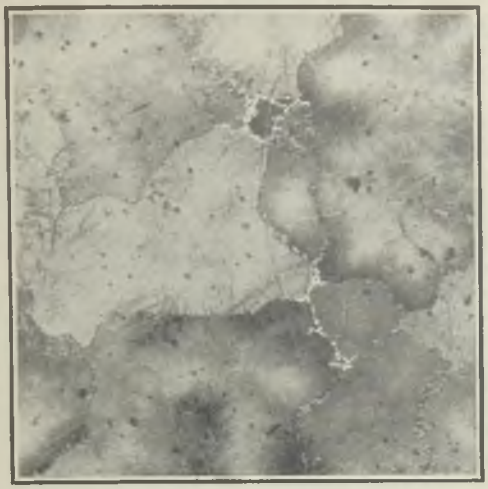

Fig. 5.—Elektron A.Z.91. Superheated 750 deg. C., cast 680 deg. C., heat-treated. × 60.

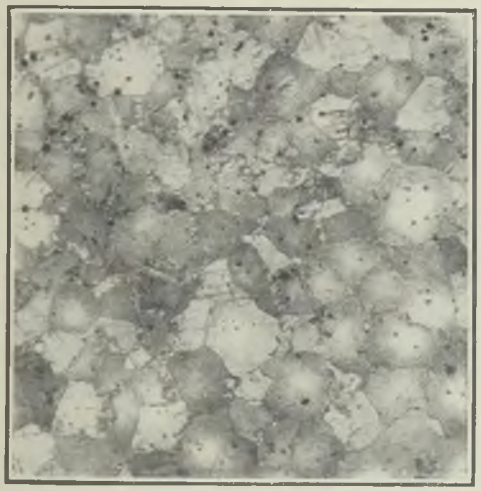

Fig. 7.—Elektron A.Z.91. Superheated 850 deg. C., cast 680 deg. C., heat-treated. × 60.

The metal must be cast without undue delay after superheating, as the grain size becomes coarse again if the melt is allowed to remain for an excessive period at a low temperature. This reversion is noticeable, for instance, in Elektron A.Z. 91 alloy which has been held for 30 mins. between 650 and 700 deg. C., and there is a corresponding deterioration in mechanical properties.

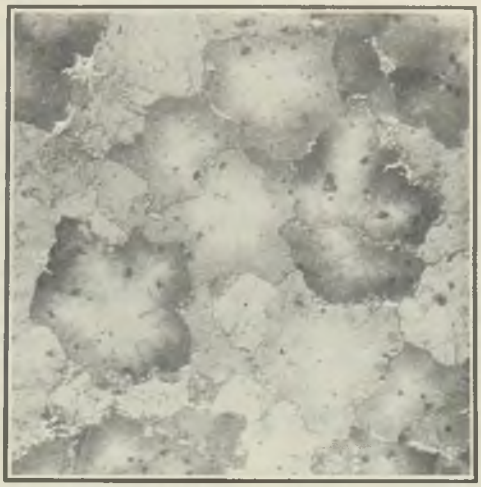

Fig. 6.—Elektron A.Z.91. Superheated 800 deg. C., cast 680 deg. C., heat-treated. × 60.

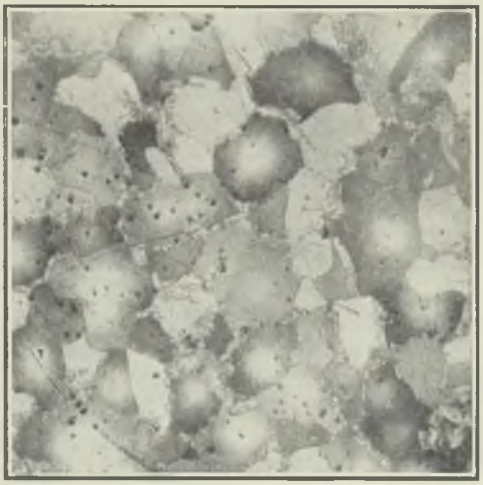

Fig. 8.—Elektron A.Z.91. Superheated 900 deg. C., cast 680 deg. C., heat-treated. × 60.

Another factor which has to be taken into account is the grain size of the metal originally charged into the crucible. A fine grain at this stage facilitates the production of the finest

possible grain after remelting and casting. This is an interesting example of the persistence of a grain characteristic through a melting operation.

TABLE II.—*Influence of Superheating on the Mechanical Properties of an Elektron Alloy.*

Superheating temp. Deg. C.	0.1 per cent. proof stress. Tons per sq. in.	Max. stress. Tons per sq. in.	Elongation per cent. on $4\sqrt{A}$.
750	8.9	15.6	1.2
800	9.4	16.35	1.0
850	9.68	18.6	1.9
900	9.3	17.5	1.3

The authors have been concerned in the present Paper with the influence which melting conditions in the light-alloy foundry can have on the composition and purity of the metal and on the physical characteristics of the castings. The examples and data which have been quoted have been drawn from experience in the technical control of aluminium and magnesium foundries; it is hoped that, for this reason, the Paper may be of some interest to others concerned with the industrial production of light-alloy castings. At the same time, the interrelation between the thermal history of the molten metal and the grain size in the solid state raises questions which seem to call for fundamental metallurgical research. The authors would feel that their communication had served a useful purpose if it could provide some stimulus in this direction.

Acknowledgment

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Paper No. 668

The Effect of Melting Conditions on Gas Unsoundness in Metals

By G. L. BAILEY, M.Sc. (Member)

Unsoundness in cast metal, *i.e.*, the presence of cavities, large or small, may be due to several causes, including contraction of the metal during solidification, mechanical entrapping of extraneous gases and gases evolved on solidification. The present Paper is concerned only with the last of these with particular reference to the influence of melting conditions on gas absorption. That serious unsoundness can be caused by the liberation of gases from the molten metal during cooling and solidification is a well-known fact of which illustration is unnecessary. The gas-holes formed by the trapping of the evolved gas in the casting may be spherical cavities of fair size or fine interdendritic films, depending to a great extent on the freezing range of the alloy. The influence of such defects on appearance, mechanical properties and tightness under hydraulic pressure is obvious, and in the melting and casting of most of the common alloys precautions are necessary to minimise unsoundness of this type.

In considering the possibility of controlling gas contamination during the melting operation it is important to know what gases are responsible for the trouble and to understand the mechanism of gas absorption and evolution in different materials. It is proposed, therefore, to refer briefly to the evidence available on gas solubility and the variations in solubility which result in gas unsoundness. Sources of gas contamination will then be discussed, and some suggestions for minimising gas absorption during melting will be explained. The principles of various methods of removing dissolved gases from contaminated metal prior to casting will be discussed briefly, but detailed consideration of such methods is outside the main subject.

Gas Solubility in Metals

The solubility of gases in metals has been studied by a variety of methods, the most important and fruitful of which has been the measurement of the amount of gas absorbed by a metal when heated in an enclosed system at a known temperature and pressure. The experimental technique needs great care and a number of possible disturbing factors must be controlled.

Much effort has been devoted to the extraction of gases from a sample of metal heated *in vacuo*, followed by analyses of the gases evolved. Widely varying results have been obtained by this method, which is open to serious objections on various grounds, and the most reliable data are those obtained by the first method, one of the pioneers in the use of which was Sieverts.[1] The most significant feature of the results is that in general the solubility of gases is greater in liquid than in solid metals, and there is therefore, with rising temperature, a sudden increase in solubility at the melting point. Solubility in the liquid metal also increases as the temperature is raised still further, until a temperature is reached at which the vapour pressure of the metal itself becomes significant. Sieverts showed that the solubility of an elementary gas in a molten metal at a given temperature was proportional to the square root of the partial pressure of the gas in the atmosphere in contact with the metal, a result to be expected, since it is known that gas molecules dissociate on solution.

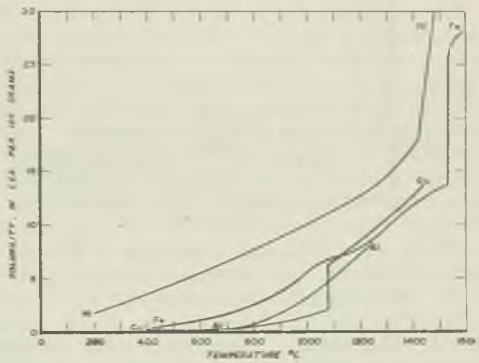

Fig. 1.—Solubility of Hydrogen in Nickel, Iron, Aluminium and Copper.

Hydrogen is the common gas most readily soluble in a large number of metals, and has consequently been the gas with which most of the experimental work on solubility has been done. Fig. 1 shows typical results for the solubility of hydrogen in iron, copper, nickel and aluminium. It will be seen from this that while

in all cases there is an increase in solubility with increasing temperature in the liquid metal, solubilities vary considerably, particularly in the solid state in which, for instance, solubility of hydrogen in aluminium is too small to measure. The presence of hydrogen in these metals can be regarded as a true solution, the equilibrium conditions changing with temperature and pressure according to known laws.

Oxygen (or the metal oxide) is soluble to a considerable extent in some molten metals, such as iron, nickel and copper, but in others, *e.g.*, tin, zinc and aluminium, the oxygen solubility, if any, is very low and accurate data in these instances are lacking. Nitrogen appears to be insoluble except in those metals which are capable of forming nitrides.

These are the three elementary gases which are the most important in this connection, but solubility or otherwise of compound gases is

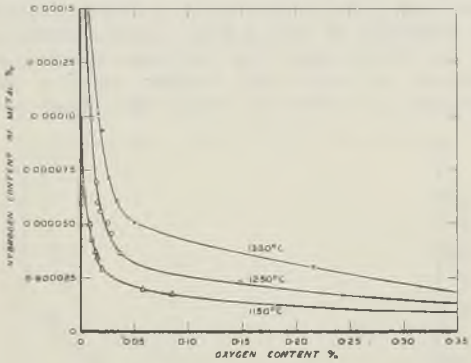

FIG. 2. — OXYGEN-HYDROGEN EQUILIBRIUM IN MOLTEN COPPER AT DIFFERENT TEMPERATURES.

equally important. Such gases as sulphur dioxide and oxides of carbon cannot, according to Smithells,[2] be dissolved as such and can only diffuse into metals after dissociation. In general the two constituents of a soluble compound gas can co-exist up to a certain limit in equilibrium in the liquid metal. Interesting examples of this type of solution of compound gases are sulphur dioxide and water vapour in liquid copper. Both copper sulphide and copper oxide are soluble in molten copper, and in this case the "solubility" of sulphur dioxide increases with temperature very much like a simple solution.[3] The reaction between water vapour and molten copper has been worked out in great detail by Allen and his collaborators.[4] The water vapour is decomposed and the hydrogen and oxygen pass into solution in the melt in equilibrium. Allen and Hewitt[4] have worked out this equilibrium relationship (see Fig. 2) from which it is apparent that the solubility of hydrogen in copper is reduced by the presence of oxygen and *vice versa*. Increasing the temperature or the water vapour concentration increases the amount of both hydrogen and oxygen which can be retained but does not affect the general relationship.

It will be obvious that the constituent elements of a compound gas may be present in a molten metal or alloy in proportions widely different from those of the compound gas, and that their source may not have been the compound gas at all. An example of this is molten steel containing both carbon and oxygen, the source of the carbon being the pig-iron charged and that of the oxygen being an oxidising slag.

The various gas-metal equilibria which are of importance in this connection cannot be dealt with exhaustively here, and these examples have been selected as illustrations of the reactions with which this discussion is concerned.

Formation of Unsoundness by Gas Evolution

The variations in solubility of an elementary gas with temperature (see Fig. 1) are reversible, and if a molten metal saturated with gas at a high temperature is allowed to cool, gas is evolved steadily as the liquidus temperature is approached, and there is a further evolution of gas during solidification. Gas evolved on solidification is inevitably largely trapped in the casting, but the gas evolved on cooling to the liquidus may or may not escape, depending on the conditions. There is, in fact, some doubt as to whether this gas does escape in practice. With slow cooling and exposure of a large surface area it does so, but under ordinary casting conditions it is possible that this gas is either trapped in the casting, owing to the rapidity of solidification, or held in the liquid metal in supersaturated solution and evolved on solidification.

Examples of simple hydrogen unsoundness are afforded by aluminium alloys and tin bronzes, to both of which nitrogen is inert from the point of view of the production of unsoundness. For instance, the results given in Tables I[5] and II[6] have been obtained during the course of researches by the British Non-Ferrous Metals Research Association on aluminium alloys and tin bronzes respectively. The unsoundness obtained after nitrogen-treatment can be assumed in each case to be due to shrinkage only, the increased unsoundness after hydrogen-treatment being due to evolution of hydrogen during solidification.

A point on which there is doubt is whether rapid cooling causes the retention of gas in the solid metal over and above the equilibrium condition. It is known, for instance, that a chill casting made from a gassy melt of bronze or aluminium alloy will contain far fewer gas voids

than a sand casting. Reference to Table II shows this effect clearly, hydrogen-treatment having increased the voids by 1.3 per cent. in the chill-cast bar and by 5.9 per cent. in the sand casting. It is difficult to see how this can be explained other than by the retention of more gas in solid solution in the case of the chill casting.

The mechanism by which a single soluble gas causes unsoundness is thus fairly straightforward, but the part played by compound gases in causing unsoundness is more complex and difficult to evaluate. The simultaneous solubility of oxygen and hydrogen and oxygen and sulphur in copper have already been mentioned. In both cases the oxygen, having a very low solid solubility, is rejected from solution on solidification and reacts, forming water vapour and sulphur dioxide respectively. All known reactions of this type appear to involve oxygen as one of the reactants, and the solubility of oxygen in various metals is therefore a governing consideration. Where oxygen solubility is low, definite values for the solubility are rarely known, and it is often assumed that oxygen is insoluble in such alloys as tin bronzes in the molten state. It must be realised, however, that the amount of oxygen required to produce gross reaction unsoundness is very low. For instance, in a copper-base alloy, oxygen of the order of 0.0001 per cent. by weight would suffice to produce sufficient steam at the melting point to cause 5 per cent. by volume of cavities if enough hydrogen were available.

TABLE I.—*Effect on Soundness of Bubbling (a) Nitrogen and (b) Hydrogen through Molten 93 : 7 Aluminium-Copper Alloy. Sand-cast Bars.*

Gas.	Treatment.		Total voids. Per cent.	
	Time.	Temp. Deg. C.	B.S.I. test-bar.	3 in. dia. cylinder.
Nitrogen	1 hr.	750 to 770	0.1	0.7
Hydrogen	1 hr	740 to 770	2·3	3·1

TABLE II.—*Effect on Soundness of Bubbling (a) Nitrogen and (b) Hydrogen through Molten 5 per cent. Tin Bronze. 1½ in. dia. Bars.*

Gas.	Treatment.		Total voids. Per cent.	
	Time.	Temp. Deg. C.	Chill-cast.	Sand-cast.
Nitrogen	1 hr.	1,200	1.2	3.8
Hydrogen	½ hr.	1,190	2.5	9.7

It was suggested by Daniels[7] that the solubility of oxygen in tin bronzes was sufficiently high to cause unsoundness by steam evolution resulting from reaction between hydrogen and oxygen in equilibrium in the melt. The evidence Daniels advanced was insufficient to justify this conclusion, but later work, still in progress, does suggest that this reaction can and does occur in tin bronzes.

Smithells[8] states that in the majority of cases gas unsoundness in non-ferrous metals is due to reaction between hydrogen in solution and oxygen, and that hydrogen alone diffuses so rapidly through most metals near their melting points that it can seldom develop as bubbles. While reaction unsoundness is extremely important, the author cannot agree that simple hydrogen unsoundness is so rare as Smithells suggests. For instance, in the case of aluminium it seems that oxygen solubility is sufficiently low to preclude reaction gas unsoundness and the author's colleague, Mr. W. A. Baker, has found that no more than minute traces of steam could be developed by treating molten oxide-bearing aluminium with hydrogen.

Reaction unsoundness is the basis of the production of rimming steels. Although the reactions occurring in this case are not fully understood in all points, there seems no doubt that in general McCance[9] is right in attributing the unsoundness to a reaction between carbon and oxygen co-existing in solution in the molten steel and evolving carbon monoxide on solidification. McCance suggests that the evolution of carbon monoxide is due to the rejection of oxygen from solution from the advancing face of the rim. This local concentration of one constituent disturbs the equilibrium and leads to the evolution of carbon monoxide. In practice the rimming action is controlled by maintaining a correct balance of carbon, oxygen and manganese. If the oxide content of the liquid steel is reduced below the solid solubility point, no rimming reaction can occur. The practice of deoxidising or killing steel with silicon or aluminium is effective because such additions remove the oxygen from the bath, and not because, as was at one time suggested, they serve the purpose of increasing the solid solubility of the gas in the steel. The same reaction occurs in nickel, carbon and oxygen being soluble in molten nickel and excess of oxygen above the solid solubility limit reacting with carbon (if enough is present) to evolve carbon monoxide on solidification. As in the case of steel, sound castings can generally be ensured in nickel and high-nickel alloys by suitable deoxidation.

Similarly, in the case of copper, the hydrogen-oxygen reaction, which is adjusted in tough pitch copper to form sufficient steam to neutralise the shrinkage of the metal and give a level set, can be suppressed by the use of deoxidisers, and

the removal of most of the oxygen by means of phosphorus, zinc, etc., from tough pitch copper gives sound metal which solidifies with a deep pipe.

These considerations emphasise the importance of correct deoxidation of molten metals before casting in cases in which remaining oxygen can give rise to injurious reaction unsoundness. For deoxidation to be effective in any particular alloy, the oxygen must be removed to below the solid solubility limit, about which little reliable information exists.

There is, however, another aspect of reaction unsoundness which is extremely important when considering the effect of melting conditions. The reactants in solution in the liquid metal are in equilibrium, and an increase in the concentration of one reactant results in a decrease in the concentration of the other. Thus over-oxidation of a tough pitch copper will reduce the hydrogen content to such an extent that the copper will pipe to some degree on casting. Where there is any solubility of oxygen, therefore, melting under oxidising conditions and thus maintaining or increasing the oxygen concentration tends to lower the concentration of the reducing element (*i.e.*, hydrogen, carbon or sulphur) in the melt, until this ultimately reaches a value at which it does not cause unsoundness. Conversely, melting under reducing conditions may effectively ensure the absence of oxygen and thus eliminate the reaction, although perhaps introducing increased difficulties due to simple gas solution.

Sources of Gas Contamination

Raw Materials.—The inclusion in the charge of materials which contain gas, or which carry hygroscopic corrosion products, obviously constitutes a potential source of trouble. This applies particularly to aluminium alloys, and the work of Hanson and Slater[10] has clearly shown that prior exposure of aluminium or aluminium alloys to corrosive conditions leads to serious unsoundness in castings made from such metal. For instance, virgin aluminium ingots were exposed under different conditions and subsequently used for making up 3L11 sand castings.

Aluminium which had not been exposed and was not corroded gave, under the conditions of test, sound castings (density 2.79 g./cc.), but aluminium exposed outdoors for 6 months or in water for 2 months gave badly pinholed castings after remelting (densities 2.77 and 2.76 g./cc. respectively). This unsoundness is due to some extent to the corrosion product, aluminium hydroxide, holding moisture which reacts with the aluminium on heating, forming hydrogen, which is dissolved by the molten aluminium. It has also been suggested that during the course of corrosion at room temperatures atomic hydrogen diffuses into the metal, where it collects in any internal cavities that may be present.

Furnace Atmospheres

Reliable analyses of the composition of the atmosphere in contact with the metal in different types of melting furnaces are not easy to come by. Considerable numbers of analyses of furnace and flue gases are published, but commonly omit water vapour, clearly most important in the present connection. R. J. Anderson and J. H. Capps[11] analysed the gases in contact with aluminium alloys in various types of melting furnaces without including water vapour. The results they give, however, are of interest and their analyses for four types of furnace are reproduced in Table III. The balance was assumed to be nitrogen.

TABLE III.—*Composition of Furnace Gases.* (Anderson and Capps.[11])

Type of furnace.	Composition per cent. by volume.				
	Oxygen.	Carbon dioxide.	Carbon monoxide.	Hydrogen.	Hydro-carbons.
Stationary gas-fired crucible furnace	0.0 to 4.5	6.7 to 10.8	1.9 to 6.3	0.7 to 6.2	0.3 to 5.4
Stationary oil-fired crucible furnace	2.0 to 12.6	6.4 to 14.5	Nil	0.0 to 0.4	0.0 to 0.5
Open-flame oil-fired reverberatory furnace	2.9 to 20.8	0.1 to 12.1	0.0 to 0.7	0.0 to 0.1	0.1 to 0.4
Indirect-arc rocking electric furnace	0.0 to 7.6	0.0 to 8.4	16.0 to 42.8	0.0 to 28.6	0.0 to 3.0

Allen and Hewitt, in the course of Allen's well-known work on unsoundness in copper, carried out for the B.N.F.M.R.A., made a large number of analyses of the composition of the furnace atmosphere in different types of copper-refining furnaces. The results varied widely according to the position and time of withdrawal of the sample, but the variations in composition obtained are shown in Table IV, the balance again being nitrogen.

These analyses include water vapour, which in fuel-fired furnaces generally constitutes the highest proportion of reactive gas. An interest-

ing feature is the very small proportion of free hydrogen or of hydrocarbons found under the conditions of these determinations. Assuming access of the gas to the metal, any considerable amount of free hydrogen is bound to lead to hydrogen solution in almost any metal. From these analyses little hydrogen would be picked up in this way, and it would appear that the most important source of introduction of hydrogen is reaction with water vapour. The discussion of the "solubility" of water vapour in metals in an earlier section was particularly concerned with cases in which both the hydrogen and oxygen were soluble to some extent. Apart from the production of reaction unsoundness under such conditions, water vapour reacts with metals such as aluminium, forming hydrogen which is dissolved in the metal, and aluminium oxide which accumulates on the surface. Hanson and Slater[12] first called attention to the great importance of water vapour as the source of hydrogen dissolved in molten aluminium, this hydrogen alone being the main cause of pinholing. Some of their results on the effect of treating aluminium and aluminium alloys with steam are reproduced in Table V.

TABLE IV.—*Composition of Furnace Gases.* (Allen and Hewitt.)

Furnace.	Fuel.	Composition of furnace gases. Per cent.						
		O_2	CO_2	CO	H_2	Hydro-carbons.	SO_2	H_2O
Bailey ..	Electric resistance (carbon granules).	0.0 to 0.4	4.1 to 19.3	0.1 to 41.5	0.0 to 1.4	0.0 to 0.9	—	0.25 to 0.8
Reverberatory.	Coal, forced-draught.	0.0 to 22.4	0.3 to 13.5	0.0 to 7.0	0.0 to 2.2	—	0.0 to 1.7	0.0 to 12.6
,,	Coal, natural-draught.	0.2 to 20.9	1.1 to 16.3	0.0 to 15.3	0.0 to 0.2	—	0.0 to 3.0	0.0 to 20.7
,,	Oil	0.0 to 5.8	8.7 to 12.8	0.0 to 7.2	0.0 to 0.2	—	0.3 to 1.4	7.5 to 16.4
Crucible ..	Oil: outside crucible.	2.9 to 4.4	10.8 to 11.6	0	0	0	0.4 to 2.1	8.0 to 13.5
	Oil: 2 in. above metal surface.	0.2 to 3.9	7.7 to 11.3	0.4 to 4.4	0	0	0.4 to 3.0	11.8 to 12.3

The other compound gases which are likely to give trouble are the oxides of carbon and sulphur dioxide. Carbon dioxide at melting temperatures can be regarded as an oxidising gas towards most metals, the first reaction being production of the metallic oxide and carbon monoxide. The rôle played by carbon monoxide itself is somewhat uncertain. There appear to be cases in which carbon monoxide can cause unsoundness by what appears to be a simple solution and consequent evolution on solidification without dissociation forming carbide and oxide. Lepp[13] states that carbon monoxide is soluble in molten copper.

TABLE V.—*Effect of Treating Aluminium and Aluminium Alloys with Steam.* (Hanson and Slater.[12])

Ingot No.	Material.	Treatment of molten metal.	Density.	Appearance.
5	U. "3L11" ..	None. Standard test casting	2.771	Moderate.
6	,, ..	Atmosphere of steam for 1 hr.	2.728	Very bad.
7	,, ..	Brisk stream of steam bubbled in for 1 hr.	2.221	,,
8	,, ..	Brisk stream of steam bubbled in for 3 min.	2.690	,,
12	Virgin aluminium ingot.	None. Standard test casting	2.673	Practically sound.
13	,,	Brisk stream of steam bubbled in for 3 min.	2.469	Very bad.
14	"2L5"	None. Standard test casting	2.934	Moderate.
15	,, ...	Brisk stream of steam bubbled in for 3 min.	2.788	Very bad.

The effect of sulphur dioxide has been much discussed, and definite evidence that this gas causes unsoundness in anything other than pure copper is lacking. There is no doubt that contact with sulphur dioxide is harmful in that it causes absorption of sulphur which may be

soluble in the liquid and thus form sulphides which are trapped on solidification. Sulphur dioxide, for instance, is an undesirable constituent in a furnace atmosphere in the melting of nickel and nickel alloys in which excess of sulphide causes embrittlement. In tin bronzes, there is no clear evidence that the oxygen solubility is high enough to cause marked reaction unsoundness with dissolved sulphur, but it does appear that the solubility of sulphur in the molten metal is sufficiently great to cause serious contamination of the solid metal with sulphide particles. These not only act as discontinuities between the metal crystals but also tend to increase shrinkage unsoundness by mechanical obstruction of the feeding of solidification shrinkage through the interdendritic channels.

Minimising Gas Unsoundness

This discussion leads to certain suggestions concerning desirable melting practice for the reduction of gas unsoundness to a minimum, which can be summarised as follows:—

(*a*) Ensure the use of clean metal free from gas contamination or corrosion product. Similarly avoid charging into the pot damp fluxes or any materials which, on heating, evolve detrimental gases which are liable to be absorbed by the melt.

(*b*) In general, melting in a slightly oxidising atmosphere is to be recommended. This ensures the absence of free reducing gases in the furnace atmosphere and also reduces the amount of detrimental reducing constituents such as hydrogen in the melt. On the other hand, oxidation must, of course, not be overdone, or the result will be a casting badly contaminated with non-metallic oxide inclusions and high oxidation melting losses. It is suggested, however, that in older practice oxidation melting losses have been given an undue importance, and their elimination by melting under reducing conditions is liable to introduce more serious defects in some materials.

(*c*) As far as possible the water-vapour content of the atmosphere should be kept down to a minimum. For instance, coke should be dry. It must be admitted that it is not possible to eliminate water vapour from the atmosphere of any fuel-fired furnace, as the air used for combustion contains from 1 to 2 per cent. of water vapour, and most fuels used contain hydrocarbons, the combustion of which forms water vapour.

(*d*) The metal should be protected as far as possible from direct contact with the flame or with products of combustion. In crucible melting, porosity of the crucible itself is a factor which should be considered, and a crucible which glazes over on the surface has obvious advantages. An inert slag is frequently desirable to protect the exposed surface of the metal. Glass is very effective in this way, but such slags are in general rather corrosive towards crucibles and furnace linings. Charcoal is very largely used as a cover in melting, its use originating mainly with the object of preventing oxidation losses. From this point of view it is very effective, but the use of charcoal as a cover may have a harmful effect either on account of an increase in the carbon-monoxide content of the atmosphere adjacent to the metal surfaces or because it tends to remove excess oxygen from the furnace gases and thus facilitate hydrogen absorption (or alternatively decrease hydrogen elimination).

(*e*) Rapid melting is important. The longer the metal is exposed to a deleterious atmosphere the more opportunity is provided for absorbing detrimental gases, particularly if the metal is allowed to run down exposed to the furnace atmosphere instead of being charged into a pool of molten metal. Rowe,[14] melting 10 per cent. tin bronze containing 0.3 per cent. phosphorus in a coke-fired pit furnace, found a loss of 4 tons per sq. in. in tensile strength and 10 per cent. in elongation when melting time was extended from 45 to 145 min.

(*f*) Over-heating should be avoided. It is apparent from what has been said earlier about increase in solubility of gases in metals as the temperature is raised that heating to a higher temperature than is necessary in the furnace will encourage excessive gas solution, and it is not at all certain that subsequent cooling to the correct casting temperature causes this excess gas to be evolved. This would only be expected to be the case if the metal were saturated with gas at the high temperature. What is more likely is that equilibrium is not reached in ordinary practice, and the additional amount of gas dissolved during the over-heating period is still within the equilibrium amount at the casting temperature.

Removal of Gases

There are some cases in which complete avoidance of gas contamination is difficult and costly, and in such cases, as well as with accidentally contaminated melts, the use of a degassing treatment prior to pouring is the best practical course. It is not proposed here to deal in any detail with the many and varied methods which have been proposed for the removal of dissolved gases, but only to call attention to the general principles involved in these methods. The most important of these is based on Sieverts'[1] observation that the solubility of a gas in a molten metal varies with the square root of the pressure of the gas in the atmosphere in contact with the metal. It follows that a decrease in the partial pres-

sure of a particular gas will result in the removal of a corresponding amount of this gas from solution. Thus hydrogen, for instance, in solution in a metal can be removed if the hydrogen and hydrogen-containing gases are removed completely from the atmosphere by displacement with some inert insoluble gas, such as nitrogen. This is the basis of Archbutt's[15] nitrogen-treatment method for degassing aluminium alloys and of a number of similar methods in which the contaminated atmosphere is swept away and replaced by an inert one into which the dissolved gas will diffuse. Where free diffusion is mechanically obstructed by an insoluble oxide skin, this can be broken up by agitation or removed chemically, as for instance in the titanium tetrachloride[16] and nitrogen plus chlorine[12] treatments of aluminium.

A second method of eliminating easily reducible gases like hydrogen lies, as is apparent from what has been said before, in oxidation of the metal. The difficulties in this case lie in oxidising to just the right extent to eliminate the hydrogen without causing trouble by over-oxidation and in introducing sufficient oxygen where oxygen solubility is low. Reitmeister[17] proposed a method of oxidation by the addition of a metallic oxide followed by reduction by means of carbon, but this necessitates striking the right balance between oxidation and "carburisation." Lepp[13, 18] has taken the application of this principle a great deal further, particularly in the case of bronzes, by providing controlled oxidation by means of an oxidising slag. Excess oxidation is avoided by introducing into the alloy some readily oxidisable metal such as zinc, the oxide of which, formed in preference to other metallic oxides, is readily eliminated from the melt.

The avoidance of unsoundness due to reaction between oxygen and some readily reducible element, like hydrogen or carbon, has been discussed at some length, and the success which can be achieved in this direction by deoxidation of the melt prior to pouring depends entirely on the efficacy of the deoxidant employed. In this connection it must be remembered that the choice of deoxidants in non-ferrous work in particular is limited to those which form deoxidation products which can readily be eliminated from the melt. It has previously been suggested[19] that this applies almost entirely to elements which form fluid oxides or oxide slags, of which phosphorus, silicon and manganese are the most common. These have not anything like so high an affinity for oxygen as, for instance, aluminium, but alumina inclusions are in themselves seriously detrimental from many points of view. Where these elements therefore have not a sufficiently high affinity for oxygen, or a sufficiently low solubility of their oxides in the melt in question, other and more complex deoxidisers have sometimes been employed, as for instance the alkali and alkaline earth elements.

Most of the methods of degasification which are in industrial use, with in some cases highly successful results, depend on one or other of these principles, the application of which will, it is hoped, be clear from the brief outline of the subject given in this Paper.

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JOINT DISCUSSION ON PAPERS NOS. 667 and 668

Gas Holes and Mass Effect

Mr. J. A. Reynolds opened the discussion by referring to de-gasification and modification. He said he had found in the case of small melts of about 25 lbs. in a coke-fired crucible, when a proprietary de-gasser or one of the sodium chloride and sodium fluoride type was used, that when attempting to modify afterwards there were invariably tiny gas holes (not pinholes) left in the thin castings. He wondered whether that was due to the fact that one could not leave small melts such as those of 25 lbs. standing after modification for the same length of time as one could leave a melt of, say, from 100 to 300 lbs.

Reversible Reactions

Mr. H. G. Warrington, commenting on Mr. Bailey's apparent view that all the reactions of gases with aluminium alloys were reversible, said there was considerable evidence that that was not so. The obvious example was that of oxygen, which immediately formed Al_2O_3, and that did not appear to be reversible on solidification of the metal. There was further evidence in, for example, the casting of ingots. They were apparently soundly cast, but after being subjected to a certain amount of cold

work, such as by rolling, there was evidence of gas, by blisters, in quantities which were not obviously present in the original ingot.

Asking for Mr. Bailey's opinion with regard to inter-dendritic porosity, he said that a good many aluminium alloys were subject to such porosity under certain conditions of casting when the eutectic was not sufficient to fill the spaces between the primary grains on solidification; it was generally assumed that the presence of a little gas in the metal would tend to balance that type of porosity by inhibiting to a certain extent the contraction at the moment of solidification. Were there real grounds for assuming that that was of advantage, or was the complete de-gasification of the metal beneficial in all cases?

Admissible Gas Content

Mr. A. J. Shore, enlarging upon Mr. Warrington's remarks, said that recently at his works some trouble had been experienced with shrinkage in a 12 per cent. modified silicon alloy, and the matter had been discussed with the suppliers. The latter had said that the metal was too free from gas and that they would supply metal which had a slight gas content. That was done, and the shrinkage troubles were overcome.

He asked Mr. Murphy whether a 12 per cent. modified silicon alloy was more active with regard to iron pick-up than, say, a 6 per cent. alloy. Did the silicon in the 12 per cent. alloy attack the iron at a greater rate? At his works some trouble had been experienced due to spoiling the modification and obtaining the large crystals referred to in the Paper by Messrs. Murphy, Wells and Payne. The iron content was certainly rather high—it was, however, less than 1 per cent.—and it was decided to scrap the cast-iron melting pots and to use plumbago pots in consequence. He asked for an opinion as to whether that change-over was the right policy.

Magnesium and Aluminium Practice Compared

Mr. G. Lutoslawski (Warsaw) said it had been the belief that the influence of gas upon magnesium alloys could be neglected; but recent experience had shown that the effect of gas upon magnesium alloys, and especially the effect of hydrogen, seemed to be very important from the point of view of the soundness of the castings made in those alloys. Hydrogen pick-up during the melting of magnesium alloys seemed to be due to the moisture in the charged metal, and in many cases it seemed practicable to dry the metal to be charged, in order to avoid that hydrogen contamination. The problem was not yet quite solved. Not only did the hydrogen give rise to porosity, but one could also observe the growth of the grains in the magnesium castings when hydrogen porosity was present. It might be, as Mr. Murphy had said, that in some aluminium alloys a small gas content was beneficial for refining the grain during solidification; but that did not appear to be the case in the magnesium alloys. Indeed, in the magnesium alloys the position seemed to be just the reverse in that respect, just as in many other respects the behaviour of the magnesium alloys was the reverse of that of the aluminium alloys.

Drawing a parallel between the behaviour of magnesium alloys and ferrous alloys such as grey iron and some kinds of steel, Mr. Lutoslawski said that in melting steel which contained chromium, for instance, if hydrogen were present it generated a very coarse structure and sometimes gave rise to considerable trouble. The effect of that phenomenon appeared to be very similar in magnesium, though perhaps for different reasons.

He drew another parallel between magnesium and ferrous alloys in regard to the effect of superheating. By superheating the magnesium alloys one obtained a fine-grained structure, just as one obtained a fine-grained structure in grey iron by superheating. Again the reasons might be different in the two cases, but the effect was similar.

Magnesium Content and Hardness

Mr. A. Logan, congratulating the authors, said that the two Papers formed a very admirable groundwork for anyone entering the field of light alloys. As the industry progressed, technical knowledge grew; those who had entered the field of aluminium alloys years ago would have been in a very fortunate position had the information obtainable from such Papers as these been available in the early days.

The Paper by Messrs. Murphy, Wells and Payne explained quite a number of phenomena which only intelligent pre-knowledge could either cater for adequately or circumvent. Various pitfalls were mentioned, such as gas absorption, and contamination in aluminium and in magnesium alloys, as well as change of composition in alloys containing small amounts of magnesium. The latter effect could be very troublesome, especially in alloys where only, say, 0.3 per cent. of magnesium was the maximum amount present. The effect was a considerable reduction of hardness if the magnesium content fell. In an alloy containing, say, 10 per cent. of copper, 1 per cent. of iron and 0.3 per cent. of magnesium, a reduction of 0.1 per cent. in the magnesium content was sufficient to reduce the Brinell hardness from 150 to 120 in the heat-treated condition. That rendered the alloy quite unsuitable for the purpose for which it was required. The same effect occurred in alloys of higher magnesium content also, and Y-alloy was mentioned in the Paper in that respect. He

asked whether the authors had found the same reduction of magnesium content when chlorine fluxes were used.

Another matter to which he referred was the coarsening of the grain when the metal was held for a long time at a temperature below the critical value of about 750 deg. C. Grain coarsening in some cases seemed to be due to a time-temperature reaction. As to the suggestion that grain-coarsened material produced by heating at 750 deg. C. could be restored to the fine-grained condition by casting in chills and re-melting, he said that that might be accepted with a little reserve, for he could provide examples of material which had not reacted in that way, the coarse grain having persisted even after re-melting. The undesirability of large grain size was well known to aluminium founders, and was rightly stressed in the Paper.

A very remarkable feature mentioned in the Paper was the difference in the feeding properties as between coarse-grained and fine-grained material. The very much improved "feeding" of fine-grained material was quite extraordinary, and it had to be experienced in order to be appreciated fully, but it was a valuable foundry asset.

Commenting on the authors' reference to niobium and titanium as grain-refining elements, he said that possibly they had not covered the whole ground there. He did not suggest that they were not aware of other such elements; but he personally had obtained remarkable results with boron, which had been known for years and was a very powerful grain-refiner.

Finally, he paid a tribute to Mr. Bailey for the valuable nature of his Paper.

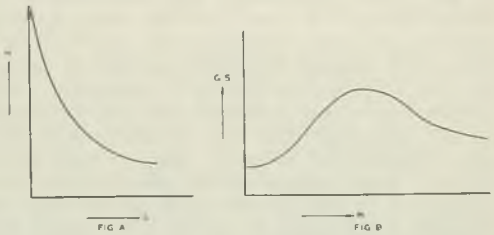
Protection for Cast-Iron Sheaths

Mr. E. N. Noble, dealing with a reference to a protective material for cast-iron pots used for melting magnesium alloys, mentioned his experience on cast-iron pyrometer tubes, when a piece of tube had melted immediately at the surface of the metal and had dropped in. He asked, therefore, whether one could use cast iron for that purpose with a protective material, and, if so, whether Mr. Bailey could recommend such a material.

Grain Size and Nuclei

Mr. G. L. Bailey, discussing the Paper by Messrs. Murphy, Wells and Payne, agreed that the factors influencing grain size should be studied more thoroughly, as too little knowledge was available about the control of grain size and the factors influencing it, although we knew that such things as titanium and niobium would solve the practical problem in aluminium alloys.

Discussing the theoretical side of the question, he said that, so far as we knew, the grain size of the metal depended on the number of nuclei in the melt at the moment solidification commenced. Those nuclei might be of two types, first the type to which Mr. Murphy and his colleagues had referred, *i.e.*, the nuclei which existed in the fluid metal, and secondly, the type of nuclei formed spontaneously at the moment of crystallisation. It was very difficult to determine the extent to which one or the other type was responsible for the ultimate grain size of a particular casting. The nuclei formed spontaneously on solidification were formed in greater numbers the greater the degree of super-cooling. On the other hand, the greater the number of nuclei which existed in the mould to start with—by which he meant the type of nuclei which might or might not be a slag cloud or something of that sort, and which acted as centres of crystallisation—the less the degree of super-cooling. The curve in Fig. A illustrated roughly the effect of the number of nuclei present in the melt (N) on the degree of super-cooling obtained (S).



In the absence of nuclei initially in the mould there might be severe super-cooling, whereas in the presence of large numbers of nuclei, super-cooling might be avoided altogether. Severe super-cooling gave more spontaneously formed nuclei at the moment of solidification. Therefore, it seemed to him that if there were no nuclei of the type mentioned by Mr. Murphy and his colleagues, *i.e.*, those which existed initially in the fluid metal, there might be severe super-cooling and a very fine grain, and with a large number of spontaneously formed nuclei present, one might also get a very fine grain. But between the two there was a moderate degree of super-cooling and a moderate number of nuclei, and one might obtain a coarser grain. This was roughly illustrated in Fig. B, where grain size (GS) is plotted against the number of nuclei present in the melt. The coarsening of grain could therefore be accounted for by two exactly opposite explanations, *i.e.*, because there were fewer nuclei and more super-cooling or, alternatively, more nuclei and no super-cooling. He was not convinced that that theory held universally, or that it held at all, and only mentioned it to support Mr. Murphy's contention that metallurgists ought to find out more of what was

happening on solidification if they were to be able to control grain size in the way they would like.

Deoxidising with Cadmium

Mr. J. A. Reynolds, dealing with the references in Mr. Bailey's Paper to the relative advantages or disadvantages of cadmium as compared with phosphor-copper for the deoxidation of high-conductivity copper sand castings, said there were certain compounds, such as beryllium-cobalt, which were subject to precipitation hardening on heat-treatment. Cadmium offered a much cheaper method of obtaining the same results, but in applying it to sand castings a mass of confused results had been obtained so far. For chill castings, cadmium-copper alloys were used quite regularly, but for sand castings he had not found much to help him so far.

AUTHORS' REPLIES

Mr. Wells' Reply

Mr. S. A. E. Wells, replying to the question of Mr. Shore concerning the relationship of silicon content to iron pick-up when melting alloys in iron pots, expressed the view that Mr. Shore had adopted the right attitude in changing over to plumbago pots as a precaution. The authors had found, however, that the whitening silicate dressings they had recommended were quite effective if properly applied and maintained. With regard to the effect of the percentage of silicon on the pick-up of iron, he believed it was right to say that the higher the silicon content the greater the action upon the iron became.

The authors were unable to say much about Mr. Logan's point in connection with the coarsening of grain of the molten metal resulting from holding the metal for a long time at a temperature below the critical value of about 750 deg.; they had not examined that aspect yet. The authors had always found the correction of the grain size by re-melting at a temperature not exceeding that critical value to be satisfactory. But inasmuch as the question of nuclei mentioned by Mr. Bailey was shown to be so involved, there might be some explanation of irregularity of behaviour about which, at the moment, the authors did not know.

The authors had not made an exhaustive examination of all possible grain refiners, but they did examine a dozen or more. Boron was not examined, because they were already aware of its effects.

Mr. Payne's Reply

Mr. R. J. M. Payne, replying to Mr. Lutoslawski's comments on the solution of hydrogen in magnesium, said that in the experience of the authors that was not a major problem. Where they had had trouble due to coarse grain, the material had always responded to super-heating treatment, and they had never been able to attribute the trouble to hydrogen in the metal. Of course, there was a good chance of the hydrogen dissolving in the magnesium, because the fluxes used contained water of crystallisation. However, he repeated that gas, even if present in magnesium alloys, caused no difficulties.

Mr. Bailey's Reply

Mr. G. L. Bailey, replying to the discussion on his Paper, agreed fully with Mr. Warrington that not all gas reactions were reversible, and he corrected a quite erroneous impression which apparently he had given in that respect. What he had intended to indicate, he said, was that simple gas solubility relationships—for instance, the solution of hydrogen in a metal—were reversible. Gas reactions, however, involving oxides, might or might not be reversible, depending upon the solubility of the oxide in question. In the case of aluminium in particular, where hydrogen was picked up by reaction with water vapour, the oxygen was not taken up at all; that was clearly a case of a non-reversible reaction.

Coming to the question raised by Mr. Warrington and Mr. Shore as to the effect of gas content upon interdendritic porosity and shrinkage, he said there was no doubt that in some types of alloy, especially for certain purposes, such as die-casting, a little gas had advantages. It scattered the shrinkage. The distinction between gas and shrinkage unsoundness was in many cases almost impossible, but it was an advantage in some cases to have the unsoundness scattered throughout the section rather than concentrated in one place. The total amount of unsoundness present, if there were gas, was certainly not less than if there were no gas; it might be more.

The modified silicon alloys were liable to scattered unsoundness which could be produced by gas, but he was becoming more and more convinced that it could be produced also in the absence of gas; with the most thorough degasification and subsequent modification one was still liable to produce scattered unsoundness, due to a scattering of the shrinkage unsoundness by some factor we did not yet understand fully.

With regard to Mr. Reynolds' reference to the relative merits of deoxidisers for copper alloys, he would say from a limited experience that cadmium was not an adequate deoxidiser for copper, and that in making cadmium-copper some other deoxidant must be employed, otherwise there would be unsoundness due to hydrogen-oxygen reactions.

Vote of Thanks

Mr. F. Hudson, proposing a vote of thanks to the authors of the two Papers, said that Messrs. Murphy, Wells and Payne indicated in

their Paper the ways and means of controlling grain size in aluminium and magnesium alloys by control of melting conditions and by the addition of small amounts of special alloys. One would like to assure the authors, and incidentally their firm (J. Stone & Company, Limited) that the Congress appreciated in no small measure their contribution to the proceedings.

The effect of melting conditions on gas unsoundness in metals was not an easy subject to expound, and Mr. G. L. Bailey should be commended for having put forward his views in so simple and understandable a way. Remembering the most interesting lecture delivered on the previous day by Prof. Bragg on the subject of "The Atomic Pattern of Metals," one could not help but feel that there were very many matters on which further information was desired, and probably so far as the foundry was concerned increased knowledge of thermal reactions, particularly the effect of gas in molten metals, was urgently required.

One very important point to remember in connection with this subject was that the usual methods employed for determining the amount of gas present did not seem to give anywhere near true results. This was strikingly exemplified two years ago at the Derby Conference of the Institute of British Foundrymen in the French Exchange Paper presented by Prof. Chaudron entitled "The Elimination of Gaseous Impurities in Aluminium." In that Paper Prof. Chaudron outlined a new method for estimating the amount of gas contained in metals, which consisted of bombarding the specimen in a vacuum discharge tube with a high-tension electric current around 130,000 volts, but only a few milliamperes intensity. Metals when subjected to these conditions released gas, and the interesting thing to note was that the amount of gas set free was in surprising quantities. For example, a 100 grm. sample of pure aluminium (99.99 per cent.) liberated 192 ccs. of gas when tested by the discharge tube method at room temperature and only 20 ccs. when melted in a vacuum. The greater portion of the gas released was hydrogen (65 to 75 per cent.), followed by carbon monoxide (18 to 20 per cent.); nitrogen (3 to 7 per cent.) and carbon dioxide (2 to 6 per cent.). This clearly showed that heating metal in a vacuum alone was quite unsuitable for determining dissolved gas. Similarly, measurement of the gas absorbed by a metal in a closed system would not indicate the total gas in solution as the amount of gas residual before heating was unknown.

Mr. Moreau had carried Prof. Chaudron's work still further and published additional data last year in the form of a thesis from Lille University.

In this later investigation, metals other than aluminium had been tested for dissolved gas by the discharge tube method, and it would appear that the solubility of hydrogen in all the common metals was very much higher than the values given for example in Fig. 1 of Mr. Bailey's Paper. This new method of estimating the amount and nature of gas present could be usefully employed by investigators in this country.

Paper No. 669

Pressure Die-Casting in Aluminium- and Zinc-Base Alloys

LIMITATIONS AND POSSIBILITIES OF THE PROCESS

By ARTHUR STREET, B.Sc., Ph.D.

During the past twenty years, pressure die-casting has emerged from the status of a metallurgical curiosity to an industry whose presence makes itself felt wherever bulk quantities of metal parts are involved. The reasons why pressure die-castings are so widely used may be summarised as follow:—

(1) Once the die has been made, production speed is high. Certain automatic die-casting machines have achieved an output of over 1,500 shots per hour; this is exceptional, but a speed of 600 shots per hour can be attained with small die-castings. Automatic machines only show their true advantages when large quantities of fairly small components are involved. For complicated or large parts, and in most cases where the quantities are less than 50,000, fully automatic machines are not often used, but ordinary pressure die-casting machines requiring the full-time supervision of a semi-skilled operator are employed. These, however, attain quite reasonable speeds of production. For example, a zinc-base alloy pressure die-casting, weighing 2½ ozs., with two concentric threads and with a brass bush cast in as insert, attains a production speed of 200 shots per hour. An aluminium-silicon alloy electric-motor body, weighing 1 lb., gives 75 shots per hour. A large and complicated washing-machine gear-case in zinc-base alloy, weighing 14 lbs., averages 18 shots per hour.

Fig. 1.—Pressure Die-castings in Aluminium- and Zinc-Base Alloys.

(2) It is possible to produce what is either the finished article or a close approach to it. Holes, threads, lettering and decorative features can be produced, and the design of the part is only limited by the desirability of opening and closing the die with the minimum of trouble. Fig. 1 shows a group of pressure die-castings in aluminium- and zinc-base alloys, representing a type

of design which specially lends itself to the process. The parts were cast on to the top of the dome portions with the moving die-block coring the domed recesses in each case. These die-castings range in weight from less than 4 ozs. to 7 lbs.

(3) The pressure die-casting is accurate to + 0.001 to 0.002 inch per in. Particularly in the zinc-base alloys holes can be cast with a taper of only 0.002 inch per in.; in aluminium alloys where the molten metal "drags" on the steel cores, the necessary draught is higher, being about 0.015 inch per in. (the exact figures depend on conditions).

(4) Mainly on account of the high pressure of injection, the surface appearance of a pressure die-casting is so good that often it can be used in the "as-cast" state, and in any case, if a finish is necessary, its cost is reduced to a minimum.

(5) On account of the rapid chilling, the strength and hardness of a pressure die-casting will be superior to those of the same alloy in the sand-cast state. For example, a zinc-base alloy sand-cast gives a tensile strength of 7 to 9 tons per sq. in.; in its gravity die-cast form the alloy has a strength of about 14 tons, while in the pressure die-cast condition the alloy will have a tensile strength of 18 to 21 tons per sq. in.

Examples from Industry

Because of the possibilities which pressure die-casting opens up, it has enabled a number of modern amenities to develop, which would certainly be less efficient and more expensive if there had been no such thing as pressure die-casting. Fig. 2 shows a group of vacuum-cleaner parts, pressure-cast in aluminium alloy, and indicates that this industry owes much to the use of die-castings. The motor-vehicle industry is one of the largest consumers of pressure die-castings, particularly in the zinc-base alloys, and many important features, such as carburettors, petrol pumps, electrical equipment, and door and window operating gear have been immensely cheapened and improved by the use of these die-castings.

Fig. 3 illustrates the well-known Rawlplug mechanical hammer, in its original state (lower half), and after an aluminium-silicon alloy pressure die-cast body had been used (upper half). The manufacturers report that they have used over 22,000 die-cast cases, and they say that the amount of machining has been reduced almost to zero. There are no rivets or screws to work loose, and it is possible to use longer and more robust bearings, as they can be "cast-in." The hammer case being made of a pair of die-castings makes assembly easy; all parts drop readily into accurately cored holes. The design is so adjusted to give strength combined with lightness—an important feature with portable tools which are subjected to much abuse. The excellent appearance of the pressure die-cast case is an added advantage.

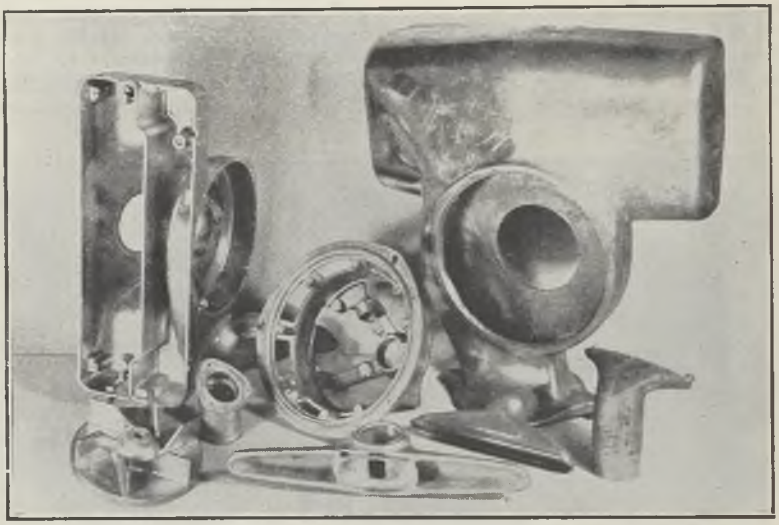


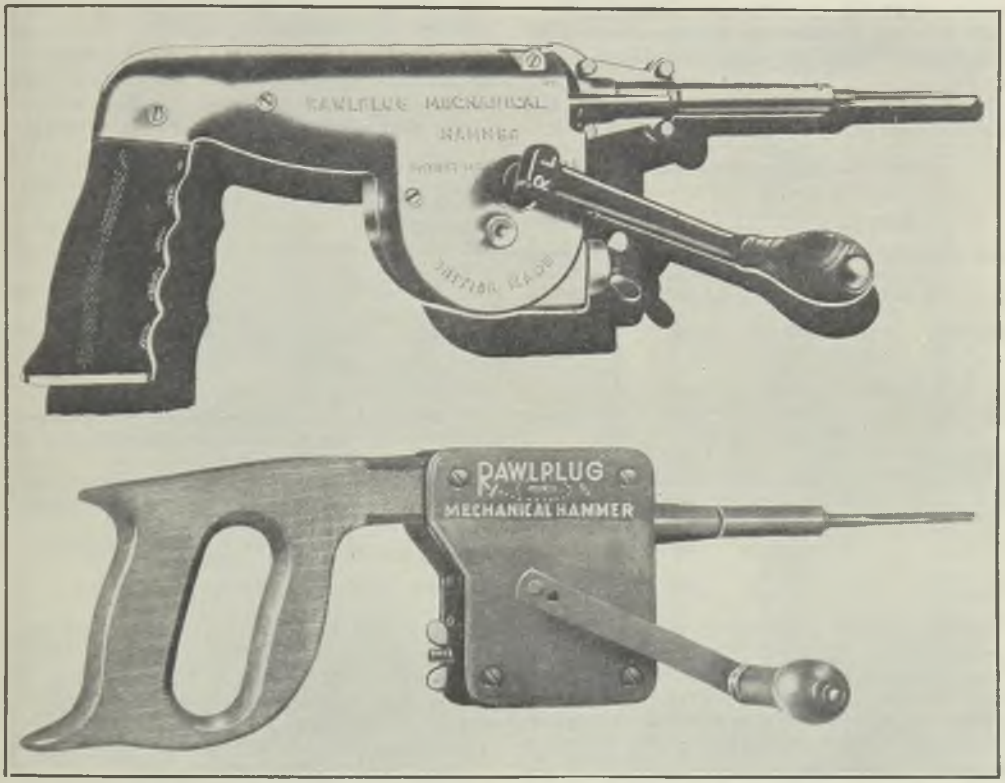
Fig. 2.—Aluminium-Alloy Pressure Die-castings for Vacuum-Cleaner Components.

Competition with Other Processes

In view of the rapid development of the pressure die-casting process it occurred to the writer that members of the foundry industry might hold strong opinions on the rise of this youthful competitor. Several Midland members of the Institute of British Foundrymen were therefore consulted on the subject of "Die-casting *versus* Sand casting." Their replies have been most illuminating and are embodied in the present Paper.

has been a stimulus to its "elder brother." For instance, the foundry manager of a large firm making weighing machines reports that although they had been using very many die-cast parts for the last 15 years, the production in their grey-iron foundry had increased by about 100 per cent. over the same period.

It seems obvious that the main reason why die-casting does not interfere with the ordinary foundry is that the process works within a number of definite limitations, which have meant



(Courtesy Rawlplug, Limited.)

FIG. 3.—"MECHANICAL HAMMER" BEFORE AND AFTER IT WAS DIE-CAST.

The spokesman of a large firm of casters in the Midlands stated that in recent years they have certainly lost orders to the die-casting industry, although the inroads of die-castings against their light grey-iron foundry business were said not to have been really severe. The other gentlemen who have been approached were not of the opinion that the industry was throwing foundrymen out of work and, indeed, in several cases it was suggested that die-casting

that die-casting has only been employed in the manufacture of certain classes of articles in a few well-defined alloys. In recent years so much has been said about the undoubted advantages of die-casting that it might be a useful change to consider the limitations of the process which explain why die-casting has been able to exist and thrive without deleterious effects on the ordinary foundry. It must be stressed that the present Paper deals essentially with pressure die-casting.

Limitation of Alloy

The conditions under which the die-casting is made are so severe that only certain alloys are ideal for the process. Over 80 per cent. of the pressure-cast tonnage in this country is made up of:—

(1) The zinc-base alloys (with aluminium 4.1 per cent., copper 0 to 2.7 per cent., magnesium 0.03 per cent.; balance zinc of "99.99 plus per cent." purity).

(2) Aluminium alloy of L.33 composition, with silicon 11 to 13 per cent.; occasionally copper up to 0.5 per cent. is added.

(3) A small percentage of aluminium alloy with copper 4 to 5 per cent. and silicon 2 to 3 per cent.

(4) A still smaller percentage of L.8 and miscellaneous alloys.

Effect of Melting Point

The life of the die is not a direct inverse function of the melting point, but an exaggerated one; thus the life of a part of a tool for zinc-alloy die-castings would be at least four times that of a part of the die producing an aluminium-alloy pressure die-casting. The problem of the effect of high melting-point alloys on the die steel which is available has caused the process to become specially associated with alloys of low and medium melting-point.

In connection with the subject of die-life, which is so important in deciding whether an alloy is suitable for die-casting, it must be mentioned that a die does not "expire suddenly" but deteriorates in stages. For instance, in the case of an aluminium-alloy pressure die-casting, it is likely that after about 20,000 shots, core pins of small diameter may show signs of necking, and may have to be renewed. Then, at about the same time, the surface of the tool may develop hair-cracks which will be reproduced on the face of the die-casting. If appearance be vital, the tool may have to be sent back for removal of these surface blemishes.

Only if the steel is quite inadequate or if the workmanship is bad does a die have to be renewed entirely. For example, careful questioning in the toolroom of Fry's Diecastings, Limited, revealed that in the last four or five years only one pressure die has had to be completely re-made, and then it had produced 60,000 aluminium-alloy parts, and the toolroom foreman was of the opinion that this particular die had been "badly made."

TABLE I.—*Effect of the Freezing Range of Various Die-casting Alloys on General Suitability.*

Alloy.	Liquidus.	Solidus.	Freezing range.	Notes.
	Deg. C.	Deg. C.	Deg. C.	
10 per cent. alum. bronze ..	1,043	1,038	5	Gravity die-casts excellently, but difficult for pressure die-casting.
Gunmetal	1,000	845	155	Can be die-cast with difficulty using special plant and low pressures. Not usually employed.
90/10 tin bronze	970	815	155	Not commercially pressure die-cast.
70/30 brass	950	920	30	If of commercial quality and therefore hot-short, cannot be pressure-cast.
60/40 brass	904	900	4	Pressure-casts well.
L.5	610	490	120	Not suitable for pressure die-casting.
L.8	622	545	77	More suitable for gravity casting than the pressure process.
L.11	630	540	90	More suitable for gravity casting than the pressure process.
L.33	600	577	23	Pressure die-casts excellently.

The list of alloys which are not considered to be commercially "pressure die-castable" include a large number of compositions which are not widely die-cast at present but which possibly could be adapted to the process if the need were very urgent. Thus gunmetal and pure 70/30 brass could be pressure-cast if the mould and the die-casting machine were specially adapted to the purpose. It might be mentioned here that improvements are being brought about in the die-casting of high melting-point alloys, for instance, cast iron and nickel alloys.

At the same time, it is a fact that certain alloys (for instance L.33 and the zinc-base alloys) pressure die-cast excellently, while other compositions (for instance, L.5, which is hot-short) are not suitable. The writer would not attempt to say definitely what makes an alloy "pressure die-castable," because there are so many variable factors, but in the hope that this question will one day be settled, the various factors are briefly discussed below.

Effect of Freezing Range of the Alloy

It seems distinctly possible that this is an important factor, and that a long freezing range means that the alloy will be difficult to pressure-cast and achieve solidity. Table I gives par-

ticulars of copper and aluminium-base alloys which are popular and unpopular with pressure die-casters. Speaking broadly, it will be seen that in each class the popular pressure die-casting alloys are those with the shortest freezing range. Aluminium-bronze is purposely put in as an exception; other factors interfere and make the alloy quite difficult to pressure-cast (for instance, high melting-point, high contraction, and tendency to form aluminium oxide in the turbulent pressure die-cast state). No doubt the reason why alloys with long freezing range are generally difficult to pressure-cast is that the first solidified metal bridges across the section encircling localities of still-solidifying alloy which is thus prevented from being fed.

Effect of Contraction

Although the cores are withdrawn from the die-casting almost as soon as its outside skin has become solid, these features of the die impose a restraint on the free contraction of the alloy. In an endeavour to get maximum production and finest grain-size, moulds are frequently water-cooled, and under these conditions the die-cast alloy falls very rapidly in temperature; thus some works experiments indicated that the first 200 deg. C. of cooling of an aluminium-alloy die-casting took place in under one second. The higher the contraction figure, the higher the stress that will be set up in the constrained die-casting. However, the contraction *per se* is not an essential factor, but is linked up with strength and ductility at high temperatures.

Strength and Ductility at High Temperatures

If a die-casting is solidifying against the restraint of the die, it will temporarily be prevented from contracting to its fullest extent. Assume that if a part could have contracted freely, it would have shrunk by X per cent. If some part of the die constrains that metal from shrinking, a stress Y will be set up. If the metal at a temperature of, say, 300 deg. C. below its melting-point is hot-short, it will only have a low elongation figure at that temperature, and if the elongation figure be less than X, a stress greater than Y will be set up, and consequently the metal will crack. Additionally, it must be remembered that because of the very rapid chilling it will be a suddenly applied and therefore augmented stress which will be set up. Table II gives particulars of the tensile strength and elongation of four alloys, together with their contraction figures and a note as to their "die-castability." The existence of the other factors which affect "die-castability" prevents definite conclusions from being drawn from these figures, but it will certainly be noted that the two alloys which do not appear to pressure die-cast so well pass through a stage in freezing when their elongation is so low as to approach the figure for linear contraction.

Solution Effect of the Liquid Metal on the Mould

If a metal or alloy tends to dissolve iron, it will not be suitable for die-casting on account of its solution effect on the die. Thus unalloyed zinc, although it can be die-cast, provided the metal is of extreme purity, is not commercially suitable because the zinc galvanises the mould. If 0.03 per cent. of aluminium is added, the solvent tendency is reduced to one-quarter. When 4 per cent. of aluminium is present, as in all modern zinc-base die-castings, iron solution is completely inhibited.

TABLE II.—*Mechanical and Physical Properties of Four Alloys.*

BRONZE.—86.5 per cent. copper, 11.9 per cent. tin, 1.3 per cent. zinc.
Total linear contraction, 1.5 per cent.
Not commercially die-castable.

Temp. Deg. C.	Tensile strength. Lbs./sq. in.	Elong. Per cent. in 2 in.
20	42,200	16.5
230	40,800	15.0
290	34,800	12.0
345	26,200	4.0
425	20,400	2.0

BRASS.—62.4 per cent. copper, 37.6 per cent. zinc.
Total linear contraction, 1.8 per cent.
Pressure die-casts satisfactorily.

25	61,000	27.0
250	53,700	20.0
390	20,900	41.0
500	7,500	43.0
550	5,800	32.0
630	2,800	27.0

ALUMINIUM-SILICON ALLOY.—With 12 per cent. silicon
Total linear contraction, 1.3 per cent.
Pressure die-casts excellently.

25	26,500	8.0
100	23,850	10.5
150	19,050	12.8
200	14,300	13.0
250	11,000	14.8
300	7,850	15.0
375	5,050	21.5

ALUMINIUM-COPPER ALLOY.—With 8 per cent. copper.
Total linear contraction, 1.2 per cent.
Not suitable for pressure die-casting intricate jobs.

25	21,700	1.0
100	21,100	1.0
150	19,750	2.0
200	17,500	1.0
250	16,250	1.0
300	11,000	2.5
375	5,650	11.8

When the author first commenced to think about the "die-castability" of various alloys, it was hoped that some definite factor would be found which would decide whether or not an alloy was suitable. As a result of the discussion above it will probably be agreed that some properties make pressure die-casting difficult, but it is likely that there are few alloys which would be quite impossible to die-cast, providing attention was given to the design of the die and the machine, and the operators were given time to get experience in making die-castings in the specific alloy. This human element factor is a very real one; the author remembers that a good many years ago when zinc of 99.99 per cent. purity was first used for zinc-base die-castings, the workmen stated most volubly that the stuff was quite impossible to die-cast, yet after a few weeks' experience with the new alloys they soon mastered the problem. Again quite recently, some of the same men were asked to make castings in one of the original zinc-base alloys containing aluminium, copper and tin, such as were widely die-cast 15 years ago. This time the operators declared that the tin-containing alloy was quite impossible to die-cast!

Weight and Size of Die-Castings

Sand castings can be made many yards long and many tons in weight, but die-castings are chiefly limited to the light-castings field. The largest pressure die-castings which have been produced have been not much more than 30 lbs. in weight. The difficulty of making a bulky pressure-casting does not only consist in constructing and handling a die, which may weigh more than 4 tons, but, what is still more difficult, provision has to be made for exerting holding pressures, which may run into hundreds of tons, to resist the bursting effect of the incoming metal. The tendency for the components of the die to spring must be avoided both from the point of view of safety and the need for maintaining accurate dimensions. The problem of filling the large die has also to be considered; if the metal temperature is raised to improve fluidity, unsoundness may result, both at the extremities of the mould and in the vicinity of the runner.

However, while a pressure die-casting is limited with regard to the production of bulky components, it must be admitted that it is ideally suitable for making small parts. The individual components of a zip fastener have been produced by this method and watch parts, weighing 1/200th of an ounce, have been pressure die-cast.

Solidity of Pressure Die-Casting

One of the foundry managers who replied to the author's *questionnaire* raised an interesting point by asserting that "where soundness is of great importance (*e.g.*, petrol or oil proof), die-castings generally are inferior to sand castings." This raised the controversial question of the soundness or otherwise of pressure die-castings.

In the first place it must be realised that, from the solidity point of view, the die-caster faces different problems from the ordinary founder. The latter is beset by a multitude of trials and tribulations which make it a source of admiration that solidity is so regularly achieved; but apart from minor evils, a sand casting may develop unsoundness from any of three causes—blowholes due to gas evolution, air-locks and shrinkage cavities. The foundryman overcomes the three forms of unsoundness by providing risers, vents and chills wherever necessary and by blending the sand to make it porous or impermeable as is required at any point.

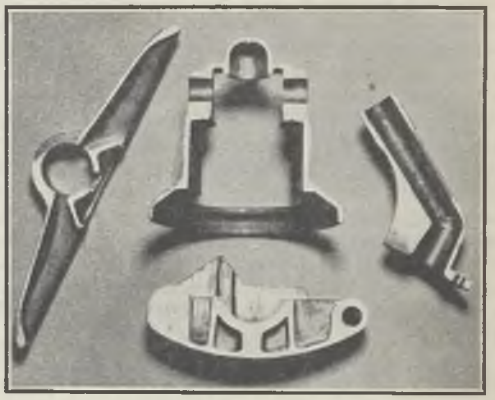


Fig. 4.—Sectioned Aluminium-Alloy Pressure Die-castings.

The evolution of gases is not serious from the die-caster's point of view. For one thing the high pressure at which the metal is cast tends to keep gas in solution and, secondly, the die-casting is generally cast as near the melting point as possible and not 50 or more deg. C. above it as in foundry work.

Although shrinkage cavities are sometimes troublesome in gravity die-castings, only a badly-made pressure die-casting suffers from them, as the feeding effect of the continued application of pressure should in a suitable alloy prevent insufficient filling of the mould. However, entrapped air can be distinctly troublesome. The metal enters in a turbulent condition and is intimately mixed with the air which was previously contained in the mould and runner. Particularly where the metal has to be run on the side of a circular impression or where the section changes abruptly, it becomes difficult to

get rid of air during the fraction of a second in which the die-casting solidifies.

Risers and very liberal vents are out of the question and the steel mould cannot be made gas-permeable. The die-caster endeavours to liberate entrapped air by venting (*a*) along the parting line; (*b*) up the narrow orifices which represent core pin clearance, and (*c*) by cutting sumps in

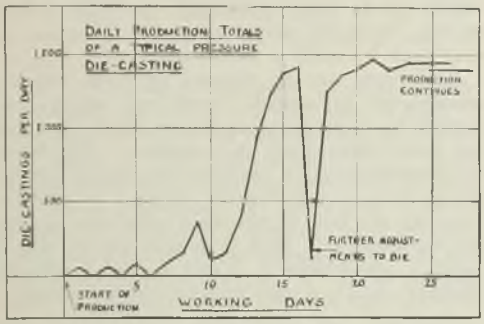


FIG. 5.—DAILY OUTPUT FIGURES OF A PRESSURE DIE-CASTING.

the die, attached to the die-casting impression by a thin channel. Entrapped air and oxide are forced into these "sumps" which are subsequently clipped away. High pressure of injection is useful in preventing unsoundness but alone it is not sufficient. The construction and venting of a tool are the real key as to whether or not the pressure die-casting will be solid. As illustration of the kind of results which are obtained, Fig. 4 shows some sectioned pressure-castings

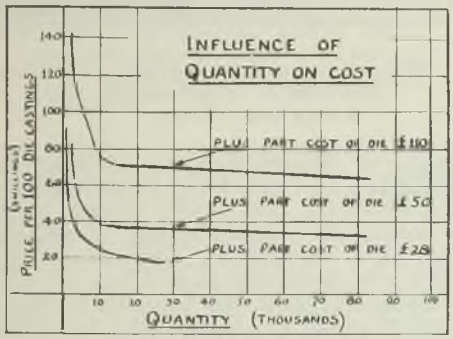


FIG. 6.—INFLUENCE OF QUANTITY ON COST.

all in aluminium alloy. It will be seen that the only part which has been at all troublesome is the wide section in the lower die-casting.

The Economic Factor

It is nowadays realised that pressure die-casting is not really suitable for the manufacture of quantities less than 5,000 per annum. Not only has an elaborate die to be made, but the production speed varies considerably with increasing experience. It is quite usual for only a few score of die-castings to be produced in the early days of production, whilst when the tool is running smoothly and the operator is accustomed to the idiosyncrasies of that particular job, the production speed may rise to several thousand shots per day. Fig. 5 is a diagram taken from the daily production figures for a medium-sized zinc-base alloy pressure die-casting. This job was more troublesome than most—it contained two cast threads, a thin spigot and a cast-in brass insert, and the diagram illustrates that at least on this particular difficult job the cost of producing the first 1,000 would have been

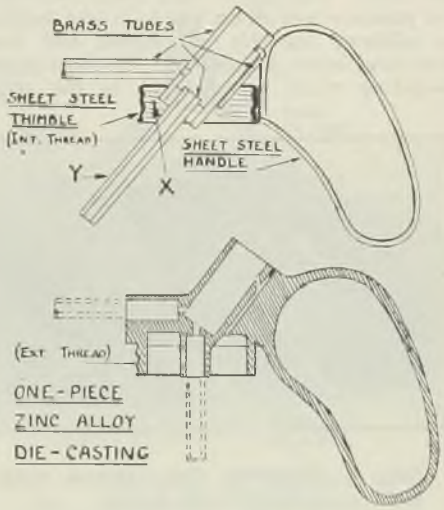


FIG. 7.—DESIGN OF AN OILER TOP BEFORE AND AFTER IT WAS DIE-CAST.

probably ten times the cost of making the tenth thousand.

Fig. 6 is based on the cost of three actual zinc-base die-castings, but the estimated cost of different quantities has been worked out to illustrate that quite apart from tool cost the question of numbers has to be seriously considered to decide whether a part is suitable for pressure die-casting.

Limitations of Design in Pressure Die-Casting

It may be assumed that any foundryman worth his salt can produce castings to practically any design in almost any alloy, but the preceding remarks will have indicated that the die-caster is not in the same happy position. Not only is he restricted in the choice of alloy, but, on account of the rigid nature of the permanent

steel mould, he is limited in the design of any part which is to be die-cast. Any feature which hinders the opening and closing of the die or which prevents the straight-line withdrawal of cores is either going to make the design impossible to execute or will cause the die-casting to be unduly expensive. The design of any die-casting must be considered on its merits, for very often a difficult feature can be produced in one case, while it would be impossible in another. However, there are certain outstanding limitations which must always be considered.

Simplicity of design must be aimed at to ensure rapidity of production. Awkward corners and recesses are frequently encountered in parts which manufacturers would like to have die-cast, and Fig. 7 indicates how such problems are dealt with. The upper view shows the section of a pressure-feed oilcan top as it was originally —a soldered assembly of pressed and turned parts—and below is shown the one-piece pressure die-casting which replaced it. In the original

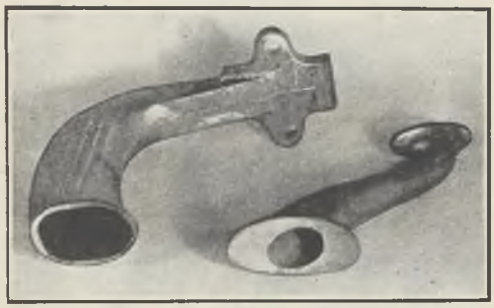


Fig. 8.—Pressure Die-castings with Curved Cored Holes.

design a recess at X was formed by the inclined inlet-tube assembly Y, and it will be seen that such a recess would prevent a steel core from being withdrawn. It was found possible (and indeed an improvement) to arrange the inlet tube vertically, as shown in the lower view, and at the same time to die-cast an external thread to suit the rolled thread on the oil container. Further, it was possible to include the handle as part of the die-casting, thus eliminating all soldering operations. Assembly costs were substantially reduced and the strength and efficiency of the article were improved.

In order to obtain maximum speed of production, cores should, if possible, be withdrawn in a straight line. The use of collapsing sand cores is quite impracticable owing to the high pressure of injection of the metal, and the "messiness" of letting sand come in contact with a complex steel die. Cored holes, therefore, are limited to shapes which can conveniently be formed by steel cores. Although straight-line holes are preferable, certain irregular shaped holes can be produced in a pressure casting. Fig. 8 shows two components with bent cored holes which have been produced by cores shaped to the arc of a circle which were rocked in and out of position. Pressure die-cast domestic taps which have been produced in brass are well-known examples where a curved hole has been produced by such a movement.

Undercuts can be formed by cores which are constructed in several pieces and which are removed by a separate operator after the casting has been taken from the machine. Fig. 9 shows an aluminium-alloy pressure casting in which the recess forms an undercut. Core 1 is withdrawn through the hole at the side while the casting is on the machine. It is then withdrawn, still containing core-blocks 2, 3 and 4, which are subsequently unlocked and removed in this order. In

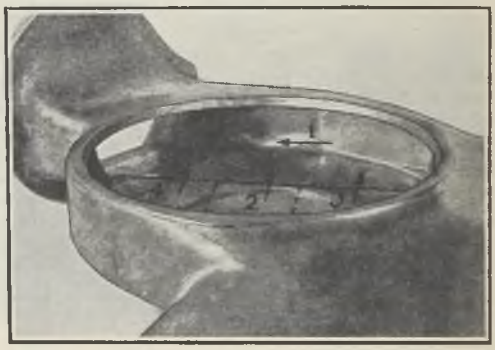


Fig. 9.—Aluminium-Alloy Pressure Die-casting produced by using a "Knock-out" Core.

the gravity die-casting process, which may be regarded as a kind of half-way house between pressure die-casting and foundry casting, undercuts of considerable complexity may be achieved by cores which are built up of several sections and which are dismantled piece by piece. Certain motor-vehicle pistons are examples of this. The pressure-casting process, however, is much more limited with regard to undercuts, for the "knock-out" core has to be constructed and fixed to withstand the heavy impact of the incoming metal while at the same time it has to be easy to dismantle.

Speaking generally, cores must be arranged to withdraw in as few directions as possible; usually cores in any one direction are operated together and, except in special cases, every direction of core movement means additional

mechanism in the die and increased operations on the machine. Because of this, die-casting designs in their early stages are carefully considered in order to assemble core movements in the minimum number of directions. For example, the electric-motor body illustrated in Fig. 10 was originally designed with radial ventilation holes. These would have involved an expensive tool, and the design was therefore altered so that the slots were cored by the moving die-block as shown on the right-hand side of the illustration.

If the die-casting contains a main dome-shaped recess, as in Fig. 10 and also in Fig. 1, such a recess is cored by the moving die-block. Smaller holes in the same plane as the main recess are produced by separate core-pins working in the moving die-block, so that they may be easily renewed without scrapping half the die.

Usually it is found more convenient when the casting is arranged to contract on to the moving die-block from which it is subsequently ejected. If the design were such that the die-casting

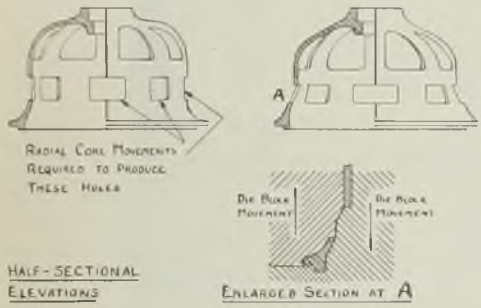


Fig. 10.—Pressure-cast Motor Body, showing Modification to Ventilation Slots for Facilitating Core Operation.

adhered to *either* die-block as the spirit moved it, the casting cycle would be considerably slowed down, particularly when the die-casting, with the runner attached to it, had to be extricated from that half of the die which was not provided with ejector pins. Very often die-casters will request their customers to provide a taper in a certain direction so that the die-casting shall be forced to withdraw in the desired direction. Fig. 11 shows a simple die-casting where a similar alteration was agreed to. The original design (shown above) would be more likely to adhere to the runner side of the die, but by the addition of a cylindrical face (shown below) the part was made to adhere to the moving die-block.

The design limitations of pressure die-casting are naturally troublesome at times. Many shapes cannot be die-cast if it is found impossible to alter their design to bring them into line with the requirements of the process. Then it is risky to undertake a die-casting if the design of the part is liable to alteration. Such an alteration in a sand casting might only mean the expenditure of a few shillings on the pattern. Sometimes, of course, alterations to a pressure die-casting are reasonably cheap; for instance, if a hole is to be made smaller, the core producing it could conveniently be machined down. On the other hand, if the same hole had to be made *larger*, it would mean making a new steel core, boring out the die and altering the mechanism to accommodate the larger core pin. Many seemingly simple-looking alterations mean the scrapping of half the die because they would necessitate adding metal to the die to form what is wanted.

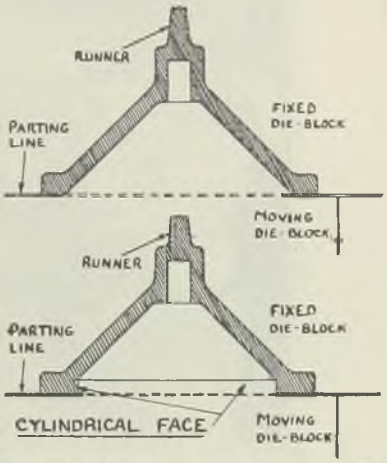


Fig. 11.—Addition of Circular Ring to Facilitate Withdrawal in Correct Direction.

A further point connected with the expensive tooling is that it is difficult and sometimes costly to test new ideas. Even if a sample foundry casting is made its strength will not be equal to that of the pressure die-casting, and so the test would not be a fair one. Unfortunately, this applies in particular to the zinc-base alloys where would-be users almost invariably want to make some sort of test, if they are unfamiliar with these essentially pressure die-casting alloys.

On the other hand it is certain that the "limitations" of pressure die-casting have brought many advantages. Human nature is prone to take the line of least resistance, and if a design is possible, users will not have much stimulus to make alteration. If, however, a die-caster tells a potential user that a certain design is quite definitely impossible, the user is very often en-

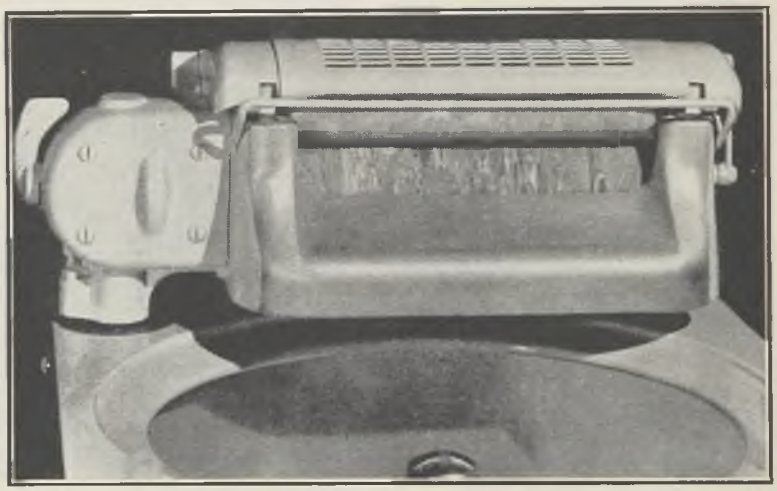
couraged to make a fresh start and consider the design from first principles, and in so doing can take the opportunity of simplifying and improving the whole assembly; this has happened on innumerable occasions. As illustrating a modern application of pressure die-casting where considerable care has been put into the design to make the components suitable for this method of production, the well-known Hotpoint electric domestic wringer and washing machine will now be discussed.

Redesigning a Domestic Wringer for Die-Casting

In the original model the wringer was of cast iron; the basic design had been found satisfactory in service, and it was desired that this should be retained, while at the same time making use of the advantages obtainable by the use of die-castings. Although it was realised that modifications would have to be made, the die-cast wringer had to be so planned that its major parts would be interchangeable with those of the original design. For instance, as the machine would give a long service, it was desirable that a new die-cast gear-box could be fitted on to the original design of wringer head and *vice versa*. At the same time as the change-over to pressure die-casting occurred, the opportunity was taken of making other improvements—improved safety mechanism was incorporated, and constant-mesh gears were adopted instead of the sliding-gear type.

With ferrous material there is a possibility of trouble through rusting or corrosion. As the wringer is naturally in contact with alkaline solution and any rust must not be allowed to contact the clothes, a non-ferrous metal was desirable. Additionally it was desired to make a reduction in weight, so aluminium-silicon alloy was chosen to be used wherever possible.

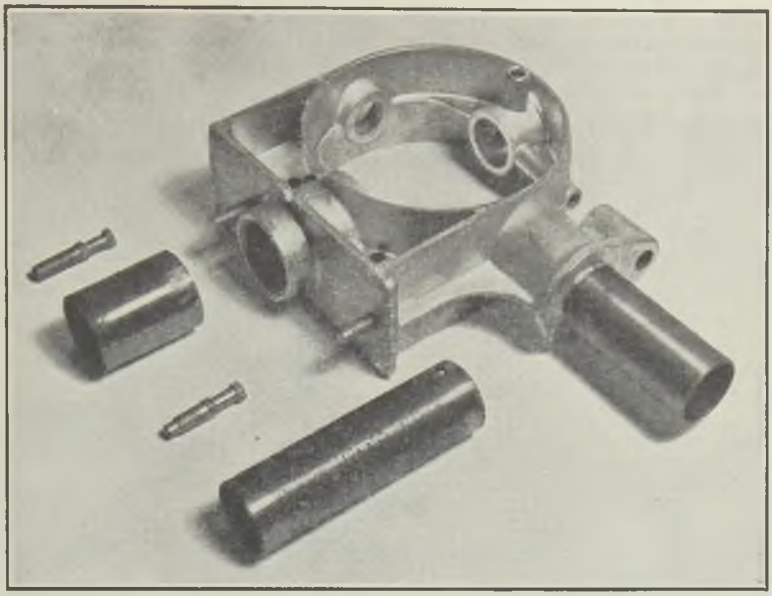
The reduction in weight was a substantial one. The total weight of the appliance was originally 45½ lbs.; in addition to this the safety mechanism introduced in the new model weighed an extra 3 lbs., but thanks to the use of aluminium-alloy pressure castings the total weight was reduced to 34 lbs. On the wringer body casting itself, which remained similar in external design, the reduction in weight was even more outstanding. The original iron casting weighed 15 lbs., but the aluminium-alloy pressure die-casting weighed only 4 lbs. That this loss of weight did not imply any reduction in effectiveness is demonstrated by the fact that the casting withstood without fracture a load of over 600 lbs. applied on its extremity, and this load is many times greater than that which the part has to withstand in service. These domestic wringers are called upon to withstand surprising loads at times. Cases have been known where housewives have used the wringer to climb up to reach a window, and as the wringer body is pivoted at one end only (the gear-box end) it will be appreciated that the die-cast assembly has to be quite robust! The wringer assembly is illustrated in Fig. 12.



(Courtesy Hotpoint Electric Appliance Co., Ltd.)

FIG. 12.—DOMESTIC ELECTRIC WRINGER, SHOWING PRESSURE-CAST BODY, GEAR-BOX, ETC.

The large castings of the wringer assembly are now of aluminium alloy, and apart from reduction in weight, they have brought considerable advantages in reduction of machining costs, accuracy of detail and matching of interdependent parts, and complete freedom from service troubles. Certain smaller components of the head assembly, such as the pressure links



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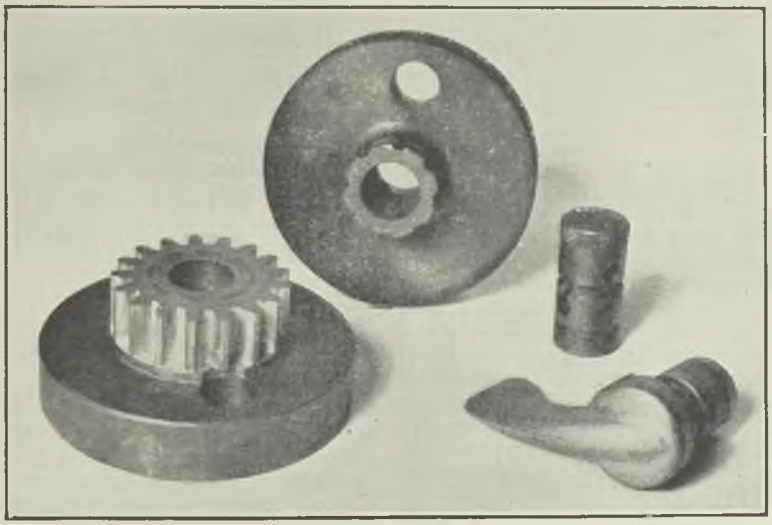
(Courtesy Hotpoint Electric Appliance Co., Ltd.)

FIG. 13.—WRINGER GEAR-BOX, SHOWING CAST-IN INSERTS.



(Courtesy Hotpoint Electric Appliance Co., Ltd.)

FIG. 14.—WRINGER DETAILS WITH LARGE INSERTS.

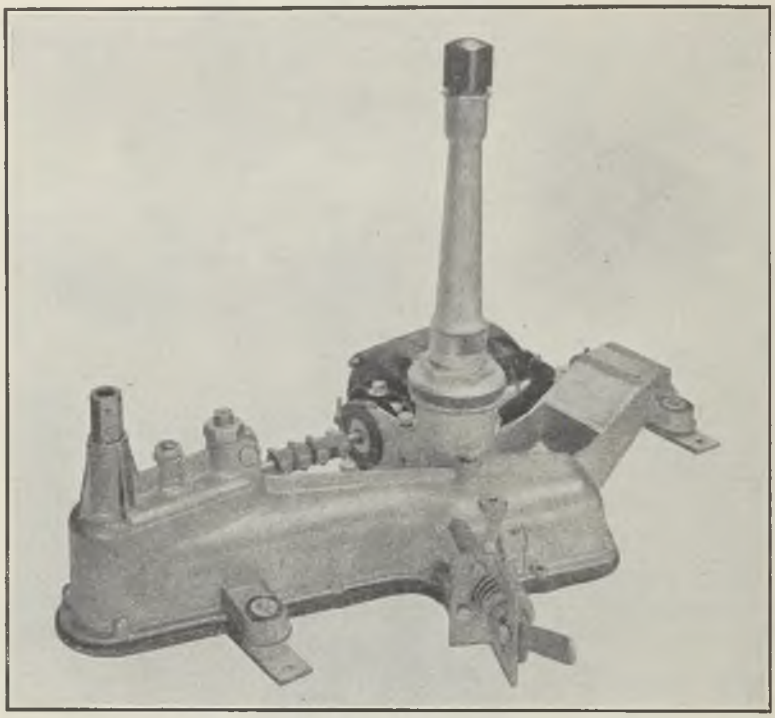
and the bearings, are of zinc-base alloy, as this material has a higher tensile strength than the aluminium.

The wringer gear-box shown on the left of Fig. 12 also embodies pressure die-castings but of zinc-base alloy throughout. A total of nine pressure die-castings, many of which are unmachined, go to make up the complete gear-box assembly. The main casting, shown in Fig. 13, has four inserts, which are also shown in the illustration. Two other details of the gear-box include inserts which are at least as large as the die-castings themselves. These are shown in Fig. 14.

The satisfactory results following the redesign of the wringer for pressure die-casting led to the subsequent redesign of the washing machine with which the wringer is used. This utilises no fewer than 27 pressure die-castings, including one of the largest zinc-base pressure castings produced in this country (Fig. 15)—surely a gesture of confidence on the part of the designers.

Conclusion

The discussion in the Paper will possibly indicate that, with all its advantages, die-casting will always be limited in its application; nevertheless, it is a flourishing and progressive industry, which delivers the bulk of its output to users of new amenities, where certain components have been designed specially for die-casting. Die-casting does not attempt to replace other and older industries, but has managed to establish its own special place in the sun. The industry has managed to work in friendly conjunction with its father the foundry trade and its cousin the stamping industry, and none of the three interferes with another in anything but a healthy manner.



(Courtesy Hotpoint Electric Appliance Co., Ltd.)

Fig. 15.—Washing-Machine Gear-case Assembly showing Pressure Die-cast Gear-case, Post and Gyrator Post Nut.

DISCUSSION

Introducing the Paper the author suggested that, by referring to the limitations of the process of die-casting, he had at least managed to discuss an aspect which was comparatively rarely considered.

When he had decided to place on record some of the limitations of die-casting, he had approached a number of foundrymen either verbally or by letter to ask their opinion about pressure die-casting. It was a humbling experience to find

that in many cases foundrymen just had no reaction at all to the die-casting industry; but it was interesting that the people who had considered the subject did not feel that die-casting was an annoying rival, but was rather what one might call the junior partner of the casting-die-casting axis.

In discussing the solidity or otherwise of die-castings he had embarked upon a subject which could not be dismissed lightly in a few paragraphs, but he had tried to show that the problems connected with unsoundness were rather different from those which the ordinary founder met, and he hoped he had been able to give the opinion that pressure die-castings were capable of being produced free from unsoundness.

He had tried to make it clear in the Paper that pressure die-casting did not consist merely of making an expensive tool and commencing immediately to produce castings at the rate of a few thousand per day; but with increasing experience, production speed rose to an outstanding degree. Recently he had been in the toils of a case where a perfectly innocuous looking die, producing a pair of aluminium alloy pressure die-castings, had been in process of being " run in " and had given trouble for practically three weeks before it would consent to produce satisfactory castings. During that time, between three and four hundred rejects had been produced, and then on one day 20 good castings were produced. That was an extreme case, but it illustrated that the making of pressure die-castings was not the purely mechanical process that many people imagined it to be.

Dr. E. M. Lips (Netherlands) emphasised the value of the Paper by reason of the exact data it contained. He asked for Dr. Street's opinion as to the bending properties of a die-casting; for instance, the possibility of making a turned-in flange as a manner of fastening some part to a zinc die-casting.

Porosity Determination by Weighing

Mr. A. J. Shore said that, having received a *questionnaire* from Dr. Street, he had looked into the question of die-casting at his own works. It was apparent that it was not considered to be a very important rival, or it would have been forcibly brought to his attention before. Although they had been carrying it on for about 15 years, die-casting had not made any deep inroad into the grey-iron business. But it had certainly a very big field, and the company had recently bought new machines which were likely, he felt, to cut in on their grey-iron business to some extent, because as the machines were more efficient and *new*, the designers would take a greater interest in them. They would consider as many components as possible as die-castings in order to keep the machines busy. Recently he had visited the die-casting department and had looked into the business thoroughly, and was surprised to find that porosity did occur occasionally; he was assured that it was practically absent on the automatic machines, but that it did happen occasionally on the hand-operated machines when a man, who was paid piecework rates, tried to operate the machine too quickly. The result was that insufficient time was allowed for the metal to enter. That problem had been solved in a simple way by using a delicate weighing machine; the castings had a standard weight, and because they were dimensionally accurate, the weight was a very good indication of the porosity.

He congratulated Dr. Street on his very direct and courageous way of presenting the Paper.

Chilled Skins on Die-Castings

Mr. A. Tipper, M.Sc.(Eng.), thanked Dr. Street for having put his case rather from the point of view of the foundrymen than the die-caster; this gave the founders the opportunity to state their case initially.

Being interested in the finish obtained on small die-castings which had to be plated, he asked Dr. Street what were the most important factors determining that finish—whether it was merely a question of the surface of the die, or whether the actual operating conditions, such as the temperature, and so on, and the composition of the alloy, had much effect. Recently he had examined the microstructure of a number of plated die-castings and had been quite surprised to find that there was not even microscopic porosity near the surface, within perhaps ten thousandths of an inch of the surface. There appeared to be columnar or chill crystals, although they were by no means regular. He asked whether it was normal in ordinary die-cast alloys to have a depth of something like ten thousandths of an inch of chill crystals at the surface.

Dr. Street's Reply

Dr. Street, dealing with the question by Dr. Lips concerning the bending radius that was possible in die-castings, said that presumably brass was referred to; but very few brass pressure die-castings were made. The usual competitors which the die-casting industry put forward were the zinc-base alloys, and they had not a very large bending radius. However, it depended upon the design. One could be considered fortunate if one could bend a sheet of zinc-base die-casting to 90 deg. The operation of bending a die-casting rarely arose, because by using a die-casting the process of bending could be eliminated. Thus it did not really matter whether a zinc alloy could or could not be bent through a large radius.

Commenting on Mr. Shore's reference to the competition between grey iron castings and die-castings, he compared the price of grey iron castings of about 2½d. per lb. with a zinc-base alloy pressure die-casting at about 6d. to 8d. per lb. Unless the weight of the die-casting could be considerably reduced, or unless the die-casting would eliminate a quantity of machining, it was difficult for the die-casting industry to compete directly with the foundry.

As to porosity, he felt that if in a die-casting there were holes which were capable of being discovered by the operation of weighing, the holes must be rather serious ones. If one produced a die-casting in which there was a hole as big as a pea, one should not merely shrug one's shoulders, but should get really worried about it. One could tolerate, say, an occasional hole perhaps as big as a small pinhead in die-casting. It was sometimes difficult to get die-castings more solid than that, but a large hole should not be tolerated. With regard to porosity being more likely to arise when working at low pressure with a hand-operated machine than when working at high pressure, he said that the high pressure certainly reduced the likelihood of unsoundness.

Replying to the remarks of Mr. Tipper concerning the chill skin of a pressure die-casting, he said that inasmuch as the metal came into such violent contact with a comparatively chilled wall in the mould, it acquired a skin about 15 thousandths of an inch thick, which had an extremely fine grain; underneath that, the alloy was more or less normal. Consequently, in any polishing operation it paid to avoid polishing below the first 15 thousandths of an inch or so of skin; otherwise, one would have a mixture of fine and normal grain.

In regard to plating—he presumed Mr. Tipper was referring to zinc-base alloy die-castings—a number of points were important. Naturally, the castings must be without pinholes, otherwise those pinholes might show up on the plated surface. Then the various operations before plating were important. The polishing must be thorough; but one must not remove the fine-grained skin. There was an art in preparing a zinc-base alloy for plating; it was useless showing it to the mop and then taking it to the plating shop, because in that case a rather draggy surface was the result. Many of the troubles which could not be explained in regard to zinc-base die-castings arose from insufficient cleaning

Paper No. 670

Light Alloy Melting Practice

By W. C. DEVEREUX, F.R.Ae.S., M.I.Ae.E.

The quality of light alloys of both aluminium and magnesium depends largely upon the conditions of melting, and considerable research has resulted from the realisation of the importance of this subject.

The successful casting of aluminium alloys depends upon their homogeneity, freedom from dissolved or combined gases, oxides and other non-metallic inclusions, and absolute temperature control. Magnesium alloys, on the other hand, are not greatly troubled by gas absorption, the chief difficulties being the production of metal free from dross and flux inclusions in a neutral atmosphere that will prevent oxidation and burning. These items are of primary importance, not only in maintaining a reputation for reliability, but as the largest single item affecting the costs of production. Next in order of importance are maintenance costs, fuel costs, melting losses and ease of manipulation (labour costs).

The following practical observations made during many years' working of various types of furnaces tend to show certain advantages and disadvantages for each of the many different methods adopted according to the variety of materials produced.

Aluminium Alloys

The earliest furnaces used for aluminium alloy melting were coke-fired lift-out or pit-type furnaces. The crucible life was extremely short and where a variety of castings was made in a jobbing foundry it was extremely inconvenient to replace the crucible in the furnace to maintain temperature when sufficient moulds were not prepared to take the whole of the metal. This resulted in metal stewing at a high temperature, and combined with the frequent use of undried coke was the cause of much rejection for porosity due to gas absorption. Tilting furnaces were next used, and with dried coke excellent quality metal could be produced with a better crucible life. The storage and drying of coke are a disadvantage, however, and with the advent of oil-fired crucible furnaces the use of oil fuel superseded coke to a large extent in this country. Fuel oil is easily stored and handling is reduced to a minimum.

Town's gas is used where supplies are obtainable at sufficiently low cost, and the rather conflicting opinions as to the effects of this heating medium on the quality of the metal produced show at least that there is no obvious detrimental effect through gas absorption where metal is well fluxed and degassed. Electric-resistance heating of crucible melts is only practised on a laboratory scale in this country, owing to the high cost of electric power. Continental applications of this method show, however, that it is the ideal method of heating, as the temperature control is absolute, and there is no opportunity for contamination of the metal by products of combustion. Plumbago and carborundum crucibles have a comparatively short life, however, in alloy mixing furnaces, and contribute largely to the cost of crucible furnace melting. In addition, they are permeable to combustion products, and the greatest care is needed to obtain gas-free casts without loss of magnesium.

Low-frequency induction melting appears to be the answer to these problems, the metal being maintained in a gas-free atmosphere and in constant circulation, ensuring complete solution of hardener alloys and freedom from segregation. The stirring necessary when mixing in a crucible furnace may cause quantities of dross and oxide to become suspended in the molten metal, with the danger of "hard spot" inclusion and porosity in the finished product. In addition, the depth of a melting crucible relative to its area of cross-section means that a covering layer of flux will afford protection to only a minor fraction of the surface exposed to the furnace atmosphere, that in contact with the crucible walls being exposed to the penetrating effect of gases in a combustion chamber at 900 to 1,200 deg. C. under the most favourable conditions.

The constant movement of the metal in an induction furnace means that a fresh surface is being continually exposed to the air, and unless precautions are taken, excessive losses by oxidation will occur. A satisfactory covering flux or an inert atmosphere (nitrogen) will prevent this effect, however, and in practice furnace losses can be reduced to approximately one-third of those obtained from a crucible furnace. Such a furnace can either be run on the batch system, where 75 per cent. of the metal is completely

emptied from the furnace and a fresh charge added, or for continuous working where one ingot or casting can be poured every few minutes, and the equivalent weight of new material added, which is completely melted and mixed in time for the next pour. A crucible furnace is limited to batch operation, as, owing to the inability to control waiting metal within reasonable temperature limits, the exposure to furnace atmosphere, and the stirring necessary for mixing, a steady deterioration of metal is realised when these conditions are attempted.

Table I gives a comparison of two furnaces in the same foundry, one a low-frequency 100-kw. induction furnace, the other an oil-fired crucible

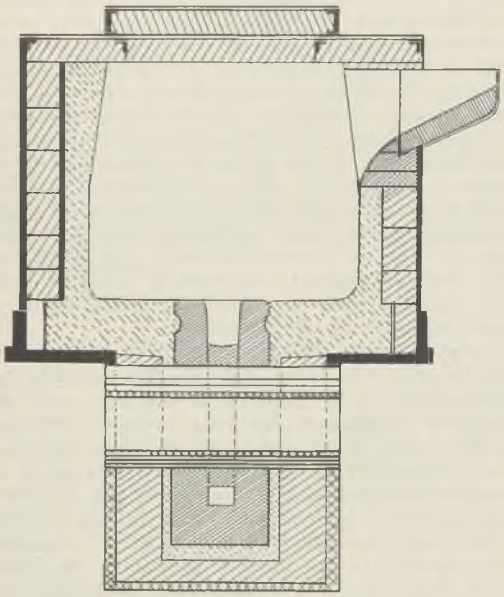


Fig. 1.—Section through 100-kw. Low-Frequency Induction Furnace.

furnace. Both were worked 24 hrs. per day over an extended period, and were capable of a similar output, *i.e.*, 4 to 5 tons per day, depending on the type of casting produced.

A section through the 100-kw. induction furnace is shown in the diagram, Fig. 1.

Melting losses vary according to the technique peculiar to individual foundries, and although they constitute an important factor in costing, may sometimes indicate careful skimming and fluxing procedure. A good flux, however, should separate dross from metal, and if undue turbulence and "frothing" of metal are avoided, oxidation losses can be kept low. The following analysis of losses from an ingot foundry employing oil-fired crucible furnaces of 500 to 1,200 lbs. capacity gives some idea of where the metal is lost and how improvements may be effected:—

	Per cent.
(1) Melting and pouring crucible clearings	0.36
(2) Splashings	0.47
(3) Metallic dross (furnace skimmings)	0.30
(4) Skimmings (ladle)	0.57
(5) Oxidation losses not accounted for	0.5 to 1.7 (Variations too great to obtain.)
(6) Metal lost on pot failures ..	0.28 (Average figures.)

Other sources of loss occurring intermittently or in widely varying amounts may reach the following figures on individual casts:—

Excess of charge over material required, 1.04 per cent.

Metal overflowing from furnace spout, 0.49 per cent.

(Average of casts showing abnormal loss only.)

A cost comparison between three different types of heating gives the following figures, working continuously on similar castings, and taking the oil-fired crucible furnace as a basis at 100 units:—

	Oil-fired crucible.	Coke-fired crucible.	Low-frequency induction.
Metal losses	55.0	56.5	28.8
Fuel or power ..	21.20	14.04	36.3
Maintenance ..	23.8	18.66	5.9
	100.00	89.2	71.0

Power costs, 0.73d. per unit. Oil costs, 3⅝d. per gallon. Coke costs, 38s. per ton.

The high maintenance costs of the crucible furnaces are due to the replacements of crucibles, which have a life of 10 to 14 days continuous working, whereas the induction furnace lining will last at least six months and occasionally longer. The initial cost of an induction melting furnace is about 20 per cent. higher than a crucible furnace of similar capacity, and installation charges are considerably higher.

Further advantages, however, are that the foundry is kept clear of all fumes and dirt, fatigue effects on the operators being noticeably reduced, making a marked difference in production per man, time lost by illness, and care in operation.

Open-Hearth Furnaces

Where large quantities of one alloy are mixed and ingoted prior to remelting for castings, it is of advantage to melt larger casts than can be

accommodated in either the crucible or induction furnace. Identification of castings with the original material is rendered simpler, and the number of check analyses per day is reduced. This is effected with the open-hearth type of furnace, which is adequately discussed in principal and detail by Zeerleder in "The Technology of Aluminium and Its Light Alloys" (1936).

Open-hearth melting may be done by means of oil, town's gas or producer gas, coke or electricity. With flame heating, a thin arch may separate the products of combustion from the metal, or, alternatively, the metal may be protected by a thick layer of covering flux. There is always some danger, however, of gas absorption by the metal, which is overcome where electricity supplies can be cheaply obtained by electric-resistance heating. Crushed carborundum resistors are preferable to metal elements, as the latter are liable to rapid deterioration in the presence of gases from reactive flux salts or by contamination from the actual flux or splashed metal.

TABLE I.—*Performance Data on Two Types of Furnace.*

	Oil-fired crucible furnace.	Low-frequency induction furnace.
Capacity	1,100 lbs.	1,760 lbs.
Working content	1,100 „	1,300 „
Consumption	12 to 15 galls. oil per hour	14 to 25 kw.-hr. maintenance load (100 kw.-hr. max. load).
Melting rate	550 to 750 lbs. per hour	600 to 800 lbs. per hour.
Output	4 to 5 tons per day	4 to 5 tons per day.
Melting loss	1.9 per cent.	0.5 to 0.8 per cent.
Total foundry losses	3.6 per cent.	1.2 to 1.5 per cent.

Puddling of the bath of metal must be resorted to in order to assure complete mixing and absence of segregation in alloys, and this tends to mix oxide films with the metal, with a certain amount of danger of inclusions at a later stage. Tilting devices are adopted on most open-hearth furnaces at the present day to enable quiet pouring into the ladle where it is customary to make magnesium additions prior to casting. The addition of magnesium to the main bath of metal is not very satisfactory, varying losses being experienced due to oxidation and to reaction with the flux salts. During the addition of magnesium and possible degassing in the ladle there is considerable temperature loss to be added to that lost in transferring the metal from the melting furnace. This makes it necessary to run an open-hearth furnace slightly hotter than is strictly desirable, and unless very carefully controlled may cause difficulties through the production of porous or gassy metal.

Many of the difficulties of the open-hearth furnace are overcome by the rotary cylindrical type. The cylinder has a refractory lining which is heated by direct contact with the gas or oil flame, the surface of the metal in the bottom being protected by a layer of molten flux. The furnace is slowly revolved, the heat from the walls being transferred by direct conduction to the metal, instead of by radiation. In addition, the need for puddling is largely obviated, the gentle turning having a mixing effect which not only prevents melt segregation, but ensures that the whole of the molten metal is brought into contact with the flux layer so that the alloy produced is largely free from oxide inclusions or absorbed gas.

Bulk melting in open-hearth or rotary type furnaces, whether on the batch principle, or continuously, means economies in fuel or power because of the direct heat transfer, and also on equipment and plant, the furnace lining lasting from six to twelve months. There is some reduction of silica in the furnace lining, but this does not cause rapid deterioration, nor is the "pick-up" of silica in the melts noticeable. The melting in bulk lots of from 2 to 10 tons means a great simplification in identification with cast numbers and testing procedure at later stages in manufacture, and means that larger quantities of the finished article are obtained with identical composition and properties, which is an economic and technical advantage when supplying materials to government specifications.

For the remelting of ingot material, bowl furnaces have much to recommend them where the casting programme is such that continuous working can be adopted, as the temperature of the metal is found to be much more controllable than with crucible furnaces, and metal transfer can be made with the minimum of turbulence and oxidation. In general, however, this type of melting can only be employed for die-castings and small sand-castings where the quantity of metal removed at any one time is small in comparison with the bulk of metal melted, and can conveniently be transferred with a hand ladle. The metal can then be maintained for long periods at a few degrees above the casting temperature, continuous additions being made which have little cooling effect, and with a well-constructed furnace under conditions where absorbed gases are liberated. The accessibility of the surface assists periodic fluxing and enables a ladle to be introduced without causing the surface skin of oxide to be mixed with the charge. Iron crucibles may safely be used with

these furnaces, there being little erosion or washing action of the metal provided they are carefully cleaned and coated with a suitable clay or whiting wash every 24 hours.

Magnesium Alloys

The melting technique employed for magnesium base alloys has already been discussed by the author in his Paper* to the Foundry Congress in Warsaw last year. It is again emphasised that the essential point in the melting of the metal is its extreme reactivity with both oxygen and nitrogen in the molten state, and it must therefore be protected from the air by means of a controlled atmosphere and fluxes. Crucible melting is therefore adopted for general foundry work, where the small surface area compared to the bulk of metal is easily covered with a layer of protective flux during the melting period. The flux performs the double purpose of cleansing the metal from oxide inclusions when intimately mixed by stirring, and then protecting the surface from further oxidation by rising to the top and setting in a hard cake, which may be removed just before casting.

Furnaces for magnesium melting are therefore limited in scope by the characteristics of the metal, and can be grouped in two general types:

(1) Crucible furnaces employing iron pots either of the lift-out or tilting type. The lift-out furnace is preferred in order to avoid unnecessary decanting of metal with consequent oxidation.

(2) Bale-out bowl furnaces with a totally enclosed top, into which an atmosphere of SO_2 gas can be admitted to protect the metal, the flux employed being of greater density than the molten metal in order to leave the surface accessible for ladling-out.

The type of heating does not in general affect the quality of the castings produced, and is chosen for economy, availability and ease of control.

DISCUSSION

Mr. W. West commented that Mr. Devereux's Paper did not leave much opportunity for discussion, because the points were put forward so excellently. All in the aluminium foundry trade would like to use the low-frequency furnace; but they were not all concerned with the production of the most expensive form of casting for aero work, and in consequence had to be satisfied with the next best melting unit, the cost of which was much lower.

He had tried to correlate the cost figures in the Paper with those obtained with oil-fired furnaces, but due to the variation of local conditions, one could hardly make a close comparison.

In asking what chances there were of getting low-frequency furnaces into this country, he said Mr. Devereux had already stated that not many had yet been installed; and he commented jocularly that it might have been better to have presented the Paper to a meeting of company directors, so that they might understand exactly where the jumping-off point was situated.

Confirming the point made in the Paper with regard to the bowl type of furnace and the insertion of sulphur dioxide, he said that as the result of experience at his works in magnesium casting, sulphur dioxide had been introduced into aluminium die-casting also. Where the design was rather intricate and the flow of the metal tended to turbulence in the mould, they had fitted up the dies with small bottles of sulphur dioxide, and tried to keep a closed top. As a consequence, they were getting much better results.

Mr. Devereux's Reply

Mr. Devereux replied to the discussion on his Paper. He agreed with Mr. West that it was very difficult to obtain a really good induction furnace, and that the cost was high. In his view, the work which he and his colleagues had done on the furnace proved that it was worth the expense, and during the past four months they had put into construction 15 furnaces themselves, although as yet only five were completed. The cost of the furnace itself was roughly £1,400, and with the complete electrical equipment it cost about £1,700, which compared with about £1,000 for the oil-fired crucible type of furnace of similar output.

He was obtaining really excellent results with the induction furnaces they had tried, their experience covering three furnaces, two years with one in Switzerland, varying down to about nine months with others; at his company's Redditch works that type of furnace would be used entirely in the one foundry, the other foundry being run with half induction furnaces and half other types. He believed the results obtained with sulphur dioxide with aluminium alloys was due largely to the class of alloy; he imagined there was some advantage in using it with, say, an alloy of high magnesium content.

* "Foundry Trade Journal." Vol. 59 (1938), p. 218.

Paper No. 671

Cutting Tools for Cast Iron

By H. H. BEENY, M.Met. (Member)

While research is necessary to interpret practical experience and extend fundamental knowledge, the machining of metals is not a subject which lends itself kindly to academic treatment, owing to the large number of variables involved. Fortunately the practical problem can be divorced from theory, as workshop methods, which are based upon a vast amount of experience, are very largely standardised and simplified. With machine tools of known capacity, the concern is mainly with cutting speeds and feeds which affect the floor to floor time for the work-piece, and with the length of time the tool material will continue to produce an accurately-machined part without re-grinding and re-setting. Habitually with automatic and semi-automatic machine tools, a cutting speed below the maximum is chosen in order to complete a batch of work without breaking down to adjust the tools, as this latter operation in a high-production multi-tool set-up can involve a considerable loss in output.

In the larger manufacturing organisations, metals being cut are carefully controlled in chemical and physical quality, permitting the establishment of cutting-speed charts for each grade for the guidance of the operator. The depth of cut is frequently not a matter of choice, but is often predetermined by the allowance found necessary on castings, bars and forgings in order to eliminate skin defects and dimensional variations. In the medium and light engineering trades, these allowances are kept as small as possible in order to save material, so that machining cuts nowadays tend to be lighter and at higher speeds than of yore. The selection of the most suitable tool material is a critical matter, and may determine the success or failure of a machine tool for a particular operation. It is the object of the present Paper to depict the general machining characteristics of cast iron and to show which of the available tool materials are most likely to yield the greatest speed and economy in production.

Machining Properties of Grey Iron

In some respects ordinary grey cast iron is an easy metal to machine, as the chips break away in front of the tool in small pieces without any great exertion of force. With any metal the form of chip generated is mainly governed by the ductility or, to include the time element, by the capability of the metal for undergoing very rapid plastic deformation without complete rupture. The graphite flakes which are scattered through grey cast iron, and the nature of the metal itself, which is heavily loaded with embrittling elements such as silicon and phosphorus, are sufficient to prevent ductility and to cause the formation of a disjointed powdery swarf, instead of the continuous ribbon-like chip which is characteristic of the tougher metals.

The type of chip formed when machining a metal is very important, as it affects the proportion and intensity of the destructive influences on a tool. These influences are heat, abrasion and stress, the last taking forms which are more or less static due to the resistance of the metal to tearing, shearing and bending, and also dynamic on account of vibration set up in the work or machine tool or due to intermittent cutting. A strong, tough ribbon-like chip from a tenacious steel delivers a high degree of stress upon the nose of the tool and, at the same time, owing to the rapid sliding action over the cutting face and the internal friction set up in tearing and deforming the chip, much heat is developed.

Tool Requirements

Under such circumstances mechanical strength is the main requirement for the tool, and modern cobalt high-speed steels with a Vickers pyramidal hardness of about 851 and a tensile strength of about 150 tons per sq. in. will put up a very good performance at cutting speeds ranging from 70 to 250 ft. per min., particularly as a coolant fluid is normally available to take away a considerable proportion of the heat. The severity of the conditions may, however, be gauged from the fact that cutting pressures on the nose of the tool range from about 100 tons per sq. in. when machining mild steels up to 200 or even 250 tons per sq. in. for the higher-tensile alloy steels. It is fortunate that, with grey cast iron, the pressure is only approximately 50 tons per sq. in., so that mechanical conditions are easier and the extremely hard and durable, but somewhat more brittle sintered-carbide tools are able to function with a greater margin of safety. As a matter of in-

terest, however, it should be pointed out here that suitable compositions and grades of these tools are being very successfully used for medium and finishing cuts on steel at turning speeds ranging up to as much as 1,000 ft. per min.

Relative Machining Speeds

It has been shown that cast iron does not impose heavy destructive stresses upon the tools, but what is the position in regard to abrasion and heating? It is significant from this point of view that leaded-brasses, magnesium and most aluminium alloys can be turned at 1,000 to 2,000 ft. per min. with carbide tools, whereas grey cast iron of roughly similar tensile strength and no ductility has to be removed at much lower speeds, which vary from 120 ft. per min. for a strong, close-grained low-phosphorus metal up to 800 ft. per min. for a soft annealed well-fettled casting. With steels, the tensile strength is the main guide to the cutting speed, but carbon content is also recognised to exert a powerful influence upon the rate of tool wear; or, in other words, increasing the carbon percentage sharply increases the abrasiveness of the cut. In good-quality irons, the combined carbon is in the region of 0.70 or 0.80 per cent., so that the matrix is pearlitic and corresponds to the composition and structure found in a high-carbon steel.

The strong action of the combined carbon upon the machinability in the case of grey cast iron is illustrated by the fact that an annealing treatment which destroys the constituent, converting it to soft ferrite and graphite, makes a marked improvement in the speed and ease of handling in the machine-shop. With the same traversing feed, cutting speeds may be doubled while multiplying the life of the tool by from three to six times. This striking difference in quality is undoubtedly due very largely to a big drop in the abrasiveness of the metal, but it cannot be entirely overlooked that the annealing also usually reduces the tensile strength, and this also will have an ameliorating tendency. It is unfortunate from the machining point of view that the annealing of irons of commendable quality reduces the wear resistance in addition to the strength, so that it is an unsuitable process for many castings.

The important influence of combined carbon applies not only, of course, to ferritic and pearlitic grey cast irons, but extends to mottled and white castings, where the constituent appears in the massive as well as in the pearlitic form. Speeds are much reduced, as one would expect, but with a suitable grade of sintered-carbide tool, white cast iron possessing a Brinell hardness number around 415 can now be successfully turned, the cutting speed being about 25 ft. per min. Even alloy white cast irons containing nickel and chromium, in which the combined carbon which is normally pearlitic is retained as hard martensite, can be machined with these tools at from 10 to 15 ft. per min. as an extreme case, although the Brinell number of the metal may be as high as 555. This contrasts with a turning speed of from 200 to 500 ft. per min. for an average unannealed grey iron possessing a Brinell number of about 200 (5-mm. dia. steel ball, 750-kg. load).

Influence of Constituents on Machining

So far prominence has been given to the combined carbon content, as apart from the graphite, which gives to cast iron its unique character, this constituent is by far the most important ingredient. Manganese and sulphur have little or no direct influence. These elements, along with silicon, which is of course very potent in this respect, exert substantial control of machinability only in so far as they alter the form of the carbon in the iron. In considering these chemical factors, it must not be overlooked, however, that the machinability of cast iron is determined not only by its abrasiveness but also by its strength, because a strong iron presses the chip against the cutting face of the tool more heavily than does a weak iron and therefore intensifies both abrasion and heating. Alterations in combined carbon content up to 0.90 per cent. affect the tensile strength, as has already been noted in connection with annealing.

Phosphorus existing either in solution or as the phosphide eutectic appears to have little direct abrasive effect within the limits usually found in commercial irons but increasing the amount of the element, say from 0.20 per cent. up to 0.90 or 1.00 per cent., causes a considerable loss in tensile strength and the overall machining quality is definitely improved. In a large machine shop, when changing over to lower phosphorus and stronger irons, slower machining speeds on planing had to be adopted. It is the author's experience that the importance of phosphorus, from the point of view of the machining of grey cast iron, lies in its effect upon tensile strength, the element making the metal weaker and more friable.

It is easy for confusion to arise when considering the machining quality of cast iron, as one is dealing with a complex operation on a complex subject, but the conclusions emerge that, in a major sense, combined carbon and tensile strength are the two factors which radically control the speed of metal removal for a given tool life. This conception simplifies the problem, as the action of other variants, both chemical and physical, can be established by their effect upon these two factors. This interpretation is in-

tended to include additions of such alloys as nickel, chromium and molybdenum, as well as physical changes produced by melting and casting conditions. There is possibly an exception in the case of austenitic cast irons, which form a class apart.

In considering machining quality it will be appreciated that abrasion and heating of the tool go hand in hand. Thus a casting inadvertently produced in too hard a grade of metal will not only wear the cutting edges intensively, but the chips will come away so hot that they oxidise on the surface to brown and purple tints, instead of remaining grey, as with an iron of normal machining quality.

Foundry Influences

The survey deals so far with the properties of the metal itself, but actual castings are frequently very abrasive, due to adhering sand and oxide on the surface and to "cold shot" in the form of very hard pellets of white cast iron just under the skin. Fins or "flashes" at core prints and joints in the mould may strike a chill back into the casting, and the use of denseners, unless carefully arranged, will produce locally-chilled corners or areas on the castings. It is clear that efficient fettling, whether by shot-blasting, tumbling or pickling, has an important bearing on machinability, but this process cannot remove all the abrasiveness from the skin, and the practice in the workshop is, therefore, to take a deep cut and so get well under the harmful layer. With ordinary high-speed steel tools, the blunting effect of the casting skin is very noticeable, but the carbide tools are much more resistant, so that when foundry considerations permit, machining allowances can be reduced. These tools are also invaluable for dealing with castings such as those mentioned above, which are chilled in places or are generally too hard, and which create great difficulties for the older types of tool.

Reasons for Dry Machining

Cast iron is peculiar from the machining point of view because of the dusty nature of the swarf, which renders the use of cutting fluids well nigh impossible. Straight oils quickly become loaded with the finer particles and soluble oil emulsions tend to cause corrosion with the swarf and form hard masses which collect on the machine and choke up the tanks and delivery pipes. Another point which affects many metals is that cutting speeds with carbide tools are frequently very high, so that the fluid is scattered violently by the centrifugal action of the work in the chuck. For finishing cuts where heating of the work interferes with the accuracy of the final dimensions, there would be an advantage in providing a cooling fluid, but machine tools built for general use make no suitable provision for the elimination of the swarf from the liquid. On this account and because in most cases there is a further finishing operation such as grinding, the turning, milling, drilling and planing of cast iron are almost invariably done dry.

The abrasiveness of strong unannealed cast irons is frequently noticed when tapping, screwing or forming; with dry cutting the fine edge tends to dull and a lard oil or a high grade of blended fatty oil is often found advantageous, the liquid being brushed on in small quantities. Taps are often made of special carbon steel and the dies or form tools of high-speed steel, as hard carbide inserts of intricate design are expensive, and in the case of threads would be liable to breakage.

It has been shown that grey cast iron is a metal which is comparatively low in tensile strength, which possesses no ductility and which consequently breaks with a short chip. Nevertheless, it is highly abrasive, due to skin conditions, and the combined carbon normally present. As castings, this metal is, moreover, subject to occasional sand inclusions and chilled spots and is machined dry, so that the tool is not aided by the cooling and lubricating action of a cutting fluid. A combination of heat and abrasion is the destructive influence which has to be countered, and as carbide tools have proved eminently successful for all types of cuts on cast iron, it may be of interest to look for those features which have contributed to this success.

Sintered Tools

The sintered hard carbides possess a tensile strength of about 70 tons per sq. in., which is fully equal to the figure for Stellite, but is only half that for hardened high-speed steels. The cold hardness, however, which ranges from 1,320 to 1,545 Vickers pyramidal numeral, is infinitely superior to that of either rival. Even more striking is the fact that at a dull red heat (600 deg. C.) the hardness is still much greater than that of the other materials *when determined in the cold state.* The author has made hardness tests at 600 deg. C. using a Rockwell machine with a diamond cone indenter under 60 kg. load and found by conversion that high-speed steels varied in Vickers hardness at this temperature from approximately 535 for a 14 per cent. tungsten steel up to 640 for an 11 per cent. cobalt high-speed steel, while Stellite gave a value of 620. Sintered tungsten carbide, however, maintained a hardness equivalent to 970 Vickers pyramidal numeral at 600 deg. C. It is abundantly clear that this retention of hardness, which at normal cutting heats on cast iron must be well over 1,100 Vickers pyramidal numeral, renders this tool material eminently suitable for the dry-machining of iron

castings and accounts for the high cutting speeds which are maintained for long periods without regrinding. The hard carbides appear not to benefit from the application of a cutting fluid, and their use on cast iron is therefore peculiarly fitting.

Reactions on Machine-Tool Design

The comparative fragility of the sintered hard carbide tools and the tremendous speeds necessitated by their unique cutting powers created a considerable revolution in machine-tool design. To-day construction aims at greater rigidity in all parts coming under the reactive stresses of cutting, and at higher spindle speeds with ample driving power and diminished vibration. The machine beds of grey cast iron are skilfully braced against twisting and bending stresses, and the tools themselves are firmly held so as to minimise any yielding under the forces of cutting. Hardened and ground high-tensile alloy steels replace older and softer materials for headstock gears, so that the increased pitch-line velocities may be sustained for long periods with silent running. Roller and ball bearings replace white-metal and phosphor-bronze for many applications, and lubrication systems have been improved by providing automatic pump filtration of the oil along with sight feeds.

The driving power is most frequently a self-contained electric motor of from two to three times the horse-power found in older machines of the same dimensional capacity; this is necessary to provide the steady feed and absence of any tendency to stalling or hesitancy under cut, which is a frequent cause of breakage with carbide tools. The machines are expressly built to withstand the gruelling action of modern high-speed cutting and are necessary if the full advantages of rapid production and economy available with carbide tools are to be attained. It is important to note that these machines permit increased rates of metal removal even with high-speed steel tools or Stellite, due to their greater mechanical stability and power. With cast iron, which does not demand the highest speeds, the older machines are capable of improved service with carbide tools owing to the much longer life between grinds and the better sizing of the work-parts, which results from the slower deterioration of the cutting edge.

The large differences existing in the quality and capacity of machine tools, on account of age or make, render it difficult to give precise cutting speeds, but 200 to 250 ft. per min. may be taken as average machine-shop practice for turning grey cast iron with carbide tools; this compares with 140 ft. per min. for Stellite and 70 ft. per minute for 18 per cent. tungsten high-speed steel, all the cuts being taken dry. The introduction of carbide tools has permitted a reduction in piecework rates of 30 per cent. in many cases, while at the same time increasing the earning power of the operator. On machine tools embodying the latest construction and design, still higher speeds are attainable with greater savings; it is interesting to note that carbide tips are regularly tested by turning grey cast iron at 700 ft. per min. on a modern lathe of heavy construction and power, the feed being 37 cuts per in. and the depth of cut 0.150 in.

Nature of Newer Materials

It is well known that the new super-cutting materials consist of minute particles of intensely hard metal carbide, which are cemented together with cobalt by a final sintering process in the neighbourhood of 1,500 deg. C. Tungsten carbide, which is believed to have the best all-round properties, is the universal choice for machining cast iron, but on steel where the conditions are very exacting due to the strong continuous chip, which tends to "crater" the top face of the tool, tantalum, titanium and molybdenum carbides are also used. The hard carbide materials are, of course, unforgeable, so that the cutting tips have to be given their final shape during manufacture, an allowance only being made for grinding and burnishing or lapping operations, which are conducted after brazing on to a steel shank. The material itself is expensive, so that many designs of tip are made, in order to conform as closely as possible to the final desired shape.

Various grades of composition of the tips are also necessary, the hardest grade for fine boring or light cutting on hard cast iron or chilled iron rolls being low in cobalt and composed of especially fine tungsten-carbide particles; such tips give a Vickers pyramidal numeral of fully 1545.

A grade for general work on cast iron retains the fineness in the constituent powder, but has extra cobalt to cement the grains more firmly together. This grade is more serviceable than the previous one under average machining conditions involving heavy cuts and feeds. The additional cobalt, which is evenly distributed between the hard carbide grains, reduces the indentation hardness slightly, so that the Vickers pyramidal numeral falls to about 1478. For planing or for intermittent cutting on grey cast iron, a softer and tougher grade is available, which has coarser particles of tungsten carbide and a larger proportion of cobalt. The average Vickers pyramidal numeral for this grade is 1372. It may be mentioned that with up-to-date machine tools, intermittent cutting on grey cast iron is now a routine operation.

There seems little need to detail the methods employed in tipped-tool manufacture, as these are already well known and as full information

is readily supplied when required by the various firms marketing the hard carbide products. Alfred Herbert, Limited, have found a silicon brass to be very successful as the brazing medium for fastening the tip on to the seating milled into the carbon steel shank. The procedure, which is simple to carry out, has been standardised for a number of years and brazing troubles are practically unknown. It is important that the shank itself should be of ample dimensions, in order to support effectively the somewhat brittle tip and to damp down cutting vibrations. Special silicon-carbide and diamond wheels have been developed, so that the fine, smooth cutting edge, which is so essential for the maximum cutting efficiency of the tip, can be quickly produced. If care be not taken a rough crumbled edge is formed which quickly fails in use.

A typical lathe tool for work on grey cast iron will have a top rake angle of 8 deg., a clearance angle of 6 deg., and will be capable of sustaining feeds as coarse as 25 cuts per in. With the hardest grade of carbide tip, a stronger tool angle is obtained by using 0 deg. top rake along with a clearance angle of 4 deg. Such a tool will machine white cast iron at between 10 and 30 ft. per min., with a feed of 100 to 250 cuts per in. and a depth of cut up to $\frac{3}{16}$ in.

Advantages Shown

The advantages of sintered tungsten-carbide tools for cast iron may be summarised as follow:

(1) Cutting speeds are from three to five times greater than with the best high-speed steels.

(2) The abrasive action of sand and scale is much better resisted than with high-speed steel, and, when foundry considerations permit, the machining allowances on castings can be reduced.

(3) At moderate cutting speeds which do not overheat the work, the sizing of parts is greatly improved owing to the wear resistance of the tools, and in some cases grinding can be eliminated.

(4) Harder and stronger grey cast irons can be efficiently and economically dealt with in the machine shop, so that the foundry can with confidence put in the best quality of product, knowing that patches inadvertently chilled will be machined. There is less temptation to anneal grey iron castings.

(5) White iron castings are dealt with which were previously unmachinable or could only be cut with great difficulty.

(6) Due to the higher cutting speeds and greater life of the tools, piecework rates can often be reduced by 30 per cent. or more, while permitting larger earnings by the operator.

Acknowledgments

In conclusion, the author would like to express his appreciation and thanks to the directors of Alfred Herbert, Limited, machine-tool makers, of Coventry, for permission to publish the Paper, and to the British Thomson-Houston Company, Limited, of Rugby, for information relative to the manufacture of "Ardoloy" hard carbide tips.

DISCUSSION

Mr. P. A. Russell, B.Sc. (Leicester), opened the discussion by asking if Mr. Beeny could give any recommended method for obtaining the comparative machinability of various grades of cast iron. What system would be recommended? He did not agree that tensile strength was one of the major factors in machinability. The prime factor was graphite size and arrangement. High-tensile castings low in phosphorus would machine quite freely.

Foundrymen must be grateful to the manufacturers for the introduction of the modern tools, for they would enable them to save a number of castings which would otherwise be thrown out.

Mr. W. Smith supplemented the question asked by Mr. Russell with an inquiry as to whether there were not other factors, such as combined carbon, which were of more importance than tensile strength. It was known that some low-phosphorus cast irons of 25 tons tensile strength and over could be machined as readily as other grey cast irons, which might only have 12 to 14 tons tensile strength.

Cutting Speeds and Strength

Mr. F. J. Cook (Past-President of the Institute) agreed with the author that the strength was of vital importance to the cutting speed. In taking hardness by the drill method, one could almost prepare a chart which would give tensile strength and resistance to wear. There was, he thought, much more in the fact that strength had an effect on cutting speed than many people imagined.

If they took the carbon over about 0.9 per cent., it was a remarkable fact that the graphite flakes would be larger in size and fewer, and one could machine such an iron quite easily. Two conditions were possible. They could have a hard iron which was readily machinable, but with the ordinary type of irons of about 18 tons tensile strength, where all graphite was reasonably fine, the effect on the cutting was greater by virtue of its increased strength.

Mr. Beeny's Reply

Mr. H. H. Beeny said that he had a machine in the laboratory for computing comparative machinability. It was a drilling machine in which the

drill was given a constant end-thrust by means of a weight pressing on the back of the spindle. Attached to the machine was an autographic recorder showing the depth of penetration against the number of revolutions. The machine had been used on a number of occasions and appeared to line up with workshop experience, the most machinable iron giving the greatest penetration.

To overcome the slight wear which was liable to occur even with the latest drill materials, samples in each series were drilled twice, the second tests being taken in the reverse order. Thus the sample drilled first in the first run would be drilled last in the second run and so on. By taking the average of the two results a comparative machinability figure was obtained, which was nearly independent of tool wear.

As to Mr. Russell's contention that graphite size and not tensile strength was the important factor, the author had not dealt specially with the action of this essential constituent in grey cast iron, because its form and amount directly affected the tensile strength. It would be seen that there was no real inconsistency between Mr. Russell's views and his own. Other things being equal, in a low total-carbon iron there was a high tensile strength, and the machinability was consequently diminished.

He was glad to hear Mr. Russell say that the latest carbide tools did save castings which were otherwise unmachinable, because that was in line with his own experience. It was useful to have a range of carbide tools by one for just such occasions.

Mr. Smith had said he considered strength was not such an important factor, and mentioned the action of combined carbon. The author agreed in regard to the preponderating position of the combined carbon, and this constituent had already been classified as one of the two major factors controlling ease of machining, but he could not agree in regard to the high-tensile low-phosphorus irons, as he had examined a range of irons from different sources which varied in phosphorus from 0.12 to 1.58 per cent. and in tensile strength from 25 to 11 tons per sq. in. The connection between strength and phosphorus was remarkably consistent, an increase in phosphorus progressively lowering the tensile figure. These irons gave an ease of machinability on the drill-tester which steadily increased with the drop in strength and rise in phosphorus.

It had to be admitted, however, that the test did not take into account the wear of the cutting tool, and he felt from his own experience that wear would be accentuated with such a high content as 1.58 per cent. This was why, in his opinion, the optimum range was about 0.80 to 1.00 per cent. of phosphorus. As to the case of a high combined carbon iron with very large flakes of graphite, mentioned by Mr. Cook, one could assume that the tensile strength would be only quite moderate in view of the large flakes.

It had been suggested that machinability depended on a number of factors or ingredients not discussed in detail which might vary; this was admitted, but the point was that such factors, which would include alloying elements, were covered by their effect upon the tensile strength or combined carbon in the iron.

Looked at broadly, the combined carbon was the most important variant, as in this case one had not only to consider grey cast iron, but also white cast iron, which might contain as much as 3 per cent. of combined carbon and could be machined only very slowly.

Mr. F. J. Cook referred to the test machine described by Mr. Beeny, and said it was designed largely on the experience gained with a similar machine designed by himself about 40 years ago. One important point was that the cutting of a drill depended on keeping the point sharp. It would be found advantageous, when testing, first of all to drill a small hole which would relieve the point of the test drill and gave the cutting speeds on the heel of the tool.

Mr. Beeny agreed that that was what they did in practice.

Paper No. 672

Optimum Blast Volume for Cupola Practice*

By Dr.-Ing. NICOLAS CZYZEWSKI

In 1908 Prof.-Ing. Georges Buzek published a Paper† in which he showed that when a cupola is operated on good foundry coke, the optimum volume of blast should be 100 cub. m. per min., on the basis of the principle that the space between the pieces of coke is 40 per cent. and the velocity of the gases passing through the cupola should be equal to 100 ft. per sec.

In the present Paper it is intended to show, on the basis of quite different considerations from those of Prof. Buzek, that by employing a good foundry coke in a quantity of 9 to 11 per cent. and a normal charge of metal, the optimum volume of the blast should be about 100 cub. m. per sq. m. per min., as demonstrated by Prof. Buzek.

If, on the contrary, the working conditions of the cupola, the use of a coke of not such good quality, the necessity for a very high temperature for superheating the iron, high temperature of the combustion gases leaving the cupola, etc., differ from the normal conditions, the optimum volume of blast will be somewhat different and will depend upon a series of factors affecting the operation of the cupola.

No details of the establishment of formulæ indispensable for calculating the optimum volume of the blast will be given, but the principal formulæ, together with the results of investigations made by the author on cupolas, will be outlined. These results confirm the complete agreement of the theoretical considerations with the practical results.

Equation (1) shows the relationship between the heat formed by the combustion of the coke and part of the charge of metal (Si, C, Mn, Fe), and the heat absorbed in remelting the metal, superheating the iron, and in losses.

$$K \,.\, U\,(1 - S_r.\,0.67) + Q_m = Q_x + Q_s + Q_i \qquad (1)$$

where K denotes the total quantity of coke consumed per 100 kilograms of charge of metal in kilograms;

U the calorific value of the coke in cals.;

S_r the combustibility of the coke—the ratio of the coke burnt to CO to the total quantity of the coke burnt to CO_2 – CO;

0.67 the loss of heat due to the combustion to CO;

Q_m the quantity of heat liberated by the combustion of the constituents of the charge of metal, in cals.;

Q_x the heat absorbed in melting and superheating 100 kilograms of the charge of metal, in cals.;

Q_s the physical heat contained in the burnt gases in cals.;

Q_i the other losses—heating the cupola, heat absorbed in melting the slag, radiation losses, heat absorbed in decomposing the limestone, etc., in cals.

Denoting by Q the sum of Q_x, Q_s and Q_i and substituting this in Equation (1), the relationship between the consumption of coke and the quantity of heat liberated and absorbed in the cupola is obtained:—

$$K = \frac{Q - Q_m}{U\,(1 - S_r\,0.67)} \text{ kilograms} \qquad .. \quad (2)$$

It is known that the maximum heat losses are due to the physical heat carried away by the furnace gases and to the incomplete combustion of the coke; the other heat values for a given cupola fluctuate within relatively inappreciable limits.

TABLE I.—*Coke Consumption per* 100 *kilograms of Metal Charge Expressed as a Function of the Combustibility of the Coke.*

Q_s \ S_r	0.7	0.6	0.5	0.4	0.3	0.2
13,000	14.6	13.0	11.7	10.6	9.7	9.0
18,000	16.0	14.2	12.7	11.6	10.6	9.8
23,000	17.3	16.3	13.8	12.5	11.5	10.6
28,000	18.6	16.5	14.9	13.5	12.4	11.4
33,000	20.0	17.7	16.0	14.5	13.3	12.3
35,000	20.2	18.2	16.4	15.3	14.0	12.9

Table I gives the coke consumption for 100 kilograms of the metal charge as a function of the combustibility of the coke (S_r) which may fluctuate within the limits 0.20 to 0.70 for the

* Presented on behalf of the Stowarzyszenie Techniczne Odlewnikow Polskich.

† "Przeglad Gorniczo-Hutniczy," 1908, p. 338, and "Stahl und Eisen," 1910, p. 354.

combustion of coke in the cupola, and also of the quantity of physical heat carried away by the furnace gases. This quantity of heat varies between 15,000 and 35,000 cals. per 100 kilograms of metal charge and depends chiefly upon the construction of the cupola, the quality and consumption of the coke, the volume of the blast and the size of the pieces of the charge of metal. The values given in Table I have been established for the following data:—

Q_m = 4,000 cals.
Q_2 = 33,000 cals.
Q_1 = 12,300 cals.
Q_s = 13,000 to 35,000 cals.
U = 7,000 cals.

Substituting these values in Equation (2), it gives:—

$$K = \frac{33{,}000 + 123{,}000 + Q_s - 4{,}000}{7{,}000\,(1 - S_r \,.\, 0.67)} = \frac{41{,}300 + Q_s}{7{,}000\,(1 - S_r \,.\, 0.67)}$$

From the figures shown in Table I, it will be seen that the consumption of the charge coke, in accordance with the quality of the coke and with the thermal conditions of the operation of the cupola, varies for a coke of low combustibility in large pieces within the limits of 9 to 13 per cent. and for the same coke, in consequence of a high combustibility, in the limits of 14.6 to 20 per cent.

Assuming that in the combustion zone the coke is burnt completely to CO_2 in the time z in minutes necessary for melting a charge of metal heated to the melting point, the quantity of coke burnt should be—:

$$G_1 = \frac{\pi \,.\, D^2 \,.\, P \,.\, z}{4p} \text{ kilograms} \quad \ldots \quad (3)$$

where G_1 is the quantity of coke burnt in the time required for melting a charge of metal in kilograms;
z the time necessary for melting a charge of metal in minutes;
p the quantity of air necessary for burning a kilogram of coke with the theoretical quantity of air, in cubic metres;
P the volume of air in cubic metres per square metre of cross-section of the cupola per minute;
D the internal diameter of the cupola in metres.

As some of the carbon of the coke is consumed in the reduction of CO_2 to CO, the weight of the coke charge should be greater than that given by Equation (3), and expressed as a function of the combustibility it will be:—

$$G_2 = \frac{2\pi \,.\, D^2 \,.\, P \,.\, z}{4\,(2 - S_r)\,p} \quad \ldots \quad (4)$$

The investigations made on various cupolas with charges of metal in pieces of various sizes have shown that the time necessary for melting a charge of metal depends upon numerous factors, principally the size and shape of the pieces and the height of the bed of metal charge. The way in which the melting time z depends upon the weight of the pieces g and the height h in metres of the charge of metal may be expressed approximately by the following empirical formula:—

$$z = 18.7\,h \,.\, g^{0.0698} \text{ mins.} \quad \ldots \quad (5)$$

Denoting the weight of a cubic metre of metal by γ, one is thus able to calculate the weight of a charge G_m forming a bed of height h metres in the cupola:—

$$G_m = \frac{\pi \,.\, D^2 \,.\, \gamma \,.\, h}{4} \text{ kilograms.}$$

Substituting in this equation the value of h obtained from Equation (5) it gives:—

$$G_m = \frac{\pi \,.\, D^2 \,.\, \gamma \,.\, z}{4 \,.\, 18.7 \,.\, g^{0.0698}} \text{ kilograms} \quad \ldots \quad (6)$$

If the coke consumption expressed as a percentage relatively to the charge of metal is K, the charge of coke will be:—

$$G_2 = \frac{G_m \,.\, K}{100} = \frac{\pi\, D^2 \,.\, \gamma \,.\, z \,.\, K}{4 \,.\, 100 \,.\, 18.7 \,.\, g^{0.0698}} \text{ kilograms} \quad (7)$$

Comparing Equation (4) with Equation (7), it gives:—

$$\frac{\pi \,.\, D^2 \,.\, \gamma \,.\, z \,.\, K}{4 \,.\, 100 \,.\, 18.7 \,.\, g^{0.0698}} = \frac{2 \,.\, \pi \,.\, D^2 \,.\, P \,.\, z}{4\,(2 - S_r)\,p}$$

whence

$$P = \frac{K \,.\, \gamma\,(2 - S_r)\,p}{3740 \,.\, g^{0.0698}} \text{ m.}^3/\text{m.}^2/\text{min.} \quad \ldots \quad (8)$$

Taking into account the fact that some of the oxygen of the air is employed for the oxidation of the charge of metal and that some is lost through leaks in the blast pipes, the quantity of air supplied should be greater than that which is indispensable for the combustion of the coke. Practice shows that the losses of air referred to are 15 to 20 per cent. It is therefore necessary to increase the volume of blast as calculated according to Formula (8). Assuming the losses to be 20 per cent., the quantity of air supplied to the cupola, allowing for the losses, will therefore be:—

$$P_c = \frac{K \,.\, \gamma\,(2 - S_r)\,p}{3740 \,.\, g^{0.0698} \,.\, 0.8} \text{ m.}^3/\text{m.}^2/\text{min.} \quad \ldots \quad (9)$$

Table II gives the values of $g^{0.0698}$ as a function of the weight of the pieces of metal.

Table III gives the volume of the blast as a function of the consumption of coke and the combustibility for pieces of a metal charge weighing 40 kilograms, on the assumption that a

cubic metre of metal charge (γ) weighs 3,000 kilograms (3 tons) and that the theoretical quantity of air (p) required for burning 1 kilogram of coke is 7 cub. m.

The figures given in Table III show that when a good coke of low combustibility is employed in a quantity of 9 to 10 per cent., the quantity of air supplied should be about 100 m.^{3}/m.^{2} per min., a figure previously found by Prof. Buzek, but if a very high superheat temperature of the cupola is required, the amount of coke employed should be increased and consequently the volume of blast increases. Likewise, with small-sized coke of high combustibility, the volume of blast should be increased appreciably.

TABLE II.—*Values of $g^{0.0698}$ as a Function of the Weight of the Pieces of Metal.*

g kg.	10	20	30	40	50	60	70
$g^{0.0698}$	1.174	1.233	1.260	1.294	1.314	1.333	1.345

A question arises here: How will the cupola behave if the blast is greater or less than that calculated according to Formula (9)?

Equation (9) may be written in a slightly different form by substituting $g^{0.0698}$ from Equation (5):—

$$P_c = \frac{K\,(2 - S_r)\,p\,.\,18.7\,h}{3740\,.\,0.8\,z} \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

It follows from this equation that if more blast is supplied than that calculated without increasing the coke employed (K), the coke burns more rapidly in the combustion zone than the metal melts. Pieces of the charge may then reach the level of the tuyeres, and at the best the metal will be cold. At the worst, the cupola may "freeze up."

TABLE III.—*Volume of the Blast as a Function of the Coke where g = 20 kilograms.*

K \ S_r	0.20	0.30	0.40	0.50	0.60	0.70
9	99	93				
10	110	104	98			
11	120	114	107	101		
12	132	124	117	110	102	
13	142	135	127	119	111	103
14		145	136	128	120	111
15			146	137	128	119
16			156	146	137	127
17				156	145	135
18				165	153	143
19					162	151
20					170	158
21						167

With a view to verifying this assertion, experiments were made in the "Wegierska Górka" foundry on a cupola having a diameter of 520 mm. (21 in.). The average weight of the pieces of the metal charge was 15 kilograms.

The consumption of coke was fixed at 13 per cent. relative to the metal charge, and the blast at 98 m.^{3}/m.^{2} per min. Coke in small pieces was used which caused the combustibility to attain as much as 72 per cent.

With a quantity of blast of 96 m.^{3}/m.^{2} per min., the iron was superheated to an adequate temperature. When, on the contrary, the volume of the blast was increased, the temperature of the molten iron fell, and when P_c was increased to 130 m.^{3}/m.^{2} per min., pieces of unmelted iron appeared at the level of the tuyeres.

With a blast less than 96 m.^{3}/m.^{2} per min., the temperature of the iron also fell, but it was not found that any pieces of the metal charge arrived at the level of the tuyeres.

In the case of a cupola having a diameter of 910 mm. (36 in.) the weight of the pieces of the metal charge was 35 kilograms (77 lbs.). The coke employed was of small size and high combustibility. Its consumption was fixed at 17 per cent. with a blast of 140 m.^{3}/m.^{2} per min.

The blast was produced by a "Jaeger" turbo-blower which could only give 113 m.^{3}/m.^{2} per min., in consequence of which the superheat temperature of the iron, intended for casting thin-walled pipes, was a little too low (1,390 deg. C. after filling the forehearth). The volume of the blast was increased by using two turbo-blowers, permitting a volume of blast equal to 140 m^3./m.^{2} per min. to be attained. Fifteen minutes after the quantity of blast had been increased, the temperature of the iron had risen by 45 deg. C.

Experiments made on other cupolas with various qualities of coke and charge of iron have also shown that optimum working of a cupola is only possible with a definite quantity of blast.

It has been shown why irregularities appear in the working of a cupola when the blast is excessive. It is now necessary to explain why the superheat temperature of the iron falls when the volume of blast drops below normal. Two causes contribute in this. The first is that, due to the reduction in the performance of the cupola, certain values for the heat losses increase per unit weight of iron melted, but above all the height of the bed of the combustion zone, precisely where the superheating of the droplets of molten iron occurs, is diminished because this height depends, *inter alia*, also upon the volume of the blast in accordance with the following equation:—

$$H = \frac{d}{2}\sqrt{\frac{P^2}{(30p\,(1 - Q)\,\gamma_p\,.\,v)^2}} - 1 \text{ cm.} \quad (11)$$

where H denotes the height of the combustion zone in cm.;

d the diameter of the pieces of coke in cm.;

p the theoretical quantity of air necessary for the combustion of one kilogram of coke, in m.^{3};

P the blast in m.^{3}/m.^{2} per min.;

γ_p the specific gravity of the pieces of coke;

v the linear velocity of combustion of the coke in cm. per min.;

Q the space between the pieces of coke occupying 1 m.^{3}.

Equation (11) was formulated by the author* and K. Gierdziejewski† as the result of their investigations in a Polish foundry.

It has been found that H, calculated by means of the Equation (11), approaches very closely the value fixed during the operation of the cupola.

DISCUSSION

Mr. L. W. Bolton (British Cast Iron Research Association) said he had found that the figure of 100 cub. metres of air per square metre of cross-sectional area, which was approximately 325 cub. ft. per sq. ft., for cupolas melting with normal metal to charge coke ratios, was rather lower than generally used in this country. It had been found from an examination of a large number of British cupolas that the average air supply used was between 110 and 130 cub. metres per minute per square metre of cross-sectional area, and many cupolas were giving excellent results with the higher figure. The difference between this practice and the experiments carried out by the author were, in Mr. Bolton's opinion, due to differences in the qualities of the coke used.

He agreed with speakers on Dr. Barigozzi's Paper‡ that every cupola had its own peculiarities, but regretted that the Paper made no reference to blast pressure, as this was a factor of great importance. The nature of the coke, as well as the nature of the charges, could have considerable influence on the resistance offered by the cupola to the blast, and when this resistance was high, the volume which would give optimum results would be affected. Certain cokes caused a high resistance to the blast, and if such cokes were of a type which gave poor results when worked with a high blast pressure, then the optimum volume of air would be low.

Pressure and Voids

It was the speaker's opinion that the velocity of the blast through the combustion zone in many cupolas was considerably higher than the figure of 100 cub. ft. per second suggested by Prof. Buzek. This figure allowed for the expansion of the air when heated to approximately 1,600 deg. C., but it did not take into account the pressure required to inject the air. It assumed that the air could pass through voids between the coke which totalled 40 per cent. of the cross-sectional area of the furnace. Even in this country, where cupola blast pressures were generally lower than in many other countries, it could be estimated from the pressure required to inject the air that the voids between the coke, etc., in the combustion zone must be less than 20 per cent. of the total area. The question of blast velocity was of great importance in cupola melting, as on it depended many factors, such as oxidation losses of silicon, manganese and carbon, maximum output for a given diameter, as well as the optimum blast volume.

Excessive Losses

Although the author's recommended figure for optimum blast volume would appear low to many users of British cupolas, the allowance he made for loss of air through leakage and oxidation of the charges appeared to be excessive. It amounted to 20 per cent. of the total air supplied to the cupola, or 25 per cent. of the theoretically estimated amount. It was not usually found in normal cupola practice that the air lost due to the oxygen combining with silicon, manganese and iron exceeded 2 to 3 per cent. of the total air supply. Taking the case of a 39-in. diameter cupola, working with a pressure of 20-in. water gauge in the wind belt, in order to lose 15 per cent. of the air supply, apertures or leaks in the wind belt and blast main would require to total 5 sq. in. This was considerably more than was met in an efficiently designed and operated cupola. It therefore appeared that some of the factors accepted by the author in his calculations were not necessarily correct, and while the theoretical figure put forward was found to be confirmed by practical trials with Polish coke, a different figure would be required for other types of coke.

Air-to-Coke Ratio

Mr. A. Campion said he doubted whether the air-to-coke ratio was of such importance as was often thought in determining the technique of the cupola operations. If the air was not evenly distributed over the whole area of the cupola, just above the tuyere level, satisfactory and controlled melting was not attained. The secret of all successful furnace operations was regularity and uniformity of combustion. Unequal air distribution would cause an increased coke consumption and at the same time give oxidised metal. He knew of cases where 3 to 4 per cent.

* M. Czyzewski, "Optimum Height of the Bed of the Combustion Zone of Coke" (in Polish), "Przeglad Gorniczo-Hutniczy," 1935, p. 437.

† K. Gierdziejewski, "Attempts to Melt Iron for Engineering Castings by Means of Coke Produced in Poland" (in Polish.) "Przeglad Techniczny," 1936, p. 518.

‡ Paper No. 695.

reduction in the amount of coke required for melting had been achieved by even distribution of the air.

Optimum Scrap Size

Much had been said in the Paper on the subject of the materials of the charge, and he agreed that the condition of the charge material profoundly affected the operation of the cupola and also the quality of the metal cast. The size of materials should be selected to suit the size of cupola more especially when a high percentage of steel was used in the charge. A good general rule was to use no piece of steel which was more than one-third the diameter of the cupola in its greatest dimension.

The size of material charged affected the working of the cupola to a greater degree than was commonly realised. The coke size was also important, and the tendency was now to use a coke graded to suit the cupola size, and this was exceedingly beneficial, especially in the bed coke, as it permitted a solid pack which stood up well to the blast. The whole secret of successful melting was in the making and burning of the bed. Pressure of blast was only one factor, and he personally did not attach a great deal of importance to it. Only sufficient pressure was required to give a penetration to the centre so as to obtain a uniform combustion over the whole area and to carry the products of combustion to the cupola stack. Pressure, of course, governed the velocity, and, if it was uniform, even combustion resulted with the production of metal free from oxidation and which cast easily and machined well. The coke consumed in melting was also less when air distribution was good.

Much depended on the class of material used. If a high steel mixture was melted, a considerable part of the coke charged was required for carburisation purposes and, therefore, when coke-to-metal ratios were mentioned, it was desirable to state the class of metal melted, because the coke used for carburising was not contributing heat to melt and superheat the metal.

Fundamentals of Control

He had reached the conclusion that the idea that every cupola was a law to itself was due partly to the method of allowing the cupola to work as best it could without much control of operations, and partly because the real reactions had not been thoroughly studied or understood. Knowledge was being obtained of the reactions and the manner in which they might be controlled every time. There was no reason why cupola operations should not be under strict control, which was essential in the production of modern high-duty material, where every phase of cupola working was closely studied and each controlled. The control must be applied to cupola design and construction, the selection of composition and size of charge metals, the structure and grading of the coke, and distribution of the air in a regular manner all over the area of the cupola at the melting zone.

Paper No. 673

Notes on the Design and Operation of the Open-Hearth Furnace for Melting Malleable Cast Iron

By G. R. SHOTTON (Member)

In considering the open-hearth furnace as a medium for melting malleable cast iron, it is not the intention of the author to draw a comparison with other better-known types of melting furnaces, but rather to set out his accumulated experiences of the design and operation of the open-hearth furnace.

In Great Britain, the air furnace, rotary furnace, cupola and, to a lesser extent, the electric furnace, are the most popular melting furnaces for the production of malleable cast iron. The open-hearth furnace has only been adopted in two or three plants, and the results obtained in these plants appear to have varied considerably.

Each of the melting furnaces mentioned above has certain advantages, and with the exception of the open-hearth furnace, there is a considerable amount of published data available regarding their construction and operation. In the case of the open-hearth furnace, however, there are few data available on its operation for the production of malleable cast iron, although it is well known as a melting medium for the production of steel.

Undoubtedly, the high initial cost of installing an open-hearth furnace is the most serious deterrent to its more general adoption in malleable foundries, though it appears probable that a wider knowledge of the results obtainable might lead to the more general use of this type of furnace. While the capital cost is high in comparison with other types of melting furnaces, it is quite economical in operation, provided it can be run at a reasonable capacity.

Before considering the more important features of design and operating data, it is advisable to explain the basis on which the data have been obtained. The notes on design, together with all the operating data given, have been obtained on a new furnace installation with a capacity of 15 tons. This furnace has been installed to cope with the metal supply for foundry extensions which were not complete when this Paper was prepared. Consequently, the furnace has been running below capacity, and there is no doubt that a further reduction in fuel costs will be obtained when operating on a full metal output. The furnace has now been operating for several months, and the operating data given are extracted from the actual daily records over this period.

As no figures are yet available for refractory costs, those given in this Paper are based on results obtained over the past three years on an 8-ton open-hearth furnace of similar design, which has now been superseded by the new 15-ton furnace. There is no doubt that the larger furnace will show a saving in refractory cost, when expressed in terms of cost per ton of metal melted.

Furnace Design

The general design of an open-hearth furnace is well known and does not call for further description. Fig. 1 is a diagram showing the general lay-out of the furnace and regenerators. Certain features of the design may markedly affect the efficiency of the furnace, and these may not be so generally appreciated. In discussing the most important details of design, it should be borne in mind that the same remarks will not necessarily apply to the large open-hearth furnaces of 50 to 200 tons capacity which are used for the production of steel. The following notes on design are of an essentially general character, but where actual figures are given they will relate to the 15-ton furnace on which the operating data were obtained.

The gas- and air-ports are shown in Fig. 1, which gives a half-elevation and half-plan of the furnace body, gas- and air-ports, and regenerators. The gas-port, which is the lower one, is approximately 14 in. wide by 9 in. high where the gas enters the furnace body. The air-port above is about 12 in. high and extends almost the full width of the furnace, so that a blanket of air effectively keeps the flame well down on the bed of the furnace.

If the air-port is too small, difficulty may be experienced in keeping the flame down on the bed of the furnace, and this is essential, since the furnace crown would be quickly melted down if the flame were allowed to impinge directly on it. For the same reason, the slope on the

ports is highly important. The gas-port is made about 10 ft. in length in order to give direction to the gas flow, and is built with a slope of 1 in 4, *i.e.*, the level of the port rises 1 ft. in every 4 ft. of length. This length, combined with the slope of the port, will effectively direct the gas flame down on to the bed of the furnace. If too steep a slope is

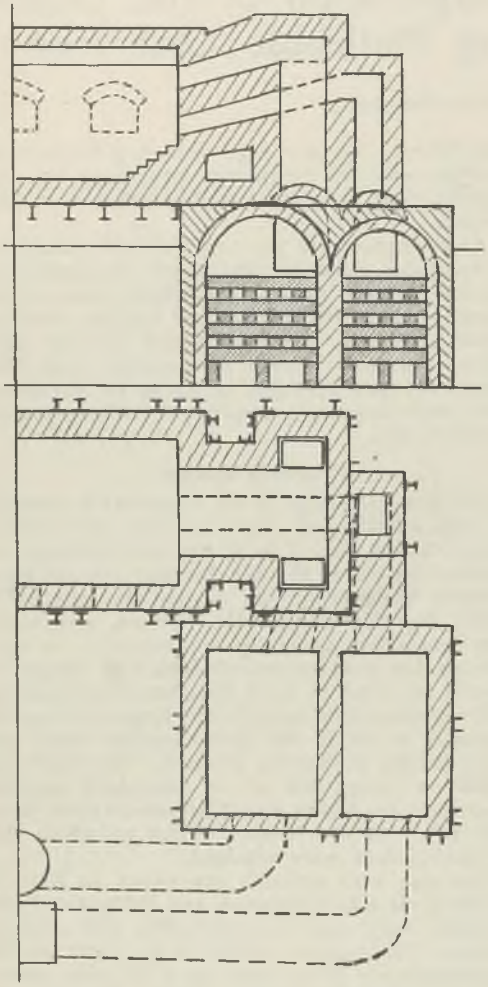


Fig. 1.—Diagram of Open-Hearth Furnace.

employed, the flame will strike the furnace bed too sharply, and eddies of flame may strike upwards to the crown, which would be melted down in a few days under such conditions. On the other hand, insufficient slope on the gas-ports would result in the flame developing too high in the furnace, and the crown would again suffer.

The air-port is sloped at approximately the same angle as the gas-port, but does not need to be so long. In the modern type of furnace, the air-port has two down-takes, and the gas-port passes through and beyond these and has a single down-take. This construction allows easy access to the port and down-take, and so facilitates the carrying out of minor repairs to the ports, etc. At the same time it enables the gas-port to be considerably longer than would be the case if its down-take was built between the furnace body and the air down-take, as was the case in the older designs.

Fig. 2 is a photograph of one end of the furnace, showing the slope on the crown of the ports, and the general construction of the port block and down-takes, the whole being well braced with buck-staves and tie-rods. It is good practice to construct an air space between the furnace body and the gas down-take

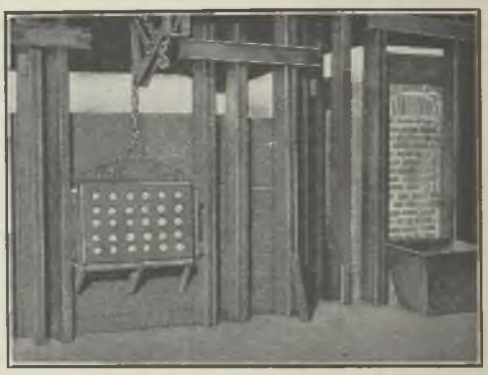


Fig. 2.—End of Furnace, showing Port Block.

as shown in Fig. 1, as this helps to cool the brickwork adjacent to the ports and down-takes and so prevents serious erosion of the lining.

Furnace Body

The body of the furnace is rectangular in shape, and to avoid excessive wear on the port noses, while allowing full development of the flame, the length of the bed should be about two and a half times the width, for a given capacity of furnace. It should be noted that the average depth of molten metal is usually appreciably less in proportion to the furnace capacity than is the case in the open-hearth furnace operating for steel castings. This facilitates rapid superheating of the molten metal to meet foundry requirements.

The crown of the furnace is arched, with about 12 in. spring from the side wall to the centre of the crown. The level of the crown may be raised a few inches just in front of the

port block to allow in part for the rapid expansion of the gases in the furnace. This practice also helps to guard against the flame being deflected against the crown while the cold charge is massed high on the furnace bed.

A general view of the furnace, together with the charging stage and the entrance to the valve pit, is shown in Fig. 3, which also shows the three working doors through which the metal is charged and manipulated, the molten metal being tapped from the other side of the furnace.

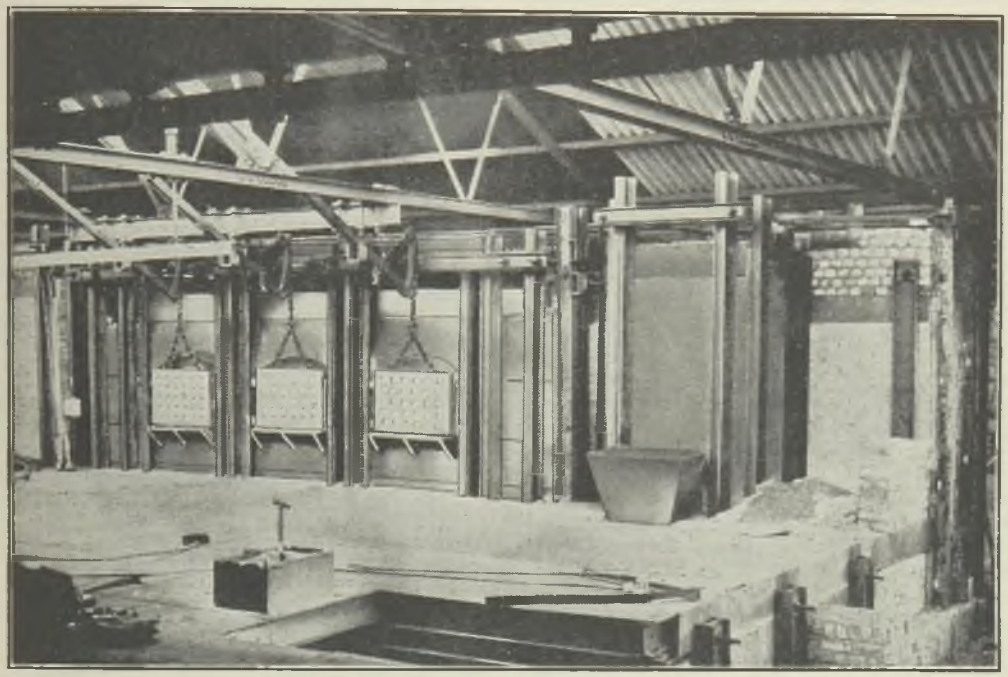


Fig. 3.—General View of Furnace and Charging Stage.

Regenerators

The intake flues leading from the bottom of the down-takes to the gas and air regenerators should be of ample size, and are lined with silica bricks. The level of these intake flues is approximately level with the top of the regenerator brickwork, so that the exhaust gases sweep right across the top of the regenerators and pass downwards throughout the whole area of the "honeycomb" brickwork, which is of good-quality firebrick.

Since the regenerators are required to maintain a temperature of between 900 and 1,000 deg. C., it is important that they be built sufficiently large to ensure a reserve of heat which will not be seriously depleted by the incoming gas and air during the 15-min. interval between valve reversals. In the 15-ton furnace now under consideration, the temperature of the regenerators reaches about 960 deg. C., and shows a temperature drop of only about 60 to 80 deg. C. on each reversal of gas and air flow.

Reversing Valves

There are many types of reversing valves giving good service in open-hearth furnaces. The essential requirement of a good valve is resistance to distortion, since it will be realised that the exhaust gases are still very hot when they pass through the valves to the stack flue, and the valve must be of robust construction if severe distortion is to be avoided.

The air reversing valve is usually of the simple butterfly type, and this will give efficient and continuous service for many years. A water-sealed valve is preferable for the gas reversing valve. This will effectively prevent leakage of gas into the stack flue and at the same time will reduce distortion on the valve plates. Since there is considerable evaporation of the water, a ball valve should be fitted to maintain a constant water level.

Maintenance of the Furnace

The open-hearth furnace can be operated continuously for several months without any lengthy stoppage for repairs. Generally speaking, the life of the brickwork is increased when the furnace is maintained continuously at a temperature approximating to melting conditions. This is effected by keeping the furnace dampered down between melting periods (*i.e.*, during the night and at week-ends), and a slow gas supply is put through the furnace during these periods so that the temperature of the furnace body and the regenerators does not fall appreciably. This is dealt with later when discussing fuel consumption.

A "swill-heat" is usually carried out at the week-end to keep the bed in good condition. That is to say, limestone is spread over the bed and around the breasts of the furnace, and the furnace is operated at melting temperature for four to six hours. The limestone attacks the silica sand of the bed and forms a lime-silica slag. After tapping this slag, the furnaceman cuts off any portions of the bed which have been undermined, so that the level of the bed is appreciably lowered. After "drying-up" the bed with wet silica sand, dry silica sand is spread thinly over to re-form the bed, and "fritted" on. This procedure is essential, since the height of the bed tends to rise during the course of a week's melting, and any small accumulations of slag or iron which have been absorbed in the bed during the week are undermined and tapped with the slag resulting from the "swill-heat." The cost of the fuel used for this "swill-heat" must, of course, be taken into consideration when taking out figures for fuel consumption.

Very few repairs to the brickwork become necessary during the working life of the furnace. The working life varies according to operating conditions, but such repairs as are necessary can usually be carried out at fixed holiday periods.

The life of the port blocks, particularly the noses of the ports, is the main factor affecting repair periods. Under normal conditions, the port blocks must be rebuilt at intervals of four to six months, and this work is usually carried out during two or three of the normal Bank-holiday periods in each year, according to the amount of wear apparent just prior to a particular holiday period. While repairs to the port blocks, etc., are being carried out, advantage is taken of the opportunity afforded to empty the regenerators and clean the bricks before replacing them. The brickwork of the regenerators tends to "fur up" after some months, but this work can usually be left until repairs to the port blocks, etc., become necessary.

The side walls and crown of the furnace will usually last for a period of twelve to twenty-four months before it becomes necessary to rebuild them. Their working life largely depends on the maintenance of the port blocks in good condition, so that the flame does not impinge directly on the brickwork of the side walls and crown. A life of approximately two years has been obtained under good working conditions, apart from minor repairs to the door jambs, etc.

The total cost of repairs to brickwork, and the cost of silica sand and plastic refractories for the tapping hole, etc., will be more or less independent of actual tonnage of metal melted. While the 15-ton furnace under consideration in this Paper has not been operating for a sufficient time to afford any reliable cost figures for refractories, etc., the data obtained from a similar 8-ton furnace over the past few years may afford an approximate comparison. In the opinion of the author, the 15-ton furnace, if operated at reasonable capacity, should show an appreciable saving over the figures now quoted.

The maintenance costs on the 8-ton capacity furnace, taken over a period of approximately three years, during which period eleven heats averaging 6 to 8 tons each were melted in each working week, are as follow:—

Silica sand and plastic refractories for maintenance of furnace bed and tapping hole ... 4d. per ton of metal melted.

Silica bricks, silica cement, firebricks, etc., used on repair work, rebuilding, etc. ..... 1s. 7d. per ton of metal melted.

The total refractories cost therefore ..... 1s. 11d. per ton of metal melted.

During the same period, fluxes used when melting and for "swill-heats," etc., average approximately 4½d. per ton of metal melted.

The total cost of all refractories taken over periods of two or three years remains constant, but the cost per ton of metal melted will naturally vary in proportion to the output of metal from the furnace.

It is fully expected that the total refractories cost taken over a period on the 15-ton furnace will not exceed by a very great amount the total refractory cost on the 8-ton furnace over a similar period. It thus follows that if the larger furnace is operated at a reasonable capacity, a large reduction in refractories cost per ton of metal melted should be obtained, and it would appear reasonable to expect that on the basis of 10-ton heats as an average charge (*i.e.*, approximately 110 tons output of molten metal per week) the total cost of all refractories used would be reduced to a figure of about 1s. 7d. per ton of

metal melted. The cost of fluxing material should show a slight decrease, and should not exceed 4d. per ton of metal melted.

Gas Producer

The success of the open-hearth furnace will obviously be dependent to a great extent on the supply of a consistently good quality of producer gas. It is not proposed to deal with producer design in detail, since there are many different types of gas producer available, and the choice of a particular type of producer will depend on a number of purely domestic factors.

The fixed-bottom producer with a hand-operated charging hopper is the simplest form of producer, and is capable of yielding an excellent quality gas. Very close supervision is necessary with this type, however, since neglect by the operators can result in poor-quality gas and excessively high coal consumption.

The gas producer used to supply gas for the 15-ton furnace under consideration is of a mechanical type. The grate can be rotated slowly by mechanical power, and has ploughs fixed in such a manner that the ash is ploughed from the bottom of the ash bed as the grate rotates. The grate makes one complete revolution in two hours, but even at this slow speed it is only operated intermittently. The tuyeres, which are fixed to the grate and rotate with it, are designed so that the coal bed is alternately raised and lowered as the grate rotates, the undulating motion thus imparted to the coal bed being very effective as a means of keeping the coal bed in an open condition, and so preventing free air and carbon dioxide formed at the tuyere zone from " blowing through " near the walls of the producer.

Some hand poking is also necessary from the top of the producer to prevent the coal caking at the distillation zone high up in the coal bed, but the amount of such poking necessary is greatly reduced by the agitation induced in the coal bed by the rotary movement of the grate and tuyeres. The efficient agitation of the coal bed is one of the most essential factors in producer practice if a high-quality gas is to be delivered to the melting furnace.

The coal feed is automatic, and can be regulated to give any required feed between 1 cwt. and 12 cwts. of coal per hr. The coal is fed from a small storage hopper by means of a screw feed, which delivers the coal into a small cone at the top of the producer, the coal falling from this cone being deflected by a slowly rotating shoe just beneath the cone, so that it is uniformly distributed over the whole area of the producer.

The current consumption of the motor driving the coal feed mechanism is about 0.50 kw. per hr., and is running for 20 to 22 hrs. every day. The grate is rotated by a 2-h.p. motor, absorbing approximately 0.75 kw. per hr., but this is only operating for about 4 hrs. per day, the period of operation varying from 15 to 30 min.

The air supply is induced into the intake pipe leading to the tuyeres by means of a steam injector, the steam supply being obtained from a small cross-tube boiler, which also provides the steam for another gas producer feeding the annealing plant.

The control of the steam and air mixture in the intake pipe is highly important, as too low a proportion of steam in the mixture will result in the formation of a heavy clinker, while an excess of steam will reduce the temperature of the lower zone and result in an unduly high proportion of CO_2 in the gas obtained.

TABLE I.—*Power Cost.*

Rate of current consumption.

Motor.	Current rating.	Power used. Kw. per hr.
Coal feed and distributor	440 volts × 1 amp.	$\frac{1}{2}$
Coal elevator to staging	440 volts × $1\frac{1}{2}$ amp.	$\frac{3}{4}$
Rotation of bottom pan	440 volts × $1\frac{3}{4}$ amp.	$\frac{7}{8}$

Daily consumption.

Motor.	Hours operating daily.	Daily power consumption. Units.	Total daily power cost at 1d. per kw. per hr.
Coal feed and distributor	22	$\frac{1}{2} \times 22 = 11$	16 units at 1d. per unit = 1s. 4d. per day.
Coal elevator to staging	3	$\frac{3}{4} \times 3 = 2$	
Rotation of pan ..	4	$\frac{3}{4} \times 4 = 3$	

The steam pressure is kept constant by means of a balancing valve in the steam supply pipe, so that the amount of steam passing through the injector depends entirely on the aperture at which the injector is set, and is thus capable of fairly close regulation. The pressure of the steam and air mixture in the tuyere box is measured on a gauge and is controlled by the regulation of the steam injector. This ensures reasonably consistent conditions in the gas producer, and a good quality of producer gas is maintained without difficulty.

The power consumption and cost, based on one penny per kilowatt hour for the electric current, are set out in Table I.

Assuming 11 charges averaging 10 tons are melted during the week, then the power cost per ton of metal melted is approximately 1.1d. per

ton, while on charges averaging 8 tons each, the power cost would rise to 1.4d. per ton of metal melted.

Operation of the Furnace

Although a soaking flame is maintained in the furnace during the night and week-end periods, it is also necessary to preheat the furnace prior to charging.

During the soaking period, the air valve is practically closed, the stack damper is lowered to leave only about 1 in. of space open for the exhaust gases, and a coal feed of about $1\frac{1}{4}$ cwts. of coal per hr. is maintained on the gas producer. The gas producer is operated at a slow rate, the steam injector being regulated to maintain a very low pressure in the tuyere box. Under these conditions, just sufficient gas is being fed to the furnace to ensure that the body of the furnace is almost completely filled with a gentle rolling flame, thus ensuring that there is no serious drop in the temperature of the furnace body, nor in the temperature of the regenerator brickwork. About two hours before charging is due to commence, the coal feed is increased to 6 cwts. per hr., the air and stack dampers are opened, and a melting flame is maintained to raise the temperature of the furnace body and regenerators.

As soon as the furnacemen come on duty, they tap out any small accumulation of slag formed during the preheat period, and then fettle the bed. If any slag has remained on the furnace bed, it is removed by "puddling" it with wet silica sand, which is afterwards raked out through the working doors, any hollows or cracks remaining in the bed being afterwards filled up with dry silica sand, which is "fritted" on before charging is commenced.

The metal is then charged through the working doors. The foundry scrap, consisting of feeders, sprues, rejects, etc., is first charged, the bulk being charged on the middle of the bed, any steel scrap to be included being distributed amongst the foundry scrap to facilitate melting. The pig-iron is then "peeled" into the furnace, the bulk of it being placed at the ends of the furnace bed. It is usual to allow an interval of about 10 to 15 mins. after charging about two-thirds of the foundry scrap. While this prolongs the charging time, it is effective in speeding up the melting-down period by reducing the tendency of the molten metal trickling down to resolidify when it comes into contact with the cooler metal on the bed of the furnace.

During the melting-down period the coal feed is at its maximum, being usually at the rate of 6 to 7 cwts. per hr., and the steam injector is adjusted to give a higher pressure in the tuyere box to maintain standard conditions in the producer itself. After about one hour, molten metal will begin to accumulate on the bed of the furnace, and the furnaceman will then hasten the melting by breaking up masses of unmelted metal, and pulling it into the pools of molten metal on the bed. The correct manipulation of the charge at this stage is a big factor in obtaining rapid melting.

A charge of 8 to 10 tons should be melted down in $1\frac{3}{4}$ to 2 hrs. after completion of charging. The charge should now be continually rabbled to raise the colder metal from the bed of the furnace and to help to melt the remaining pieces of solid metal floating in the bath. Under normal conditions, an 8-ton charge will be completely molten in about $2\frac{1}{4}$ hrs. after completion of charging, a 10-ton charge taking perhaps 20 mins. longer.

The furnaceman notes the time when the charge becomes completely molten, and continues to rabble the metal at frequent intervals to ensure that the charge is thoroughly mixed,

TABLE II.—*Daily Time Table for Two 10-ton Heats.*

Time.	Operation.	Coal feed.
4.0 a.m.	Commence preheat ..	6 to 7 cwts. per hr.
6.0 a.m.	Furnacemen come on duty. Slag tapped and furnace bed fettled	Feed stopped.
6.20 a.m.	Commence charging ..	6 cwts. per hr.
7.30 a.m.	Charging completed ..	7 cwts. per hr.
8.50 a.m.	Pools of molten metal collecting on bed. Furnaceman commences to manipulate unmelted material to hasten melting	Not altered.
9.55 a.m.	Charge completely molten	6 cwts. per hr.
10.10 a.m.	Test sample taken for analysis	Not altered.
10.55 a.m.	Laboratory report received	
11.00 a.m.	Tapping commenced. Air valve and stack damper closed slightly	5 cwts. per hr.
11.50 a.m.	Tapping completed and bed fettled	5 cwts. per hr.
12.15 p.m.	Commence charging second heat	6 cwts. per hr.
1.20 p.m.	Charging completed ..	7 cwts. per hr.
3.40 p.m.	Charge completely molten	6 cwts. per hr.
3.55 p.m.	Test sample taken for analysis	Not altered.
4.40 p.m.	Laboratory report received and metal tapped	5 cwts. per hr.
5.30 p.m.	Tapping completed ..	Feed stopped.
5.45 p.m.	Bath fettled	—
5.50 p.m.	Gas flues opened for cleaning	—
7.00 p.m.	Gas flues sealed. Air valve and stack damper closed sufficiently to maintain soaking flame in furnace	$1\frac{1}{4}$ cwts. per hr.

and about 15 minutes after melting has been completed, when the metal charge is well mixed, a small sample of metal is ladled out and cast into a chill mould. This is quenched and drilled, and the drillings are hurried to the laboratory for the estimation of total carbon and silicon. About 45 minutes are absorbed by the quenching and drilling of the test sample and the subsequent analysis.

While this is in progress, the furnaceman will continue to rabble the metal bath, which usually receives sufficient superheating during this period to enable tapping to commence immediately the analysis is approved by the laboratory. If adjustment of analysis is considered necessary, suitable additions are made to the bath, and after a thorough rabbling of the charge to ensure uniformity of analysis, the metal is tapped. As the metal is shanked from the furnace in 1-cwt. ladles, a small tapping hole is used. A 10-ton charge will normally be tapped in about 50 minutes, though this can be modified to suit the requirements of the foundry.

After the metal has all been tapped, the slag is drained from the furnace bed, and the latter is fettled as before. Charging of the next heat can then commence, after an interval of 10 to 20 minutes to " frit " on any sand added to the bed when fettling. Usually the second heat can be melted and tapped in 15 to 30 minutes less time than was occupied by the first heat. A typical daily timetable for two 10-ton heats would be as shown in Table II.

As instanced in the schedule set out in Table II, a 10-ton charge will normally take about 3½ hours from completion of charging to commencement of tapping. This is equivalent to about 5½ hours' total time, from commencement of charging to completion of tapping. No very great reduction in time is apparent with smaller charges, as an 8-ton heat occupies 5 to 5¼ hours overall, and a 6-ton heat takes 4¼ to 4¾ hours from commencement of charging to completion of tapping.

Melting Losses

Melting losses are very consistent, and little difficulty is experienced in tapping metal to the required analysis. The iron produced is a low total-carbon white iron suitable for the production of blackheart malleable cast iron. Most of the melting losses take place during the melting-down period, only a slight change in analysis being apparent during the superheating period.

The melting loss on total carbon is usually between 0.32 and 0.40 per cent., the required total carbon being of the order of 2.4 per cent. Except under certain abnormal conditions, the metal is usually tapped with a total carbon content within ± 0.05 per cent. of the desired figure.

The silicon content normally shows a melting loss of between 0.30 and 0.35 per cent., the required silicon content being about 1.0 per cent. The normal variation of silicon content in the metal tapped is within ± 0.03 per cent.

Occasionally the losses on total carbon and silicon will vary outside the above limits, but as this is detected when the test sample is analysed, the metal in the furnace can be corrected before tapping. Such abnormal variations in melting losses usually coincide with an appreciable change in the time occupied in melting down. Occasionally a charge is melted down in an appreciably shorter time than is usual, and the melting losses under such conditions are lower. Conversely, if the melting-down time is prolonged, greater oxidation of the charge will take place, and the losses on total carbon and silicon will be greater.

Provided that the quality of gas supplied to the furnace is maintained at the normal standard, the melting-down time for a given size of charge is fairly regular, and consecutive charges can be tapped within the limits of analysis given above.

Fuel Costs

The cost of both fuel and power will show a rather wide range of variation, when expressed in terms of cost per ton of metal melted. The fuel absorbed during the soaking periods, *i.e.*, during the night and at week-ends, together with the fuel absorbed by the " swill-heat " at the week-end, will be relatively high when compared with the fuel used for actual melting.

The furnace is soaking for about 9 hrs. every day, during which period the coal feed is between 1.0 and 1.5 cwts. per hr. The same feed is used for the week-end period, with the exception of the " swill-heat " periods, which total between 6 and 10 hrs. in duration, during which time the coal feed is at the rate of 5 to 6 cwts. per hr. A simple calculation will thus show that approximately 140 cwts. of coal per week will be absorbed in addition to the coal used for the final preheating of the furnace and in melting the actual charges. This figure is confirmed by actual coal consumption figures obtained over a period. The coal consumed during soaking and " swill-heat " periods will, therefore, be fairly standard over any given period, independent of the tonnage of metal melted.

The coal consumed when melting the charge, including the coal utilised for the final preheat each morning, will vary according to the size of the charge melted, but will not be in strict proportion. It is thus apparent that if the furnace is worked at low capacity, the coal consumed in melting will show a slight increase when expressed in cwts. of coal per ton of metal

melted, while the coal utilised for soaking, etc., will show a figure which, expressed in terms of consumption per ton of metal melted, will vary in inverse proportion to the tonnage of metal melted.

Fuel consumption figures are given in Tables III and IV for the operation of the furnace on periods, etc., of 1.60 cwt. of coal per ton of metal melted. On the other hand, if the furnace is being operated on charges averaging 10 tons each (110 tons per week), the fuel consumption on soaking periods, etc., will only be at the rate of 1.28 cwt. per ton of metal melted, and there would be a corresponding reduction

TABLE III.—*Coal Consumption for Soaking Periods and Swill Heats.*

Soaking.—	
Daily (Monday to Friday), 9 hours at 1¼ cwts. per hr.	12 cwts. daily for 5 days.
Ditto (Saturday), 14 hours at 1¼ cwts. per hr.	18 cwts.
Ditto (Sunday), 12 hours at 1¼ cwts. per hr.	15 cwts.
Total fuel used during soaking periods	93 cwts. per week.
Swill heat.—	
(Sunday), 8 hrs. firing at 6 cwts. per hr.	48 cwts. per week.
Total fuel used weekly apart from actual melting	141 cwts.

Note.—This coal consumption is fairly standard over each weekly period, and bears no relation to the capacity at which the furnace is worked.

TABLE IV.—*Fuel Consumption on Melting.*

Case (1).—Based on average charges of 10 tons each, *i.e.*, 110 tons of metal melted per week.

Preheat	2 hours at 7 cwts. per hour on 6 days	84 cwts. per week.
Melting	*Charging, etc.*, 1½ hours at 6 cwts. per hour on 11 heats	99 ,, ,, ,,
	Melting down, 2½ hours at 7 cwts. per hour on 11 heats	192 ,, ,, ,,
	Superheating, 1 hour at 6 cwts. per hour on 11 heats	66 ,, ,, ,,
	Tapping and fettling, 1 hour at 5 cwts. per hour on 11 heats	55 ,, ,, ,,
	Total fuel to melt 11 heats of 10 tons each	496 cwts.

This is equivalent to 4.51 cwts. of coal per ton of metal melted.

Case (2).—Based on average charges of 8 tons each, *i.e.*, 88 tons of metal melted per week.

Preheat	2 hours at 6 cwts. per hour on 6 days	72 cwts. per week
Melting	*Charging, etc.*, 1½ hours at 6 cwts. per hour on 11 heats	99 ,, ,, ,,
	Melting down, 2¼ hours at 7 cwts. per hour on 11 heats	173 ,, ,, ,,
	Superheating, 1 hour at 6 cwts. per hour on 11 heats	66 ,, ,, ,,
	Tapping and fettling, ¾ hour at 5 cwts. per hour on 11 heats	51 ,, ,, ,,
	Total fuel to melt 11 heats of 8 tons each	461 cwts.

This is equivalent to 5.24 cwts. coal per ton of metal melted.

8-ton and on 10-ton heats. Unfortunately, no data are yet available for larger heats over a period, but a further reduction in fuel costs is certain to be experienced when regularly melting heats of 12 to 15 tons. The figures given are the calculated coal consumptions based on the rating of the automatic coal feed and the time taken on the various stages of melting. These figures can be taken as representing the average actual coal consumption, which naturally varies somewhat from heat to heat, but which is checked weekly by a comparison of the calculated consumption with the actual coal consumption over each weekly period.

If the furnace is being operated on charges averaging 8 tons each (*i.e.*, 88 tons per week), this will show a fuel consumption for soaking in consumption rates if still larger metal charges were regularly melted.

The total fuel consumption per ton of metal melted will be the sum of the fuel used on soaking and on actual melting.

For 110 tons per week this equals
1.28 plus 4.51
= 5.79 *cwts. per ton of metal melted.*

For 88 tons per week it is
1.60 plus 5.24
= 6.84 *cwts. per ton of metal melted.*

To the figures of Tables III and IV must be added the coal used on the boiler supplying steam to the gas producers. This boiler uses approximately 8 tons of coal per week, and supplies a duplicate gas producer also, which provides gas

for the annealing plant. Half of this coal should be allocated to the melting furnace (*i.e.*, 4 tons per week), and this will raise the fuel consumption figure by 0.73 and 0.91 for 110 tons output and 88 tons output respectively.

Therefore the gross fuel consumption used on the entire melting plant will now be:—

On 110 *tons weekly output*
5.79 plus 0.73
= 6.52 *cwts. of coal per ton of metal melted.*

On 88 *tons weekly output*
6.84 plus 0.91
= 7.75 *cwts. of coal per ton of metal melted.*

These figures will bear comparison with any other type of melting furnace capable of operating on low total-carbon white iron. It is considered probable that the fuel consumption may fall below 6 cwts. of coal per ton of metal melted if the furnace is operated continuously on larger heats of 12 to 15 tons each. As heats of over 10 tons have not yet been melted with any degree of regularity, this is, for the time, a matter of conjecture and cannot yet be checked over any lengthy period.

Total Operating Costs

The total cost of operating the open-hearth furnace will be the sum of the fuel cost, plus the power costs, plus cost of refractories and fluxes. These costs have all been itemised under their different headings and they are now assembled in Table V.

Apart from affording a fairly close statement of operating costs on the open-hearth furnace, these figures also serve to emphasise the rather wide variation in melting costs dependent on the output from a particular furnace. The relatively high cost of the fuel used when the furnace is not actually melting metal, together with the cost of refractory materials used for maintenance and repairs, has a profound effect on melting costs when expressed in terms of cost per ton of metal melted.

Conclusion

In conclusion, the principal advantages and disadvantages of this furnace can be briefly summarised as follows:—

The high capital cost is a serious disadvantage, as in addition to the cost of the furnace itself, gas-producing plant also must be installed.

Since the furnace proper is constructed of silica bricks, it is necessary to maintain its temperature fairly near to melting temperature when not in operation. Violent fluctuations of temperature would result in spalling of the silica bricks and necessitate more frequent shut-downs for repairs. It is also important that the temperature of the regenerative chambers be maintained near working temperature. Therefore the amount of fuel absorbed in soaking periods is relatively high compared with the fuel used in actually melting the charge, and it thus follows that the total fuel cost may become uneconomically high if the furnace is operated well below capacity. If the furnace is operated at normal capacity, fuel costs are relatively low, as evidenced by the data given in the section dealing with melting costs.

The furnace can be operated continuously for long periods, and will, in fact, yield better results under such conditions. On the other hand, any major repairs which may become necessary will necessitate a complete shut-down for several days.

TABLE V.—*Total Melting Costs.*

Case (1).—10-ton charges (110 tons per week).

Gross fuel cost (including boiler), 6.52 cwts. at 21s. per ton	7s. 0d.	
Power costs on gas-producer plant	0s. 1.1d.	
Total cost of fuel and power	7s. 1.1d.	
Refractory and repairs	1s. 7.0d.	Estimated. See text.
Fluxes used for melting and swill heats	0s. 4.0d.	
Total melting and maintenance costs (excluding labour)	9s. 0.1d.	per ton of metal melted.

Case (2).—8-ton charges (88 tons per week).

Gross fuel cost (including boiler), 7.75 cwts. at 21s. per ton	8s. 1d.	
Power costs on gas-producer plant	0s. 1.4d.	
Total cost of fuel and power	8s. 2.4d.	
Refractories and repairs	1s. 11.0d.	Estimated. See text.
Fluxes used for melting and " swill heats "	0s. 4.5d.	
Total melting and maintenance costs (excluding labour)	10s. 5.9d.	per ton of metal melted.

Since the supply of molten metal for the foundry is intermittent, it precludes the use of a fully-mechanised continuous moulding system. Under certain conditions this may be a disadvantage. On the other hand, it supplies a large bulk of metal (according to the furnace capacity) which is all of a uniform analysis.

It admits a close control of analysis. Melting losses are fairly constant, but when variations do occur, the analysis can be corrected before tapping the metal. In this respect, it is usual to take a bath sample of molten metal for analysis about 45 minutes before the charge is due to be tapped.

The molten metal can be superheated to suit foundry requirements by holding the charge in the furnace until the required temperature is reached. During this period the slag layer covering the metal will prevent any serious oxidation of the charge.

Close supervision and technical control are essential, owing to the somewhat complex nature of the open-hearth furnace and gas-producer plant.

It will be evident from the data given that the open-hearth furnace is a comparatively cheap melting unit when operated near maximum capacity, and might be considered an economical proposition even when operated down to about half capacity. On smaller outputs, however, the operating costs may quickly become prohibitive.

DISCUSSION

Mr. F. J. Cook, speaking from experience of a similar type of furnace twenty years ago, congratulated Mr. Shotton on the Paper. If he (the speaker) had had such a Paper to help him, he would have been much happier, for there were many difficulties to be encountered.

The Paper would be valuable to anyone proposing to operate such a furnace, for there were a great many advantages in connection with the quality of the work which could be thereby produced. The points raised by Mr. Shotton were well worth attention where a high-grade malleable was needed.

Compositional Control

Mr. J. H. Cooper asked if any ill effect resulted from having, during charging, to leave the furnace for a time partly charged, and if such a wait had any deleterious influence on the silicon content or other constituents of the metal.

Mr. F. J. Cook supplemented his previous remarks by asking how Mr. Shotton got rid of the "bear" which had a tendency to form in the bed of the furnace. It could be a very great nuisance.

Mr. H. A. Fox asked if any tests had been made on the metal as between the beginning and the end of a tap, and if there was any appreciable variation in the composition.

Mr. Shotton's Reply

Mr. Shotton, replying, said there were a considerable number of initial difficulties in operating one of these furnaces, and it was largely by experience that one attained correct practice.

The "bear" on the bed of the furnace was composed largely of residual iron, and most of it was removed during the "swill-heat." Occasionally they got oxidised iron that did not go away with the "swill," and in such cases they had found it helpful to put on some ferro-manganese, which was quite effective in reducing the iron. Actually there was not much trouble from that cause. It was a matter of careful furnace practice. It was essential, after the metal had been drawn from the bed, that the bed should be dried off and puddled with wet silica sand to remove any remaining pools of iron.

As to the loss of carbon, silicon and other elements if the charge was allowed to stand in the furnace during melting, that did have a very big effect. He had found that the melting losses on the charge varied directly with the melting-down time. If for any reason the melting-down time was prolonged, the losses on silicon and carbon were very much greater. The plant did not suffer from appreciable hold-ups, but the test samples taken did show variation if the melting-down was prolonged.

There was naturally a slight variation in the analysis of a tap as between the top and the bottom metal. The top metal was not only the hottest, but it was in contact with the flame for a longer period. He found the silicon and manganese showed no appreciable change, but there was a loss of carbon towards the end of a heat, which might be anything from 0.05 to 0.15 per cent. His practice was to "pig back" the end of the heat by putting in a little pig-iron on the furnace breasts so that it just melted down into the remaining two or three tons. This helped to keep up the carbon content at the end of the heat. The loss was not serious, but it did exist.

Paper No. 674

Relationship between the Quality of Iron and Steel Castings and the Nature of the Materials of the Melt

By Dr.-Ing. P: BARDENHEUER

The most important conditions for the production of sound castings of high quality in the iron and steel foundry are the use of satisfactory materials for the melt and their appropriate and correct metallurgical treatment during the melting process. Until a few years ago, the means available for examining the quality of the raw materials were still inadequate, and the metallurgical processes taking place during the melting operation had likewise not been investigated to any great extent. It was often found that certain materials, for instance, foundry pig, despite satisfactory chemical composition and satisfactory melting conditions, produced castings which were of unsatisfactory quality in many respects, while the same pig-iron from another source, but with the same composition and melting conditions, resulted in good castings in every respect.

Only the development of suitable analytical methods for determining the gases and oxides in iron and its alloys has provided metallurgists with valuable means for examining the raw materials and products from fresh points of view and elucidating the influence of the gases and oxides on the quality of the products. At the same time, on this basis, ways and means have been discovered for eliminating the previously unexplained defects of the materials, and, in addition, for investigating and improving the processes for the production of iron and steel. Particularly in connection with steel production, very considerable progress has thus been made, but the new knowledge has not been applied to very great advantage in regard to the metallurgical problems of the iron and steel foundry. The following remarks are intended to provide a contribution to the elucidation of the relationships between the nature of the materials of the melt, their metallurgical treatment during melting and the quality of the products.

Characteristics of Defects caused in Ferrous Castings by Gases and Oxides

Considerable difficulties may be produced in iron and steel foundries by gases which have either been dissolved in the molten metal or have been formed by reaction. Apart from the occurrence of blowholes which are formed during solidification, and which in many cases render the casting useless, gases which only separate out after solidification may impair the mechanical properties of the material without any visible defects showing in the casting. Hydrogen and nitrogen are the most important of the dissolved gases, while carbon monoxide

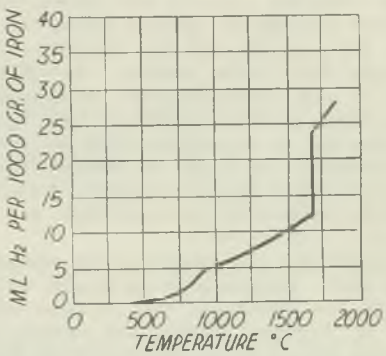


Fig. 1.—Solubility of Hydrogen in Iron in Relation to Temperature. (Sieverts.)

formed by the reaction of carbon with oxides is the principal reaction gas.

The *dissolved gases* are either already present in the materials of the melt or are absorbed during remelting. Their behaviour in relation to the temperature is best shown by the solubility curve of hydrogen in iron. Fig. 1 shows this curve according to Sieverts.[1] The solubility increases with the temperature up to the melting point, when it increases suddenly to about twice the value and then increases slowly again in the liquid phase, although more rapidly than in the solid phase. Nitrogen behaves quite similarly. In most types

of steel and foundry iron, the solubility conditions are fundamentally the same as in pure iron.

The molten metal is thus capable of absorbing very considerable quantities of gas, and on cooling it gives off the gases again in accordance with the same law. If the molten metal was saturated with gases, then during the solidification of the metal in the mould, considerable quantities of gas are liberated in accordance with the steeply falling solubility curve, and are capable of forming blowholes in the casting.

The same defects may also be formed by *reaction gases*. The latter often initiate the separation of dissolved gases which, despite the saturation of the metal, and without this stimulation by reaction gases, would have remained in solution until after the solidification of the metal. In the operation known as "killing" the steel, the very reactive oxides, ferrous oxide and manganous oxide, are converted into silica or very unreactive silicates by the addition of silicon, any formation or separation of gas being suppressed in most cases. A corresponding effect is produced by the addition of aluminium.

The deterioration of the mechanical properties by dissolved gases is less known than the obviously perceptible defects caused by blowholes. If a liquid steel has absorbed so much hydrogen that, upon cooling, the saturation value is only attained after solidification is ended, then, as the temperature falls, hydrogen separates out in accordance with the diminishing solubility. It might be assumed that this gas would escape from the material without any harmful consequences, but conditions are rather different.

The hydrogen is dissolved in the atomic form in the iron. In this form, it is able to diffuse through iron unimpeded even at room temperature. If, however, during the cooling of the iron, the crystal is no longer able to keep the hydrogen in solution, owing to the diminished solubility, and on its way to the surface the hydrogen comes to a grain boundary or some other free place in the steel or a non-metallic inclusion, two hydrogen atoms combine to form a molecule. Molecular hydrogen is insoluble in steel, and is no longer able to escape from it by diffusion. It collects in narrow cavities under high pressure, as may be observed in the case of blister formation in pickling.

This process is illustrated by the following simple experiment.[2] A mild steel rod about 200 mm. (8 in.) long was provided at one end with an axial bore tightly closed by a pressure gauge. Atomic hydrogen was liberated on the surface by electrolytic pickling and diffused in that form into the steel. In the bore, however, it was converted into molecular hydrogen to which the steel was impervious. The pressure of the molecular hydrogen in the bore increased very rapidly, and at 300 atm. the experiment had to be discontinued. In an exactly similar manner, hydrogen separated from the iron crystal in consequence of the reduction in solubility can very rapidly accumulate on the grain boundaries under pressures of many thousand atmospheres. It produces considerable stresses in the material and can make its way to the outside only with the destruction of the structure. At elevated temperatures, the hydrogen also reacts with the oxides, sulphides, carbides, etc., forming the corresponding hydrogen compounds, which are also insoluble in steel, and are therefore unable to diffuse, so that they produce the same defects as molecular hydrogen.

According to investigations by Houdremont and Korschan[3] and by Bennek, Schenk and Müller,[4] flakiness in steels is to be attributed to local accumulations of hydrogen under high pressure.

Korber and Mehovar,[5] after heating freshly rolled rails for one hour at 200 to 600 deg. C., or even after long storage, found a very considerable increase in the elongation and reduction in area in the tensile test. The cause of this improvement can only be the expulsion of hydrogen. This was confirmed by further experiments with freshly rolled rails,[6] in which the hydrogen content fell from 2.13 to 0.1 ml. per 100 grams, both after heating for one hour at 200 deg. C. and after storing the tensile test specimens for seven weeks at room temperature. At the same time, the elongation in the tensile test increased by about 50 per cent. and the contraction in area by about 100 per cent. In similar experiments, Drescher and Schäfer,[7] in the case of cast steel of a tensile strength of about 60 kg. per sq. mm., found that heating for 60 hours at 100 deg. C. resulted in an increase in the elongation from 7 to 24 per cent. and in the contraction from 8 to 36 per cent.

Ageing of Castings

It is often observed that machine parts of grey iron or cast steel are distorted when they have been at the working temperature for some time. Experienced practical men, without being aware of the causes, often prevent this by keeping the parts in storage for a considerable length of time, often a whole year, before machining. Others expose the castings in drying chambers for one or more days to a temperature of about 200 deg. C. In all cases, the result of the treatment is that the castings, after machining, no longer warp in service for the reason that the gases held in the material under high pressure have been expelled, thereby equalising the strain.

Various difficulties in the vitreous enamelling of grey iron castings and steel may be attri-

buted to the gases remaining under high pressure in the casting.

All these experiments and observations show that the gases left in the castings after solidification greatly impair the mechanical properties of the material and can lead to appreciable trouble. Even though similar investigations have not yet been made on other cast metals, it may be concluded from extensive works experience that also the quality of these metals may be detrimentally affected by hydrogen in the same way.

After this general account of the characteristics of the defects produced by gases and oxides in cast products, it is intended to deal in what follows with the problem as to how the gases and oxides find their way into the cast metal and how the defects caused by them may be prevented.

Gases and Oxides in Pig-iron

Until the threshold of the previous century, the greater proportion of iron castings were made directly from the blast furnace, and this method of working was also retained long after the introduction of the cupola furnace. As the production of the blast furnace came to be increased more and more by increasing the height, blast pressure and furnace temperature, serious difficulties arose through the numerous faulty castings caused by blowholes, and consequently this method of working had gradually to be abandoned entirely. After the solidification of the iron in the pig bed and remelting in the cupola or reverberatory furnace, the behaviour of the iron was satisfactory.

Even after this treatment, however, the iron often produced defective castings as the development of blast-furnace smelting proceeded in the above direction, particularly when the blast-furnace output began to be increased by artificially increasing the burden by large quantities of scrap. Of the English specialists in particular, Fletcher[8] has pointed to the difficulties caused in this way in the iron foundry.

Moldenke,[9] the well-known American foundryman, has dealt very exhaustively with this problem. He cited cases in which so much scrap was added to the burden that the blast furnaces became cupolas. A saving in coke of 30 per cent. and an increase in output of 60 per cent. were certainly attained, but when this pig was used in the foundry, the complaints regarding porous castings became very insistent.

The literature shows that serious efforts have been made in many quarters to explain and remove the difficulties, but up till now the results have not been wholly successful, evidently because it has been impossible to gain a complete picture of the more deeply-lying causes.

According to the present knowledge of the processes taking place in the blast furnace, the iron is already completely alloyed with carbon, silicon, manganese and phosphorus when it reaches the hottest zone of the furnace in front of the tuyeres. During its passage through this zone it is subjected to intense oxidation. In addition to considerable amounts of iron, the alloying elements which have the greatest affinity for oxygen, above all silicon and manganese, are affected by the oxidation. As shown experimentally by Wüst,[10] a foundry iron has much higher silicon and manganese contents above the tuyeres than the iron when tapped.

The iron together with oxides of iron and its accompanying elements and slag thus trickle from the plane of the tuyeres down into the hearth, where, as in the hearth type of furnace, the molten iron is covered by a layer of slag.

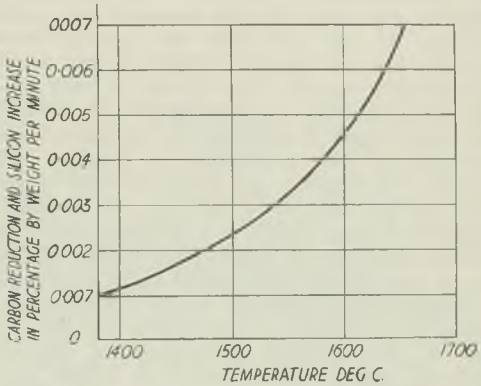


Fig. 2.—Silicon Reduction in Relation to the Temperature.

The slag has the important function of retaining the oxides which descend with the iron. The separation of the oxides from the metal is more complete, the lower the content of these oxides in the slag and the thicker the layer of slag. If, however, when employing a high-iron burden —for instance, when the burden is enriched with scrap—the layer of slag is only very thin, it may easily happen that the concentration of oxides in the small quantity of slag becomes so great that further absorption of oxides is rendered difficult. Also, even when the slag has not yet reached saturation, the absorption of oxides is rendered difficult when the path of the oxide-containing iron alloy through the layer of slag is only very short. The complete removal of the slag during casting has particularly unfavourable consequences, because for the first period the iron is not covered with slag at all. In such cases, therefore. oxides of iron, silicon and manganese can pass into the molten iron. In an iron con-

taining silicon and manganese, the oxygen passes over to these elements and iron and manganese silicates are mainly formed.

As shown by Fig. 2, the reduction of silica by carbon, which even at 1,400 deg. C. already proceeds at an appreciable velocity, increases rapidly with rising temperature. Manganese silicates in particular are very difficult to reduce. If the conditions in the iron bath are not very favourable for the reduction of these oxides by the carbon, either because the temperature is not very high or the time before tapping is too short, the reaction of the carbon with these oxides continues after tapping.

With falling temperature, the conditions become increasingly unfavourable towards this reaction so that it soon ceases and cannot proceed to the end. As a rule, cavities in the pigs imply that the evolution of gas has continued up to the solidification of the iron. In the case of foundry pig, the reaction between the oxides retained in the iron and the carbon, which reaction has not been completed in the hearth of the blast furnace and in the pig bed, may also continue after the remelting of the iron in the cupola until solidification in the mould, thus resulting in the production of castings with cavities. A foundry pig produced from a low-iron burden, that is to say with an abundant quantity of slag, exhibits a perfectly quiet behaviour both during solidification of the pig and also in the casting after remelting in the cupola.

Unsatisfactory behaviour is often observed particularly in the case of high-silicon foundry pig. This is very probably on account of the fact that the pig has been killed by silicon in a similar manner to steel. Even though the carbon content of pig-iron is much higher than that of steel, the silicon content is also higher and the temperature lower. Thus, in the hearth of a blast furnace, a pig which has a certain carbon content, and boils vigorously with a low silicon content, can be killed by increasing the silicon content so that it no longer boils, similar to the behaviour of molten steel.

If a high-silicon iron lies quietly in the hearth on account of the absence of any boiling movement, the equalisation of concentration within the metal bath is rendered very difficult, so that, within narrowly limited reaction zones, a stationary condition between the oxides and carbon of the bath is very soon attained and further reaction no longer takes place. Reaction can only continue upon casting when mechanical mixing of the iron occurs, and this resumption of the reaction is favoured by the fact that upon casting an additional oxidation takes place through the molten metal coming into contact with the air. The same can occur after remelting, Thus, whereas a low-silicon iron can boil vigorously in the hearth of the furnace, the oxides being reduced as far as a certain condition of equilibrium, it is possible, in an iron killed by a higher silicon content, for a considerably greater quantity of oxides to be left, in consequence of the incomplete equalisation of concentration, and then such oxides only react during and after casting or after remelting.

The oxide content of the pig is comparatively low, but it must be remembered that even very low oxygen contents can exert a decided influence on the behaviour of the pig, since in the reaction of only 0.001 per cent. of oxygen with the carbon which is always present in excess, the volume of carbon monoxide formed is about 40 per cent. of that of the iron at 1,100 deg. C.

In addition, the formation of reaction gases in the molten iron before and during solidification initiates the liberation of the dissolved gases. As in the case of the killing of steel by silicon

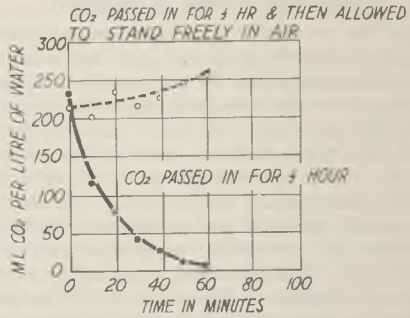


Fig. 3.—Amount of CO_2 per litre of Water related to Time during which Air was blown through or the Water allowed to Stand.

or aluminium, dissolved gases may remain in solution in iron, despite supersaturation, provided no reaction gases are formed.

For removing the dissolved gases from the iron, it is advantageous that the bath in the hearth of the blast furnace should boil. As is well known, boiling is due to the reaction of the metal oxides with carbon to form carbon monoxide, which is insoluble even in iron. The bubbles of carbon monoxide produce in the metal itself and on its surface an atmosphere of carbon monoxide, in which the hydrogen and nitrogen pressure is equal to zero, so that the partial pressure of these gases in the metal bath tends to equalise with the lower pressure of the same gases in the surrounding atmosphere, the dissolved gases being thus gradually removed from the bath.

The process of the expulsion of dissolved gases from the metal bath is illustrated by the following experiment. Carbon dioxide was passed for

30 minutes into two identical vessels filled with distilled water. Then air free from carbon dioxide was passed through the water in one of the vessels, while the second vessel was allowed to stand quietly in the air. A sample was taken from both every ten minutes and the carbon dioxide content determined in it. The result is shown in Fig. 3. The air which was blown through had gradually removed almost all the carbon dioxide from the water within an hour, while the carbon dioxide content of the water in the second vessel was maintained during that time.

Vigorous boiling of the bath is thus the only possible means of removing gas from the iron in the hearth of the blast furnace. If the silicon content be so high that, with the given composition and temperature, the iron bath is killed, there is practically no evolution of dissolved gases. It must furthermore be borne in mind that if the iron is to have a high silicon content, the blast furnace should be operated at a correspondingly higher temperature, and as the solubility of gases in iron increases with the temperature, this is an additional reason for generally expecting that the gas content of the iron will be higher with increasing silicon content.

The Behaviour of Gases and Oxides in the Remelting of Pig-Iron and Steel

The slow solidification of the iron in the pig bed has the advantage that the greater portion of the dissolved gases escapes from the iron. Another portion may escape during storage. During remelting, the dissolved gases are given off more completely by the iron, the slower the rate of heating, and the lower the content of the furnace atmosphere in the gases which are to be removed. In this respect the reverberatory furnace and still more so the crucible furnace are to be preferred to the cupola.

During remelting with access of the furnace atmosphere, it is always necessary to take into account the possibility that the iron will absorb gases therefrom, particularly hydrogen, when it is exposed to that atmosphere for a considerable time at a high temperature or even in the molten state. In a slow-melting cupola, the molten material may become so saturated with gases as to produce porous castings. A high gas absorption is observed in particular when, in consequence of low tuyeres, the molten iron in the hearth of the furnace is exposed to an intense current of blast.

The oxides left in a finely divided condition in the pig-iron after solidification cannot be entirely removed therefrom during remelting in the cupola either by mechanical separation or by chemical reaction with the carbon, because the time elapsing from melting to pouring is insufficient for that purpose. In many cases, the reaction still continues in the casting ladle and in the mould, so that defective castings are unavoidable. The oxides formed in the furnace on the surface of the charge may, on the contrary, accumulate in the slag, but if the blast entering the furnace from the tuyeres impinges at too high a velocity on the iron so that the latter is vigorously whirled up or even formed into spray, it is conceivable that there will be a greater additional absorption of oxides.

The absorption of gases and oxides during melting in the cupola is limited to a minimum if the melting operation is accelerated as much as possible by blowing sufficient amounts of combustion air through tuyeres of adequate size and well distributed over the furnace cross-section.

In reverberatory furnaces, the iron charged melts more slowly. If the furnace atmosphere be favourable, a gas-containing iron can give off more gas than it absorbs. As soon as it is melted and its dissolving capacity for gases has increased considerably, it is removed from any further action by the furnace gases by the fact that it sinks below the covering of slag. The oxides and particles of slag are able to separate from the molten metal in the usually long time elapsing before the bath has reached the necessary casting temperature, provided they are not reduced by the carbon. Consequently, when the melting operation is properly conducted, it is easier to produce satisfactory castings from a reverberatory furnace than from a cupola.

For the production of steel castings from the reverberatory furnace, the working conditions to be observed are the same as those known for the production of steel in the Siemens furnace. The charge generally consists of a small proportion of pig and a large proportion of scrap. In the open-hearth process, the melter has always considered it of great importance to ensure that, after melting, the steel still contains so much carbon that the bath is able to boil vigorously for a certain time until the desired carbon content has been attained in the molten metal, because if this requirement be not satisfied, the steel does not merely cause difficulties through considerable evolution or separation of gas during solidification, but it also has poor technical and mechanical properties.

From present knowledge of the open-hearth process, carbon is the most powerful and most effective deoxidiser. According to the equilibrium relationships between carbon and oxygen in the steel bath, only very little oxygen is stable in the presence of a high carbon content, but the more the carbon is removed from the bath by decarburisation, the greater is the quantity of oxygen which can be absorbed by the steel in the form of ferrous oxide. The theoretical variation of the oxygen content in the steel bath with the carbon content during an open-hearth melt is

shown in Fig. 4 on the basis of the equilibria determined by Vacher and Hamilton.[11] A decarburisation of from 0.6 per cent. to about 0.05 per cent. at a rate of about 0.25 per cent. carbon per hr. has been taken as basis. This diagram shows that the carbon content of the bath, as long as it is present in adequate concentration and can react, is the primary deciding factor for the oxygen concentration. As more carbon disappears from the bath, so more oxygen passes into the bath from a slag rich in ferrous oxide. In the case of a low carbon content of the bath, therefore, the oxygen content of the bath can be kept low only under a slag which is poor in ferrous oxide. The diagram in Fig. 4, however,

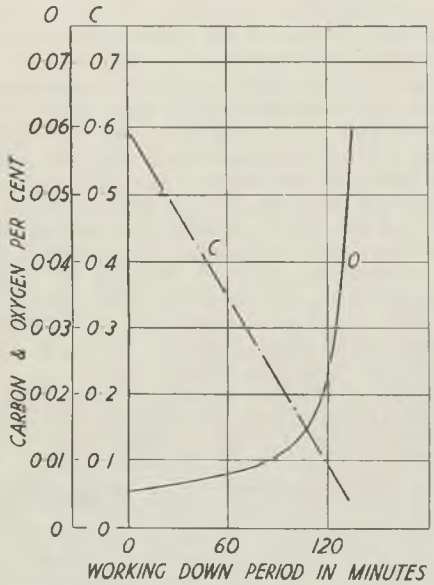


Fig. 4.—Carbon and Oxygen Contents related to Working-down Period.

also shows the advantage of "catching" the carbon in open-hearth melting. For instance, a steel caught with 0.25 per cent. C would contain somewhat less than 0.01 per cent. O in the case of equilibrium according to the curve. If, however, the same melt was decarburised down to about 0.05 per cent. C and recarburised subsequently, it would absorb very considerable amounts of oxygen, which under ordinary conditions could be removed from the bath again only to a small extent by the carbon subsequently added. It is not possible to rely upon the removal of oxygen by the subsequent addition of deoxidisers (for instance, manganese or silicon), because the oxygen is not removed directly by these additions, but is merely converted into another chemical compound. The total oxygen content may be even slightly increased by these additions. In any case, however, keeping the oxides away from the bath is always more satisfactory and reliable than any measure for their subsequent removal.

The boiling of the steel bath has the important function of removing the dissolved gases. This process has already been fully dealt with in discussing the production of pig-iron. For instance, according to the author's investigations, the high nitrogen content of basic-Bessemer steel which is charged molten into the open-hearth furnace in the duplex process falls to about one-third of its original value after a short boiling. Vigorous and sufficiently long boiling of the steel is particularly essential when the charge contains much rusty scrap. As is well known, iron

Table I.—*Gas Content of Steelmaking Additions*

	O_2. Per cent.	H_2. Ml. per 100 g.	Total gas. Ml. per 100 g.
Nickel	0.035	30.0	86.1
Chromium metal ..	0.045	7.60	200.0
,, ,, ..	0.011	5.45	56.9
Tungsten powder ..	0.45	52.4	793.3
Cobalt metal ..	0.13	3.30	183.5
,, ,, ..	0.032	2.36	52.9
Ferro-chromium ..	0.063	1.83	103.0
,, ..	0.014	1.99	25.1
Ferro-tungsten ..	0.046	7.6	75.4
,, ..	0.031	3.1	46.8
,, ..	0.030	6.7	46.1
Ferro-molybdenum	0.171	21.1	274.0
,,	0.142	12.8	230.0
,,	0.096	7.0	150.0

rust differs from the pure oxides of iron by its content of chemically-combined hydrogen. It should be borne in mind that through 1 per cent. of rust adhering to the charge per ton of steel, about 2.5 cubic metres of hydrogen, that is at 0 deg. C. and 760 mm. Hg almost twenty times the volume of the steel, are offered to the steel bath and are partly absorbed by it.

Absorption of Gas by the Steel from Alloying Materials

It has been emphasised that dissolved gases can only be removed from the steel bath by intensive boiling. For this reason it is necessary to prevent gases from entering the steel bath after the termination of the boiling period. In the production of alloy steels in particular, it is often impossible to avoid adding alloying materials to the steel bath after the termination of the boil. These alloying materials, however,

sometimes have a high content of gases and oxides which may exert a detrimental effect on the finished steel if they are added to the highly heated metal bath with its high capacity for dissolving gases.

Table I gives the results of the oxygen and gas analysis of a number of alloying materials, the oxygen content being expressed as a percentage, the hydrogen content in ml. per 100 grms. and the total quantity determined by the vacuum melting method in ml. per 100 grms. It should be pointed out that the highest available experimental figures have been selected in order to show the contents which must be expected in these alloys in unfavourable cases.

If, for instance, ferro-alloys having a high hydrogen content are added to the finished steel,

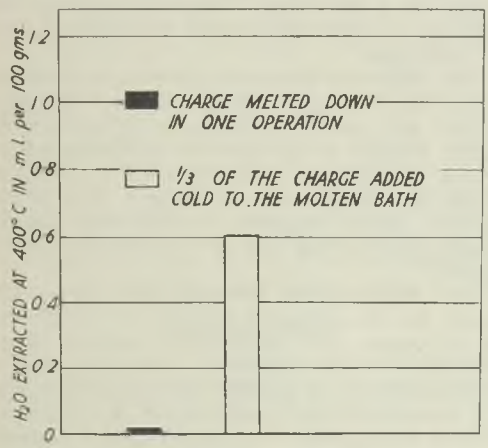


FIG. 5.—INFLUENCE OF MELTING METHOD ON HYDROGEN CONTENT IN MELTING ELECTROLYTIC COPPER.

even a well deoxidised and killed steel will often become wild when poured and will cause the ingots to rise. This observation may be made even with transformer steel having about 4 per cent. Si if the steel has been alloyed in the ladle with ferro-silicon containing hydrogen.

The effect of the subsequent addition of materials containing hydrogen to a molten bath of metal is clearly illustrated by the following example. Electrolytic copper, which is well known to contain large quantities of hydrogen, was slowly melted in a high-frequency furnace. A ladle sample, when heated in vacuum at 400 deg. C., gave only 0.012 ml. H_2 per 100 grms. of metal. Electrolytic copper to the amount of one-third of the weight of the charge was then added to the molten bath. A fresh sample gave 0.60 ml. H_2 per 100 grms. of metal, *i.e.*, 50 times the amount originally found. The results are shown in Fig. 5. Hydrogen is thus greedily absorbed by the molten metal of high dissolving capacity.

It is therefore seriously recommended that all alloying materials subsequently to be added to the finished molten metal should be previously annealed for expelling the gases. In doing this, care should be taken to see that the treatment takes place at a temperature at which the solubility of gases in the alloy is not very great, preferably at a dull red heat, and in an atmosphere from which the absorption of gases is impossible.

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DISCUSSION

MR. T. R. WALKER (English Steel Corporation) remarked that the Paper followed many others which Dr. Bardenheuer had published in the German technical Press concerning the effects of gases, especially hydrogen, in metals and particularly in steel. Dr. Bardenheuer claimed that the effect of hydrogen in steel was always deleterious, and Mr. Walker asked whether it was now established beyond doubt that hydrogen was the real and only cause of hair cracks. There had been a good deal of argument regarding this matter, in which Dr. Bardenheuer had taken a prominent part.

Expressing agreement with Dr. Bardenheuer's remarks concerning the effect of the gases in pig-iron on the properties of the resultant steel, Mr. Walker asked whether he had been able to trace any general relation between the amount of gas in pig-iron, and either the country of origin or the process employed in manufacturing the pig. For example, it was commonly assumed in this country that Swedish pig gave better results when certain types of steel were being manufactured than English pig of similar analysis. Was that attributable to a difference in gas content between the two types of pig? Again, in the manufacture of certain types of iron castings, some makers attached a great deal of importance to the use of cold-blast iron and claimed that it gave improved results. Was that also connected with the gas content of different types of iron?

Case of Ferro-Manganese

Although Dr. Bardenheuer had given the results of the gas content for different alloying materials he had omitted reference to ferro-manganese, which, however, definitely contained gases. If samples of ferro-manganese, of the same grade but manufactured by different makers, were treated with cold water, gases were evolved, the volume of gas from the same weight of ferro-manganese being different for different makes. Presumably this was due to the fact that the different makes of ferro-manganese contained different constituents.

Dr. Bardenheuer had also omitted any reference to the nitrogen content of ferro-alloys; although this was unimportant in most cases, it was of special importance in ferro-chromium. Ferro-chromium containing high contents of nitrogen was being used both in America and Great Britain on account of the effect it had on the mechanical properties and the grain size of the resulting steel, which was commonly high-chromium steel. In that case at any rate it was evident that the effect of gas content in the ferro-alloy was significant in determining the properties of the resultant steel.

Major Difficulties for Ironfounders

Dr. Bardenheuer, dealing with the question as to whether hydrogen caused hair cracks, said that the presence of hydrogen had at any rate an important effect and was undoubtedly one of the causes, probably the most important one, but was not the only cause of hair cracking.

Many references were to be found as to the different behaviour of various kinds of pig-iron having the same chemical composition but of different origin. To-day there was no doubt that this behaviour had its origin in the gas and oxide content of the pig-iron. Foundry pig-iron from small blast furnaces, especially cold-blast iron, generally contained less gas. With larger furnaces and higher temperature, and also with higher pressure and especially with a small proportion of slag, the difficulties in foundry practice thereby arose. The superiority of Swedish pig-iron had its origin in its greater purity; it carried less sulphur and other deleterious components.

Difficulties such as those with which the ironfounder had to contend did not arise in nearly the same degree as in steelmaking practice, because boiling removed the dissolved gases and the carbon reduced the oxides. In the melting of cast iron, the removal of these impurities was impossible, because there was no boiling and the temperature was too low.

Ferro-manganese was not mentioned in the Paper; but it had been established that from 80 to 100 ml. of gas might be contained in 100 grams of ferro-manganese. The gas content of carbon-rich ferro-alloys was generally lower than in alloys which were poorer in carbon. Nitrogen was determined, but was not mentioned in the Paper. Moreover it might be mentioned that in some iron alloys, for instance in ferro-chromium, the nitrogen was combined as chromium nitride. In other alloys the nitrogen occurred as a gas dissolved in the metal. Generally speaking, the nitrogen contents were about the same as those of hydrogen.

Mr. Bensimon (France), referring to the statement that hydrogen, though the most important cause, was not the only cause of hair cracks, asked whether it was possible to distinguish between the different causes to which the different kinds of defects were attributed. Did all the causes operate together or did they operate singly, each giving rise to a particular kind of defect?

Dr. Bardenheuer repeated that hair cracks could not be attributed entirely to the presence of hydrogen; hair cracks were ruptures caused by forces which occurred in the material. As he had established in 1925* hair cracks and flakes in chromium-nickel steels could be caused by crystal segregation. In later Papers he showed that local ruptures quite similar to the formation of pickling blisters were caused by hydrogen under high pressure. This hydrogen, however, became liberated during the period of diminishing solubility brought about by lower temperature. Finally, shrinkage stresses could contribute to this effect. Thus the cracks occurred at those places where the amount of stresses exceeded a certain limit. In most cases shrinkage stresses in the ingot only determined the direction in which the hair cracks ran; if the shrinkage stresses of ingots were so strong that this force alone would destroy the ingot, the cracks always had a very large extension.

* "Die Flocken im Nickelchromstahl," Mitt. K.-Wilh. Inst. Eisenforschung, Düsseldorf, 1925, pp. 1-15.

Paper No. 675

Process of Crystallisation in Commercial Alloys*

By Dipl.-Ing. W. PATTERSON

For examining the processes accompanying the solidification of molten metals there exist a number of methods of investigation which, by ascertaining the changes in properties during crystallisation, make it possible to describe this technically so important process. Reference may be made to the methods for determining mould filling power, shrinkage, cavity formation, liberation of gas, electrical conductivity, specific heat, etc., as well as to the metallographical etching methods. The scope of the present Paper is intended to examine whether direct thermal analysis is suitable for studying solidification at the rates of cooling obtaining during the casting of alloys and what information can be obtained from the resulting curves. The ideas developed will then be exemplified by the results of some experiments made in this direction.

Theoretical Part

First of all, the deductions which can be made theoretically from the shape of the cooling curve of a commercial alloy will be examined. In this connection, it is possible to consider three principal lines of thought.

(I) In the investigation of constitutional diagrams, thermal analysis serves exclusively to establish the range of existence of the phases which occur. For this purpose, the melt under investigation is heated or cooled very slowly with temperature variations of 1 to 5 deg. C. per min. In the temperature ranges where there is no transformation, the time-temperature curve has the well-known Newton form (Fig. 1). If, however, crystals separate out, the heat of crystallisation liberated at the same time alters the direction of the curve, or the curve bends and assumes a horizontal direction if the separation of crystals proceeds at constant temperature. By plotting the breaks and critical points thus obtained in the concentration-temperature diagram and joining the points together, a large number of the lines in the constitutional diagram are obtained in the well-known manner.

The determination of the thermal data of alloys is, however, also of considerable importance in the investigation of commercial melts. It is well known that commercial alloys, in addition to the elements added intentionally, also contain other elements as impurities. These unwanted components may be determined by a complete chemical analysis, but they are manifest in the variation of the character of the cooling curve, either by the fact that a temperature interval is observed instead of the critical point or new thermal effects are produced by new types of structure or transformations. Therefore, if only a partial chemical analysis is available, it is possible from the interpretation of the cooling curve to decide whether a fuller analysis is necessary. By recording the cooling curves,

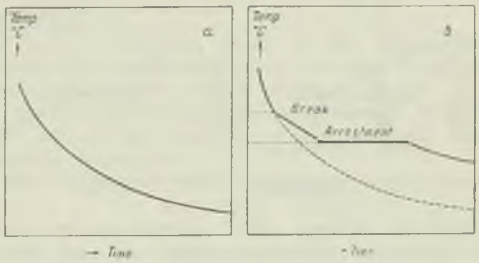

Fig. 1.—Form of Cooling Curve in the Homogeneous Region (*a*) and the Case of Crystallisation Processes (*b*).

therefore, chemical analysis can be supplemented or checked to a certain extent.

(II) The result of the thermal analysis of cast specimens can also be interpreted in a second direction. It is a well-known fact that with increasing rate of cooling, the commencement of the changes of phase or of transformations is retarded. Before the commencement of the formation of a new phase, under-cooling sets in. For organic substances, the influence of under-cooling on the size of grain of the crystallised state has been defined by Tammann and his collaborators to the effect that, with increasing under-cooling, the number of the nuclei and the measurable rate of crystallisation increase at first and then fall again after passing through a maximum. The size of grain of each crystalline group is obtained from the position of these two curves relatively to one another.

* Presented on behalf of the Technischer Hauptausschuss für Giessereiwesen.

The applicability of Tammann's crystallisation laws to the process of solidification of metallic melts has been repeatedly contested on various grounds or its effect has been considered to be of secondary importance. In recent years, however, the increase in the measurable rate of crystalline growth and the number of nuclei with the degree of under-cooling has *inter alia* been satisfactorily established in the case of metals of low melting point by Tammann and his collaborators, and also by Czochralski, as well as by E. Jenckel and collaborators.

In the criticism of Tammann's laws, the mistake frequently made is that of regarding the crystallised state as being determined exclusively by the degree of under-cooling. Tammann himself, as long ago as 1903, expressed the possibility of inoculation or initiation by other types of crystal and the resulting increased nucleus formation in the following words:

> "At the boundary face between an under-cooled melt and a crystal which is growing in the melt, there frequently occurs the formation of a new type of crystal which covers the first crystal uniformly, as if every point on the boundary face were the place of the first new formation. The number of crystallisation centres on such a boundary face is therefore very considerable and very much greater than in the melt itself."

The frequently observed effect of very small additions on the structure of cast ingots does not therefore contradict the validity of these laws.

Furthermore, the under-cooling of metallic melts, as measured until recently, was of such a low value that there was great reluctancy to ascribe to such slight temperature differences the far-reaching differences which the structure of a casting may exhibit. Further remarks on the degree of under-cooling will be made in the experimental part of this Paper.

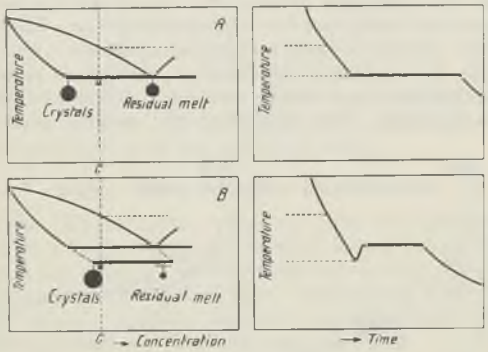

FIG. 2.—EFFECT OF UNDERCOOLING OF THE EUTECTIC CRYSTALLISATION ON THE DISPLACEMENT OF THE QUANTITATIVE PROPORTIONS.

Crystallisation of Organic Salts

There are various reasons why the laws governing crystallisation were discovered through investigations carried out on organic salts.

(1) Most of the substances investigated were transparent when liquid.

(2) The freezing point lay in the vicinity of the room temperature, so that the investigations were very considerably simplified.

(3) At such temperatures, the atomic mobility is relatively low. The course of the reactions can therefore be determined without complicated means. The capacity for under-cooling often amounts to many degrees, and the time elapsing before spontaneous nucleus formation sets in can be measured in minutes. The rate of growth can be measured in millimetres per minute by means of a stop-watch.

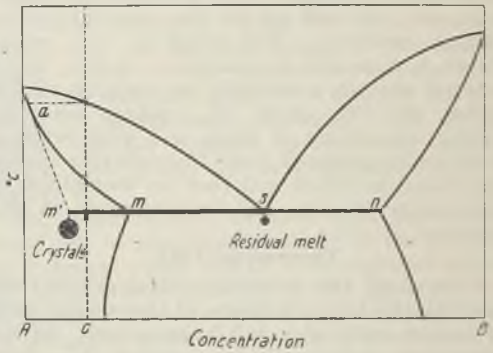

FIG. 3.—OCCURRENCE OF A NEW PHASE (*n*) IN CONSEQUENCE OF PRONOUNCED CRYSTAL SEGREGATION IN A MELT OF CONCENTRATION C.

(4) A high degree of purity can be attained much more easily in the case of organic substances than in the case of metals.

With metals, conditions are much more unfavourable. Opacity makes the interpretation of the results difficult. It is only quite recently that it has been possible to produce very pure metals. The high temperatures involved mean high reaction velocities. In the case of subjective measurement, the period elapsing before spontaneous nucleus formation sets in very soon becomes immeasurably short. Jenckel, for instance, has measured rates of crystalline growth of up to 850 mm. per min. at 4 deg. C. under-

cooling in the case of lead. Here, the duration of the experiments was only 5 secs. and was approaching the limit of the skill of the investigator. In such cases, thermal analysis employing measuring apparatus of the maximum possible sensitivity could be applied and simultaneous measurement at different points in the melt would enable the connections between under-cooling, grain size and structure to be established.

Effects of Undercooling

Besides acting on the grain size, under-cooling also acts in a second way.

(1) If, for example, a primary solid solution undercools, the particles which crystallise first have a different composition from those which would separate out on slow cooling. Under-cooling, therefore, also influences the degree of crystalline segregation, and by measuring the under-cooling, it is possible to make deductions regarding segregation.

(2) After previous primary crystallisation, eutectic solidification may also set in after an under-cooling stage. It must be concluded from this that an excessively large number of primary crystals are separated out, because the available temperature interval is increased by the under-cooling. Consequently, there is a displacement of the quantitative proportion of the structural constituents. Fig. 2 illustrates this possibility in the case of a very slight under-cooling (A) and a more pronounced under-cooling (B). The displacement of the quantitative proportions will be seen from the lever diagram shown in both cases.

New Crystal Types Disclosed

(III) A third possibility which would be observable by thermal analysis is the detection of new crystal types due to segregation. The diagram of Fig. 3 is intended to show how such new formation can occur. In the case of the composition C selected for consideration, the solidified melt should, according to the diagram, consist exclusively of solid solutions. Since, with the assumed rate of cooling, equalisation of concentration within the separated crystals is insufficient, the mean composition of the solid solutions is not shown by the solidus curve $a\ m$, but by the dotted line $a\ m'$. When the eutectic temperature is reached, therefore, there is still a residual melt which crystallises eutectically with separation of the solid solutions m and n. It must here be pointed out that $a\ m'$ is not an equilibrium curve, but merely indicates the mean chemical composition of the crystals separated at each temperature. Only the outermost zone of B-rich solid solutions is in equilibrium with the melt.

To summarise the foregoing, it may be said that thermal analysis could be of value in the following cases:—

(1) As an indicator of the chemical composition by showing the presence of additional elements which have escaped an incomplete analysis. Thermal analysis, to a certain extent, thus checks chemical analysis.

(2) For ascertaining under-cooling phenomena which may be expected to affect both the grain size and the structure of the casting, and also the displacement of the quantitative proportions of the constituents in the structure.

(3) For detecting new types of crystals which owe their formation to segregation. In this case, therefore, thermal analysis can assist in metallographical interpretation.

In addition, deductions can probably be made from the shape of the cooling curve regarding the peculiarities in the build-up of various types of structure, the causes of which perhaps reside in the presence of anisotropic regions in the melt.

Experimental Work

Only one method, satisfying the following principal conditions, is suitable for the thermal examination of the possibilities indicated in the foregoing:—

(1) The measuring point in the melt should possess the least possible mass in order to obviate any buffer action on the thermal effects.

(2) The indicating instrument should indicate and record the measured value with the least possible retardation.

The apparatus employed resulted from a modification of the measuring arrangement on the Kurnakow principle. The method consists in allowing a ray of light reflected by the mirror of a galvanometer, controlled by the thermocouple current, to fall on a revolving drum round which is secured silver bromide paper, thus recording a time-temperature curve. The mirror galvanometer is of very light construction and the moving system is comparatively dead beat. The maximum deflection of the galvanometer is regulated by means of a variable resistance.

Any desired temperature range can be adjusted by turning the suspension knob on the galvanometer, thus obviating the necessity for compensation currents and the possible disturbances which they may introduce. The width of the drum is 180 millimetres. Thus, by adjusting a range of 90 deg. C. it is possible to measure very accurately amounts of 0.1 deg. C. = 0.2 millimetre. The Le Chatelier thermocouple was used, and in order to be able to measure rapidly-occurring processes, the junction should be as small as possible. For measuring the temperature, it is best to use an unprotected junction, which, however, is only possible if neither a reaction of the melt with the platinum nor penetra-

tion of the melt into the protective sheath is to be feared.

In other cases, a thin outer protective tube or a coated junction must be employed. It is, however, then no longer possible to record accurately processes which take place rapidly. By careful manipulation and by employing double bore protective tubes only 2 mm. thick, it is possible to form the thermocouple junction so that only a hemispherical part of the junction projects and the melt cannot penetrate into the protective tube.

To investigate the proportionality of the deflection of the mirror galvanometer, a second mirror galvanometer was connected in parallel, by means of which the same curve could be recorded, if desired with different temperature gradients. By working in this way, it is also possible to record a pilot curve by means of the first galvanometer, details being recorded by means of the second galvanometer. A large installation for measurements at 4 to 8 different points in the melt or of a casting is being constructed with the assistance of the German National Research Association.

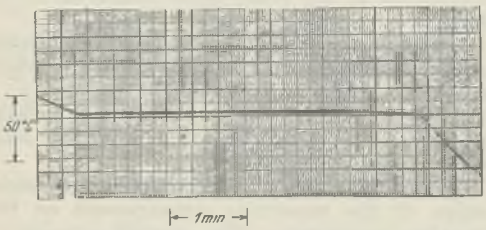

Fig. 4.—Cooling Curve of Pure Copper in the Freezing Interval. Rate of Cooling 30 deg. per min.

Experimental Results

The ideas developed in the foregoing will now be compared with the results of some experiments. Fig. 4 shows the freezing curve of *pure* copper used for calibration purposes. The rate of cooling, 30 deg. C. per min. in the molten part, is low (cooling in a small furnace). After a slight under-cooling, a pronounced arrestment is observed, from which the curve bends very suddenly after freezing is completed.

The shape of the cooling curve of aluminium of high purity (99.99 per cent.) shown in Fig. 5 is very similar. The melt weighed about 50 grams and was cooled in the air in a carbon crucible. In the molten region, the rate of cooling was about 130 deg. C. per min. In this case, the curve extends rectilinearly parallel to the time axis during crystallisation. A disturbance-free curve and chemical purity are in conformity with one another.

A correspondingly uniform course of the cooling curve can be expected in the freezing of a *purely* binary eutectic. Twenty grams of a Silumin (Alpax) alloy with 13 per cent. Si, 0.3 per cent. Fe and 0.3 per cent. Mn were melted at a furnace temperature of 750 deg. C., and after being maintained at the temperature for 5 mins.

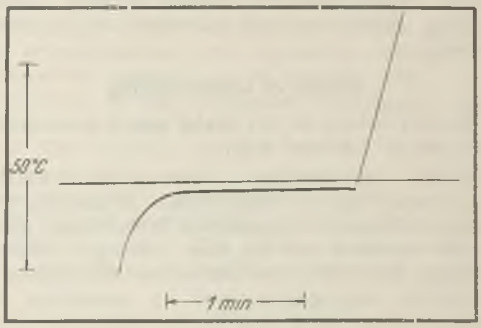

Fig. 5.—Cooling Curve of High-Purity Aluminium (99.99 per cent.). Rate of Cooling 130 deg. C. per min.

were allowed to cool in still air. The curve (Fig. 6) corresponds to a hyper-eutectic Silumin alloy, the eutectic crystallisation being marked by a long critical point which, however, prematurely falls slightly towards the end. This drop is to be attributed mainly to the small amount of impurities present. The commencement of the primary separation of silicon is

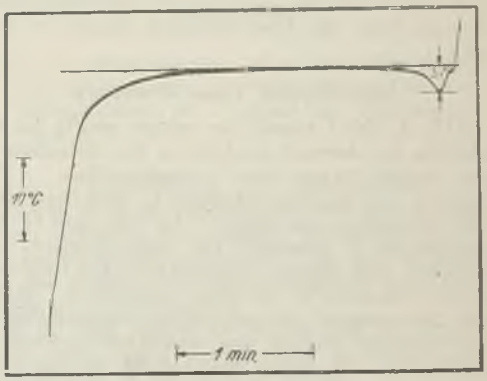

Fig. 6.—Cooling Curve of Silumin, with 13 per cent. Si, 0.3 per cent. Mn, and 0.3 per cent. Fe. Rate of Cooling, 153 deg. C. per min.

marked by a bend. Despite the previous crystallisation of silicon, separation of the eutectic only commences after under-cooling of 3.1 deg. C.

Another Silumin alloy was subjected to thermal analysis under the same conditions as the above

melt. In addition to 12 per cent. Si, the melt contained 0.25 per cent. Fe, 0.4 per cent. Mg, and 0.5 per cent. Mn. The curve corresponds to a hypo-eutectic melt. After pronounced under-cooling of the primary separation of aluminium mixed crystals, extending in its lowest point to below the eutectic equilibrium temperature, crystallisation of the binary eutectic takes place without under-cooling in a temperature interval, an indication that some of the impurities are dissolved. Furthermore, at this rate of cooling, which was 150 deg. C. per min. in the liquid region, two other effects occur (indicated by arrows). In the microscopic examination of these two melts after solidification, in the first case, only primary lamellar Si crystals and a uniformly developed eutectic of coarse type were observed. In the case of the alloyed Silumin alloy, on the contrary, besides the binary eutectic, zones of eutectic development were to

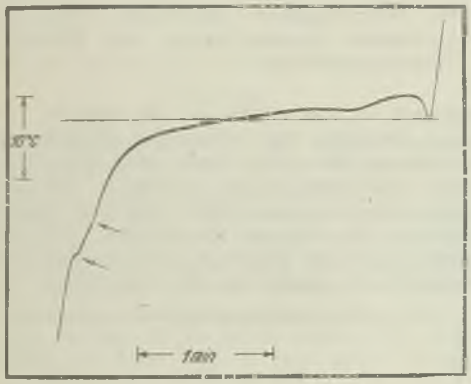

Fig. 7.—Cooling Curve of Silumin, with 12 per cent. Si, 0.25 per cent. Fe, 0.4 per cent. Mg, and 0.5 per cent. Mn. Rate of Cooling, 150 deg. C. per min.

be seen, these containing Mg_2Si crystals and also probably a complex containing manganese. The presence of slight amounts of foreign elements and the occurrence of new crystal types are thus evinced in the cooling curves.

Figs. 6 and 7 showed that under-cooling of several degrees can occur both before the commencement of primary crystallisation and also before the separation of the eutectic. Despite the presence of primary crystals which, in themselves, ought to have an initiating or inoculating action, it is possible for the eutectic residual melt to under-cool. In order to check this observation, some quasi-eutectic melts of the Al-Si system were made and subjected to thermal analysis under the same conditions.

The compositions of the melts are shown in Fig. 8. It will be observed that in the hyper-

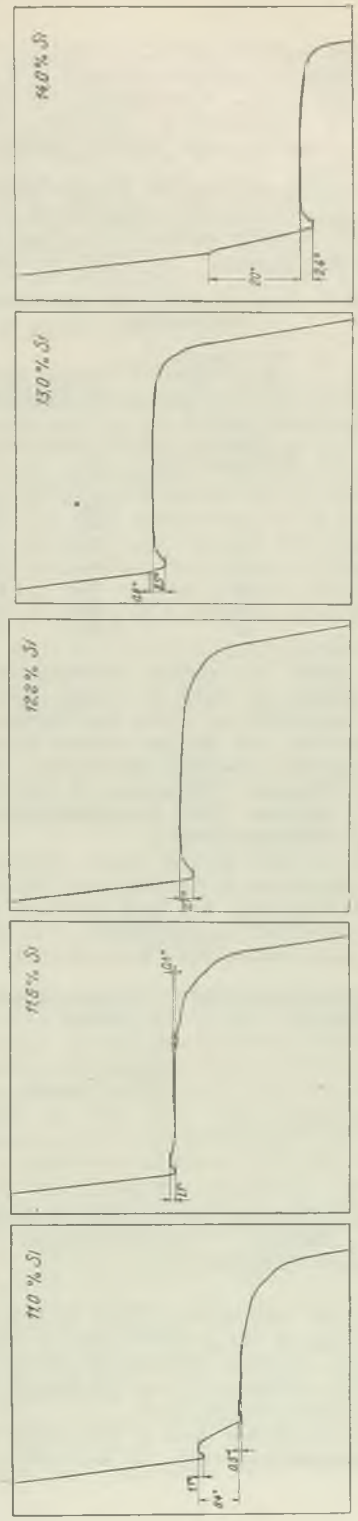

Fig. 8.—Cooling Curves of Quasi-Eutectic Al-Si Melts.

eutectic melts, under-cooling of about 2.5 deg. C. occurs, whilst in hypo-eutectic melts it is absent or only very slight. Furthermore, the familiar pronounced under-cooling capacity of the primary aluminium solid solution separation is clearly shown.

The different behaviour of primary crystals on the initiation of eutectic crystallisation was also observed in a similar manner in the case of some other binary systems. In Table I, the first

TABLE I.—*Binary Systems Exhibiting Eutectic Under-cooling.*

System.	The eutectic residual melt under-cools in the case of primary separation of	Freezing point of the components	
		A.	B.
		Deg.	Deg.
$Al-Al_2Cu$ ..	Al	660	590
$Mg-Mg_3Al_2$ ..	Mg	650	455
$Al-Al_3Mg_2$ ..	Al	660	454
Al-Zn ..	Al	660	419.4
Sb_2Zn_3-Zn ..	Sb_2Zn_3	566	419.4
Si-Al ..	Si	1,414	660

column shows the systems investigated, the second column the kind of crystal, after the primary separation of which the residual melt can under-cool, and the last column shows the freezing points of the pure components. (Taken from M. Hansen, "Structure of the Binary Alloys" (Aufbau der Zweistofflegierungen), Berlin, J. Springer, 1936).)

It will be seen that in binary systems, the primary separation of the component having the higher *melting* point has little influence on the initiation of eutectic crystallisation. The eutectic residual melt freezes after under-cooling. With

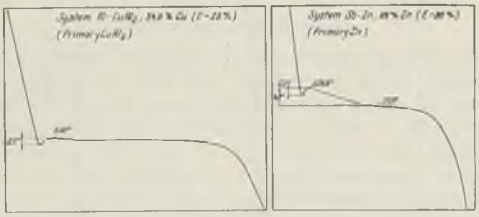

FIG. 9.—EXAMPLES OF DISTINCT INITIATION OF EUTECTIC CRYSTALLISATION OF PRIMARY CRYSTALS.

regard to the component of lower melting point, under-cooling of the residual melt is more or less absent. It must therefore be assumed that the primary crystals exert an inoculating action on the eutectic residual melt.

Figs. 9 and 10 show some of the cooling curves of this experimental series. In the former, there is under-cooling only of the primary crystallisation. In the case of the separation of Al_2Cu, this is so pronounced that the lowest point reached by the under-cooling is below the eutectic temperature. In Fig. 10 on the contrary, under-cooling is well-pronounced in the case of both crystallisation processes.

In the experiments so far discussed, the rate of cooling was about 100 to 150 deg. C. per min. Under-cooling amounted to several degrees

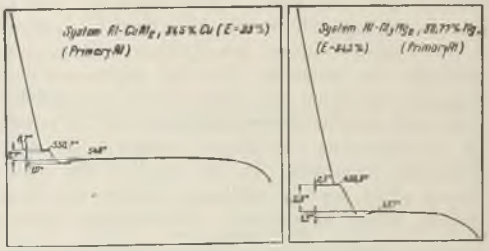

FIG. 10.—PRIMARY SEPARATION DOES NOT SUPPRESS UNDER-COOLING OF EUTECTIC CRYSTALLISATION.

measured in the middle of the sample. This means, however, that before the commencement of freezing, the entire melt must have under-cooled, and since during cooling in the liquid region there is a temperature gradient from the middle to the edge of the sample, it is to be assumed that the degree of under-cooling is not inconsiderably greater in the outer zones.

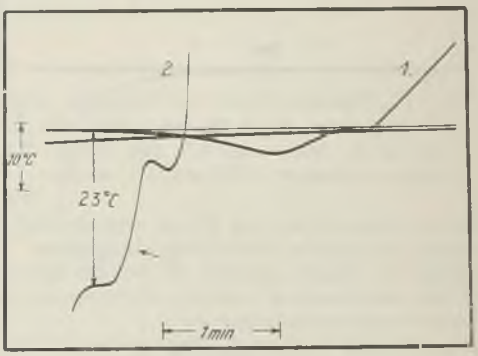

FIG. 11.—COOLING CURVES OF TWO SILUMIN ALLOYS: (1) 13.11 PER CENT. SI (RATE OF COOLING, 110 DEG. C. PER MIN.). (2) 11.5 PER CENT. SI (RATE OF COOLING, 2,400 DEG. C. PER MIN.).

When the rate of cooling is further increased, for example by casting in a metal mould, under-cooling ought to be much greater. An illustration will confirm this and also show the efficiency of thermal analysis. Fig. 11 shows portions of

the cooling curve of two Silumin alloys. The alloy containing 13.11 per cent. Si, solidifying slowly in a crucible in the air (rate of cooling about 110 deg. C. per min.) serves as a kind of pilot or calibration alloy in the investigation of alloys in the region between 500 and 600 deg. C. It always gives the same curve provided the experimental conditions are kept constant. The

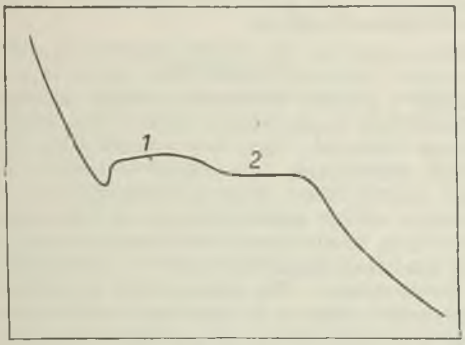

Fig. 12.

primary crystallisation of the silicon lies just above the eutectic critical point, which was still recorded on the second revolution of the drum (periphery 500 mm.). The eutectic under-cooling is 3 deg. C. The second sample with about 11.5 per cent. Si was poured in a thick-walled iron mould of 20 mm. internal diameter. The rate of cooling is accordingly higher, being about 40 deg. C. per sec. in the liquid region, this corresponding to 2,400 deg. C. per min. Despite

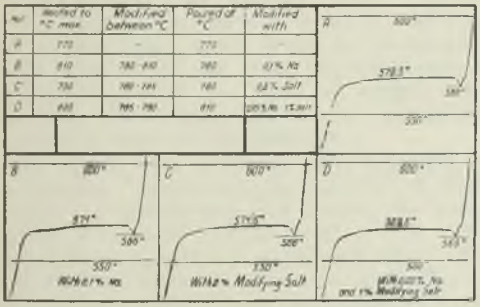

Fig. 13.—Silumin Modification.

this high rate of cooling, the crystallisation process is still detected by the apparatus.

For the commencement of the aluminium crystallisation, maximum under-cooling is 6 deg. C. below the eutectic equilibrium temperature of the pilot alloy. Eutectic crystallisation commences in consequence of inoculation by the primary crystals at the point marked by an arrow, perhaps even before. The most pronounced crystallisation, which in consequence of the heat of crystallisation liberated almost results in maintenance of the temperature of the melt, only takes place 23 deg. C. below the critical point of the pilot curve. The investigation of the effect of such considerable under-cooling is one which shows much promise and to which thermal analysis can be usefully applied. The proposed investigations employing a number of thermocouples in different zones of the melt should be particularly informative.

Conclusion

To conclude, reference will be made to an observation showing the further relationships between the result of thermal analysis and that of microscopic examination. In the "modification" of Silumin with sodium, a very fine eutectic is formed. The temperature of its formation is some degrees lower than in the unmodified material with coarser development of the eutectic. In the case of semi-modified material, the structure shows zones of fine and coarse eutectic,

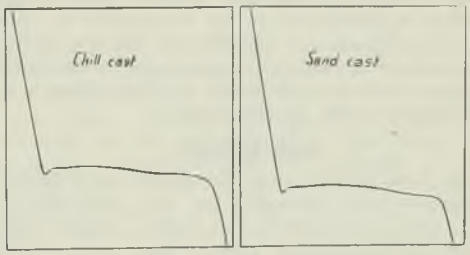

Fig. 14.—Heredity Phenomena in Silumin.

often clearly separated but in other cases characterised by a continuous transition of the degree of fineness. In the case of partial modification, the cooling curve shows a stepped formation during the critical point, as is indicated diagrammatically in Fig. 12. The length of the two steps appears to be a measure of the quantitative proportions of coarse and fine eutectic. Fig. 13 shows the curves of such an experimental series. Diagrams A and D are the cooling curves of unmodified and correctly modified Silumin without stepped formation. In the case of the sample (B) modified with 0.1 per cent. Na there are two distinct steps, the lower of which is apparently connected with the separation of the finer structure. The effect of 2 per cent. of modifying salt alone is less (C), this being shown by a displacement of the length of the step.

The same stepped formation was also observed in the case of some sorts of remelted Silumin. Chill-cast and sand-cast bars, 20 mm. in

diameter, were made simultaneously from melts of different origins. Centrally-located pieces about 35 mm. long were sawn from these bars and remelted under the same conditions in a furnace controlled by a regulator, and were maintained at temperature for 10 minutes. The crucibles were then stood in the air for cooling and at the same time the temperature variation was measured by means of a thermocouple with unprotected junction. Upon examining the hardness of these specimens, which had been melted under the same conditions and cooled at the same rate, it was found that the specimens from the chill casting were harder after remelting than the sand-cast specimens. Thus, for a furnace temperature of 650 deg. C., the hardness of the sand-cast specimen was found to be 53.6 and that of the chill-cast specimen 57.2. Fig. 14 shows the curves of such a remelted Silumin with different lengths of step in the case of sand casting and chill casting. Microscopic examination showed eutectic areas of different degrees of fineness in the case of such stepped formation. It must be left to further investigation to ascertain whether this not immediately explicable formation of an apparently in both cases binary eutectic of different degrees of fineness and at different temperatures in the same sample is to be attributed to the presence of anisotropic zones in the melt.

DISCUSSION

The first speaker was Professor A. Portevin (France), who remarked on the perfection of the curves produced by the author, which represented a further step towards the completion of the work performed by Tammann and Professor Piwowarsky, and showed a new application of thermal analysis. In order to obtain such perfect curves, he said, it was necessary to use very accurate methods and very precise apparatus for measurement, which was not always available; without such methods and apparatus it would not be possible to obtain the precise quantitative results given. It was a new application of precision thermal analysis.

With regard to the double supercooling effect, Professor Portevin raised the question as to whether a possible distinction should be drawn between the cases where, before the eutectic cooling occurred, the first modification had already taken place. He suggested that in that case, possibly, there was no direct effect on the structure of the metal, whereas in those alloys where both those effects took place, it was possible that that might be the cause of the change in the structure. The nature of the pro-eutectic constituent might act upon the eutectic structure in a different way, according to whether it was or was not the "directive constituent" of the eutectic aggregate.*

Professor E. Piwowarsky (Germany) said that where there was a break in the curve of the eutectic crystallisation it was always possible to distinguish a change in the structure of the metal. One part of the curve was definitely to be correlated with the existence of a coarse structure, and the other part of the curve with the fine structure in the metal.

* A. Portevin, "Structure of Eutectics," Institute of Metals, March, 1923.

Paper No. 676

The Progress of Inverse Segregation during Solidification*

By Dr. JOSEPH ALEXANDER VERO

Introduction

In the extensive literature dealing with inverse segregation, experiments are described which were carried out mainly to prove or disprove different theories of segregation, while important particulars which undoubtedly were germane to the understanding of this interesting phenomenon have been entirely neglected. To fill up one of the existing gaps, the present investigation was carried out; and in order to visualise the formation of inverse segregation during solidification, the following particulars were taken into account:—(1) How the extent of inverse segregation changes with the progress of solidification, in the solid part of the ingot; and (2) whether and how the average composition of the solid part and that of the liquid are changed during solidification.

Previous Work

The literature of the subject recently has been reviewed in separate Papers, [1 2] and by reference to these it will suffice to mention only those experiments which are akin to these described in the present research.

In the discussion on Genders' Paper[3] supporting the gas pressure theory, Archbutt mentions that a bled ingot made from an aluminium-copper alloy (11.57 per cent. Cu) contained at the periphery 12.27 per cent. of copper, thus indicating the presence of inverse segregation at an early stage of solidification.

Bled ingots were produced and examined by W. Gödecke,[4 5] again with the intention of showing that the first formed solid shell of the ingots consists of primary crystals rich in the high-melting point constituent of the cast alloy. The shells differed, however, from the cast alloy in their composition by a few hundredths of 1 per cent. only, while 1 per cent. or more was expected from consideration of the equilibrium diagram. Herefrom it is concluded that the residual liquid may not be separated from the solid shell, and that it is incorrect to assume normal segregation due to the formation of the primary crystals and proceeding to the final inverse segregation.

* Presented on behalf of the Magyar Outodei Szakem berek Egyesulte.

THE PRESENT RESEARCH

Experimental

The experimental alloy, composed of 95 per cent. of commercial aluminium and of 5 per cent. of "Banca" tin was prepared in a gas fired furnace. This alloy solidifies, according to the equilibrium diagram of the Al-Sn alloys,[6] over a very wide temperature range, the primary and the secondary constituent differ much from each other, and in addition its analysis is very simple; thus it is very suitable for segregation experiments.

Definite portions of this alloy were remelted, well stirred and then samples were taken by means of a small plumbago spoon. The mould, 100 mm. high, had a diameter of 65 mm. at the top and of 45 mm. at the bottom and a wall thickness of 20 mm.; at the bottom it was open. Before pouring, the mould was preheated to 125 ± 5 deg. C. The alloy was cast at the temperature of 750 ± 10 deg. C. On pouring, the mould stood on a level bed of slightly preheated moulding sand, and immediately by the side of the mould a cavity was made in the sand. After a part of the alloy had solidified in the mould, the latter was tilted and the liquid residue ran into the cavity of sand.

The pit samples gave the original composition of the alloy. By making two radial cuts through the shell, samples were obtained giving information on the average composition of the solidified parts of the ingots; the remainder of the shells was then machined, layer by layer—the layers were 2 mm. deep—to detect the segregation. The residual liquid which solidified in the conical cavity of sand was sampled by taking two radial cuts reaching the centre.

Analysis was effected by dissolving the sample in HCl and titrating with $FeCl_3$; proper choice of methods and standardised careful work resulted in an accuracy of ± 0.01 per cent.

Experimental Results

The results of analytical examination together with the data characterising the stages of solidification were collected in the upper part of the Table I. The progress of solidification is indicated in the second column of this table by the

relation of the cross-sections of the whole ingot and of the shell, calculated as a ratio of the corresponding weights. Since the compositions of the single melts vary to some extent, the divergences of the tin contents of the single layers from the original composition of the corresponding melt are shown in the lower part of the Table I, enabling comparisons to be made between the different castings.

Casting I indicates the earliest stage of solidification. It was 2 to 3 mm. thick; thinner shells could not be produced, as they broke down and fell from the mould during inversion. At this stage of solidification there is a slight, but distinct, segregation of the inverse type; the average compositions both of the bled ingot and of the residual liquid agree accurately with the composition of the melt. The latter observations also proved valid for the later castings, except in the case of Sample III, which will be discussed later. Thus the liquid part of chill cast ingots is not affected by any segregation taking place in the solidified parts of ingots and consequently the segregation is only connected with those parts where solidification has already begun.

With the progress of solidification, the segregation steadily increases in extent, as is indicated especially in the data in the lower part of Table I; this increase is first quite slow (*vide* castings II and III), but as soon as the half cross-section of the ingot has solidified, it becomes more rapid and the major part of the total segregation arises during the solidification of the internal parts of the ingot.

This progress of segregation is clearly shown by Fig. 1, wherein the extent of segregation, expressed by the divergence of the extreme tin contents from that of the cast alloy, is plotted against the cross-section relationships indicating the stage of solidification. The positive values, referring to the periphery of the castings, increase in a uniform manner, while the curve of the negative divergences shows a steep deflection beginning at about the cross-section ratio of 0.6. The alteration of the negative values is due, at least partly, to the different thickness of the innermost layers.

Both curves of Fig. 1 have a distinct tendency to run into the 0 point of the co-ordinates representing the original composition of the cast alloys, though the nearest experimental points at about 0.2 cross-section ratio lie a little distant from the 0 point. Here the course of the curves is not perfectly determined; the curves as drawn doubtlessly fit into the experimental points. If so, then the composition of the first formed layer of chill cast ingots must be identical with that of the cast alloy.

The experimental alloy solidifies over a very wide temperature range, and thus, on bleeding the shell remaining in the mould is obviously

TABLE I.—*Analytical Results.*

No. of the casting.	Stage of solidification.	Pit sample.	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	Whole casting.	Residual liquid.
		Tin content, per cent., of the layer, proceeding from the periphery															
I	0.208	5.27 5.26	5.28 5.30	5.21 5.20	—	—	—	—	—	—	—	—	—	—	—	5.265 5.26	5.26 5.27
II	0.365	5.16 5.18	5.19 5.23	5.18 5.18	5.15 5.13	—	—	—	—	—	—	—	—	—	—	5.16 5.18	5.18
III	0.390	5.24 5.26	5.11	5.06	4.99	—	—	—	—	—	—	—	—	—	—	5.05 5.06	5.27 5.29
IV	0.575	5.07	5.30 5.28	5.05 5.06	5.00 5.00	4.875 4.88	—	—	—	—	—	—	—	—	—	5.05 5.06	5.07 5.07
V	0.790	5.26 5.28	5.70 5.70	5.58 5.59	5.40		5.17		5.02		—		—		—	5.25 5.31	5.27 5.82
VI	1.00	5.21 5.21	5.91 5.90	5.80	5.55		5.05		4.90		4.55		4.40		4.25	—	—
I	0.208	—	+0.025	−0.05	—	—	—	—	—	—	—	—	—	—	—	0	0
II	0.365	—	+0.04	+0.01	−0.03	—	—	—	—	—	—	—	—	—	—	0	+0.01
III	0.390	—	+0.055	+0.005	−0.065	—	—	—	—	—	—	—	—	—	—	—	+0.03
IV	0.575	—	+0.22	−0.015	−0.07	−0.19	—	—	—	—	—	—	—	—	—	−0.015	0
V	0.790	—	+0.43	+0.315	+0.13		−0.10		−0.25		—		—		—	+0.01	+0.005
VI	1.00	—	+0.70	+0.59	+0.34		−0.16		−0.31		−0.66		−0.81		−0.96	—	—

not perfectly solid, but pasty; one might think that further cooling may produce changes in the distribution of tin and that therefore the examination of the shells does not give a true picture of the actual state. To clarify this doubtful point, one of the castings, No. III, was quenched in ice water, together with the mould, immediately after bleeding. On quenching, the inner surface of the shell was immediately cooled by the water, while the periphery facing the mould was obviously kept hot by the heavy mass of iron. Thus quenching reversed the direction of heat flow in the shell; nevertheless, it was unable to give rise to any difference in the distribution of tin in comparison with the similar casting No. II, but the average tin content was considerably lower than that of the cast alloy. On quenching, the shell was covered by many cracks and the water which entered them caused

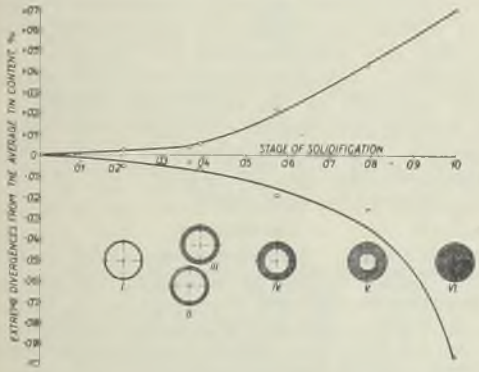

Fig. 1.—Progress of Inverse Segregation as presented by the Extreme Values of Composition.

appreciable corrosion, due to the great potential difference between tin and aluminium; in consequence of the oxidation of aluminium, lower tin contents were obtained.

Correlation of the Results with Segregation Theories

The fact that the segregation is slight in the early stages of solidification and that its major effect takes place during the second part of solidification, proves in the first instance the correctness of that theory that the segregation is a consequence of the migration of the residual liquid from the centre towards the outside of the ingot at some stage prior to complete solidification. The migrating liquid will become richer in the lower melting point constituent with falling temperature. At an early stage of solidification, the solid shell is thin and the temperature differential between its internal and external parts may be only small; thus migrating liquid will also be enriched in the fusible constituent to a small extent and the migration of a liquid—which does not differ much from the original composition of the alloy—may produce slight changes in the local composition of the casting. With the progress of solidification, however, the temperature differential existing in the solidified part and the enrichment of the fusible constituent during its migration increase, giving rise to a more extensive segregation.

With regard to the cause of the migration of the residual liquid, there are divergent opinions. It is not the author's intention to draw conclusions from the results in this respect, but an observation noted in many cases, and which is not discussed in the literature, is worth detailing. Immediately before the end of solidification, a visible contraction of the residual liquid occurs at the bottom of the shrinkage cavity, and in consequence porosity appears between the primary crystals, being visible at low magnifications. This observation is explainable only by suction action exerted by the previously solidified parts of the ingot, but not by the evolution of gases; gas evolved close to the surface of the casting would preferably disappear in the air, rather than drive the residual liquid through some obviously existing resistance towards the outside of the casting.

The conclusion that the composition of the first formed solid layer of chill cast ingots is identical with the composition of the cast alloy, as shown by Fig. 1, is in contradiction to the fundamental assumption generally used in explaining the phenomena of segregation. According to its final form,[1] this assumption says:—"From consideration of the equilibrium diagram of a binary alloy system, it is possible to visualise one type of segregation. The first crystals to separate from the molten alloy are rich in higher melting point constituent and occupy a position close to the mould face. As solidification proceeds, the crystals grow towards the centre of the ingot, pushing before them the residual liquid, which is becoming continually enriched in the lower melting-point constituent. The latter might be expected to be found, therefore, in greatest quantity in the central, last solidifying part of the ingot. The segregation in this case is described as 'normal,' . . ." This interpretation of the process of solidification may be found in every Paper or text book dealing with segregation; its original author is uncertain. It is, however, possible to pursue its existence as far as to 1906, when C. R. Andrews gave a similar description of the process of solidification in the discussion of Talbot's[7] report on the segregation in steel ingots.

The concept in question rests upon two facts: (1) That, according to the equilibrium diagram, crystals rich in the high melting-point constituent separate first from the melt; and (2) that on pouring into metallic moulds, the solidification begins at the mould face and proceeds then, layer by layer, towards the centre of the ingot. A combination of these facts, postulating that the first formed solid layer of the ingot consists essentially of the first formed crystals, led to the opinion outlined. The two facts, however, are quite independent of each other, and their combination is, generally speaking, inadmissible; on the contrary, neither does the equilibrium diagram indicate that the first separated crystals form a perfectly solid layer, nor may it be assumed that the shell growing inwards consists solely of primary crystals.

Because the distribution of the constituents of an alloy is probably uniform in the filled mould before the crystallisation begins, a solid layer being rich in the high melting point constituent could be produced only by some motion—such as the migration of the constituents. This migration, however, is not to be deduced from considerations of the equilibrium diagram, but only if at least one of the following possibilities proved correct:—(1) if prior to crystallisation, a corresponding composition-gradient were present (inverse Ludwig-Soret effect); (2) if the primary crystals formed in the melt could change their original position inversely, as advanced by Watson,[8] or (3) if the residual liquid would be squeezed out from the region of primary crystallisation, by some considerable increase in volume. The first two possibilities need not be considered[9, 10] and also the third one does not occur in every case of segregation. Thus there is no reason to assume, even from considerations of the equilibrium diagram, the early formation of a solid shell, rich in the high-melting-point constituent, since experimental results disprove this opinion.

But independently from the circumstance whether the above possibilities may be active or not on solidification, they doubtless are processes of which there is no indication in the equilibrium diagram. The equilibrium diagram gives information only on the succession of the processes and reactions of crystallisation, but not on the distribution of the alloying elements in a casting, and neither the one nor the other type of segregation may be derived from this diagram. The compositions of castings cooled under several conditions were doubtless uniform, if only the processes indicated in the equilibrium diagram did take place on solidification and if secondary factors did not play a part. On explaining the phenomena of segregation the equilibrium diagram may be used only so far as to show that at some stage of solidification there is a residual liquid differing in composition from the cast alloy and being thus able to produce local changes of the composition of the casting, if it is forced to migrate by secondary factors.

A further consequence of these considerations is that the differentiation of "normal" and "inverse" segregation may not be postulated with reference to the equilibrium diagram. It is, however, not suggested to reject these familiar premises, but only otherwise to explain their origin, the one type, for example, as "normal," *i.e.*, frequent in steel ingots.

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Paper No. 677

General Principles Applicable to the Compounding of Alloys by Melting*

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By accepting the invitation to present a Paper on behalf of the Association Technique de Fonderie, there was the obligation imposed to deal with the general subject recommended by the International Committee of Foundry Technical Associations, since it was the French delegation which suggested it. The subject is of outstanding interest because of its fundamental importance to founding and also because it has not so far been to the author's knowledge the object of a general discussion. The only general conceptions of the subject that are available in French technical literature are those to be found in the lecture courses given to the students of the Paris Foundry School and are, therefore, only available to a very limited public.[1] Moreover, this scarcity of information is a difficulty which adds to those resulting from a study of the subject. Thus, the matter presented must perforce be in the nature of a lesson, and because of this a request is made in advance for sympathetic consideration if there should be incorporated any lapses or inexactitudes in what is a general didactic *exposé*, which the author has developed in a somewhat novel form. The subject will be covered where possible by examples, and especially by general rules, whilst risking the non-applicability of premature generalisations in particular cases.

PART I.—THE PROBLEM STATED

The problem to analyse and solve can be postulated as follows:—

> Being given raw metallic materials currently available and particularly industrial metals, the problem is to produce economically a liquid homogeneous alloy, ready for casting, without changes acting adversely against the useful properties of the casting.

Under this very condensed form this hypothesis calls for some additional explanations. "Economically" implies melting losses of the lowest possible order, but at the same time without having recourse to irksome melting processes in relation to the price of the alloy and its usages. Thus, for cast iron, recourse will usually be made to the cupola, an economic method of melting only used at the moment in quite rare cases in connection with copper alloys. This also implies, from the cost price point of view, that *the foundry scrap should be re-used;* that is to say, re-enter into later furnace charges, so as to ensure continuous production. This condition stresses and defines the phrase "without acting adversely against," for by repeated meltings the alterations to the bath are accumulative and become progressively noticeable by repetition.

"*Liquid Alloys.*"—Processes for making alloys by electrolysis, cementation, compression or reaction in the solid state can naturally be excluded, as also can those carried out for the object of making master alloys or "additions." "*Changes acting adversely*" can, moreover, be widened to embrace various points of view, such as *chemical change* modifying the specific properties of the cast metal or the soundness (depending upon physical defects) of the actual casting or physical change through *modification of the solidification crystallisation.* These changes are extremely diverse according to the alloy and the melting conditions. The limits of tolerable change are above all variable with the alloy, the type of change and its use.

"Ready for casting" implies that the liquid alloy is at the requisite temperature and has *the chemical composition within the specified limits,* such limits being variable with the alloy and being different, for example, in the cases of coinage and anti-friction alloys. This equally implies that the alloy is adequately protected against the changes occurring during casting.

The solution of this problem is therefore dependent on the two following fundamental factors:—(A) Raw materials; and (B) melting conditions. These must be briefly examined for a proper understanding of the problem.

PART II.—FACTORS IN THE PROBLEM

(A) *Raw Materials.*—The raw materials are those which enter into the make-up of the melting charge. They are defined by the chemical

* Presented on behalf of the Association Technique de Fonderie de France.

nature and their physical state. From the point of view of *chemical nature*, the charge can include:—(1) *Metallic components* called *virgin metals* of varying purity[2]; (2) alloys already carrying the same composition as the desired alloy. These may consist of *scrap*—foundry, machine shop, old (castings discarded through obsolescence); alloys cast as *analysed ingot*, that is to say of the desired composition; (3) *master alloys*, that is to say, alloys specially compounded under special conditions and of a composition different from that of the desired alloy; and (4) *additions* made with diverse objects, to be referred to later, and in particular including those destined to form melting fluxes.

The nature or chemical composition of virgin metals, analysed ingots, master alloys and additions is well known; this is not so, however, of scrap, and therein lies a grave source of difficulties and of failure in the foundry not possessing facilities for sorting and classifying scrap. Classification should be based on considerations of (*a*) the origin of the scrap which allows its general chemical composition to be established.

This chemical composition is known for that emanating from internal manufacture, that is, foundry scrap and customers' returns. In other circumstances it is necessary, or at least desirable, to undertake chemical analyses, or have recourse to some method of rapid characterisation or differentiation. For tests of a physical type, one can cite colour in the case of brass, fracture with cast iron, scratch hardness or bend test for light alloys. For composition tests there is, in the case of aluminium alloys, the "spot" test.[3] To avoid excessive analytical testing, ingotting embracing methodical mixing can be practised.

From the point of view of *physical state*, the size and shape of the pieces should be considered as much in the direction of rapidity of melting as in the sense of melting losses and changes. The question should therefore be examined in conjunction with melting processes and melting conditions to be dealt with later. For the present it will suffice to draw attention to reduction to suitable size which can be achieved by breaking up; by melting and casting into notched ingots; by shearing when the metal is malleable, or exists as malleable sheet or wire, or smashing up in the case of fragile materials.

B—Melting Conditions

Outstanding amongst conditions influencing the compounding of alloys, are the following:—B1—method of heating usually known as type of melting furnace; B2—melting atmosphere (or melting flux) and B3—nature of the furnace chamber or melting medium. Conditions B2 and B3 define the chemical nature of the external *milieu*, that is to say, the substances or gaseous phases (atmospheres), liquids (fluxes and slags) and solids (walls) in contact with the alloy and capable of reacting with it. They thus govern as a function of the temperature the changes of the metal; they are interconnected. The choice of atmosphere or melting flux must depend upon that of the furnace chamber and reciprocally. They are, however, equally in relation with the method of heating, as will be shown.

B 1—Methods of Heating and Type of Furnace for the Melting of Alloys

There are two major classes of furnace: (i) Combustion or flame furnaces, (*a*) shaft, (*b*) hearth and (*c*) crucible, and (ii) Electric furnaces, (*d*) resistance, (*e*) induction and (*f*) arc.

When choosing an alloy melting furnace, the following factors must be taken into consideration: (1) the precision of temperature control it is possible to impose, (2) thermal acceleration and (3) the atmosphere and refractory walls which can react with the charge or alloy. These last two factors will be examined later. Attention is drawn to the agitation of the liquid bath which characterises induction furnaces as this considerably increases the speed of homogeneisation; but it also enhances the reaction rate of the liquid bath with external surroundings.

The following remarks seem germane to the subject:—

Shaft furnaces are but little used, although this type of furnace has recently been tried out for brass melting.

Arc furnaces can only be practically employed for melting alloys of high melting point since the arc has a temperature of 3,700 deg. C. It is primarily used for making special steels, despite the risk of carburisation.

The hearth furnace is suited for the manufacture of large tonnages; there are drawbacks which result from its fundamental principle, and amongst these is the contact between the surface of the bath and the products of combustion.

It can thus be stated, for the sake of simplification, that there is the choice of three furnaces, the crucible, electric resistance and induction. Amongst factors deserving of consideration is that of the thermal acceleration, as it is often neglected.

Crucible furnaces heated by poor quality gas and electric furnaces using metallic resistances show but slow temperature increase; oil-fired furnaces, on the other hand, have an important thermal acceleration.

Obviously, it is always worth while to increase the speed or reduce time of melting, because by so doing the heat losses through radiation and

fuming (which are proportional to the length of time taken in melting) are reduced, and also, and often very seriously, the changes such as oxidation and gas absorption, to be considered later, are similarly reduced. It is, however, very important that the melting process should allow of a precise temperature control, and if possible it should also bring about the mixing of the melted materials. In this respect the introduction of the induction furnace into the brass foundry has brought a better uniformity and very low zinc losses.

B 2—Melting Atmosphere

The atmosphere or gaseous phase in contact with the metal should be considered from a dual aspect—its chemical nature and pressure. Leaving aside precious metals for which there is no alteration in air, at normal pressures, it is possible to postulate the following diverse cases of melting:—

(1) *Melting without chemical change*, by carrying out melting *in vacuo*, under conditions of an inert or inactive gas or an atmosphere in equilibrium or a protecting flux.

(*a*) *Melting under an inert or inactive gas*, as, for example, the melting and casting of refined copper in hydrogen or nitrogen or magnesium or calcium in argon.[4] It is worth noting that certain metals combine with numerous gases in considerable quantity, as is the case with calcium or magnesium in contact with oxygen, nitrogen and hydrogen. On the surface of the bath, a local atmosphere can be created, as for example carbon monoxide, by dry or well-burnt charcoal.[5]

(*b*) *Melting under an atmosphere in equilibrium*. This would be the case with steel, in an atmosphere of $CO + CO_2$ or $H + CH_4$ in proportions defined by the temperature and the carbon content of the metal. Accordingly, there will be carburisation or decarburisation.

(*c*) *Fusion under a protecting flux*. It is essential that this flux be practically impermeable to gas of the atmosphere above it, as under these conditions it tends to put itself in chemical equilibrium simultaneously with the metal and the atmosphere, which latter causes reaction between these two phases. This leads in certain cases to the use of considerable thicknesses of flux, if an excellent protection be sought. An example is afforded by the method of melting magnesium used by Dow Chemical Company (60 per cent. $MgCl_2$ + 40 per cent. KCl or NaCl). The weight of flux is from 45 to 50 per cent. the weight of the metal being melted and serves at the same time to protect it against the atmosphere and the walls of the crucible.

(*d*) *Melting in vacuo*.— The phrase defines melting under negative pressures of the order of 0.01 to 1 mm. in furnaces of small capacity, and from 1.0 to 2 mm. for larger furnaces (in practice 4-ton furnaces are used for the casting of nickel alloys and special steels).

If vacuum melting is advantageous in respect to non-oxidation and degasifying (extremely variable factors, being very effective in the cases of palladium and tantalum and feeble with aluminium), yet contrarily it introduces certain troubles[6] especially in pronounced vacua (< 0.01 mm.) for there are such factors as the vaporisation of the metal through boiling, distillation or evaporation, and sublimation; the vapour tension of metals increases exponentially with temperature ($\log p = -\frac{a}{T} + b$). Thus, Mg, Ca and Be are purified by sublimation; iron of which the boiling point is 3,235 deg. C. sublimes at 1,300 deg. under sufficient vacuum. Chromium possesses, when approaching its melting point, a vapour pressure so great that it cannot be so melted, because it sublimes prior to this. The melting of a metal under high vacuum is thus only possible by creating a reduction of section and so bringing about a stagnation of vapours at the surface of the metal bath. To overcome this, there is the possibility of introducing either inert or neutral gases, especially some rare gases, so as to obtain pressures of a few millimetres.

Interesting factors in this connection are (*a*) the reduction of even refractory oxides forming the walls of furnaces by the carbon of the metal as is the case with steels and cast irons, or various metals such as Ti, W, Al, etc., and (*b*) the vaporisation of the materials incorporated in the construction of furnaces and notably the heating elements such as Nichrome, Pt, Mo, etc.

(2) *Melting with Chemical Change*.—This is the general case in the foundry with an atmosphere formed by air or furnace gases. As a result there is oxidation and maybe nitrogenisation (in the case of Mg and Ca) simultaneously with gas absorption. In this respect it should be pointed out that the presence of small quantities of compounds decomposing when hot in the presence of metal, such as water vapour, or ammonia gas has a very active action by liberating the gaseous elements to the atomic state whence follows a serious absorption of H and N. There are chemical changes of which the magnitude varies within wide limits according to the metals melted and the physical state of the products of reaction, as will be shown later.

Yet it should not be necessary to present the simple or cumulative change as a general and necessary result, since remelting can be exactly a purification process of a "changed" metal. Even oxidising conditions during melting—a process commonly used in metallurgy (as for in-

stance in the production of copper and iron)—can be usefully used in the foundry (as in the case of the elimination of the Fe and Al impurities in tin alloys.

(3) *Melting with Refining.*—This refining can be undertaken by the general processes of chemistry, such as:—

(*a*) *Simple decantation.* For example, the undisturbed melting in the crucible of cemented bar and so eliminating the numerous silicate inclusions, or again the passage of pig-iron through the mixer brings about by decantation the separation of the manganese sulphide.[7] Magnesium, as received from the electrolysis plant, can be freed by this means from practically all the included magnesium chloride (the Cl content can be reduced from three to <0.01 per cent.). Tin and its anti-friction alloys when changed by contamination with iron from the melting chamber contain the heavier $FeSn_2$, which can be reduced down to something of the order of 0.1 per cent. of Fe.

(*b*) *"Sticking" or coagulation with weight increase.* By an addition of a mixture of MgF_2, $BaCl_2$, etc., to molten magnesium, the former spreads itself slowly through the liquid and induces a coagulation of the inclusions (Hérenguel, Thesis, Lille, 1936, p. 30) just as albumen is used for cleaning wine.

(*c*) *Filtration.* This process is very seldom used on account of the difficulty of finding filters sufficiently resistant to the action of hot liquid metals, in a manner similar to the cold filtration of mercury through chamois leather. It is, however, possible to point to the case of the forced filtration of magnesium through a metallic cloth sheet and perforated iron sheet (Hérenguel, Thesis, Lille, 1936, p. 31).

(*d*) *Extraction or Absorption by Flux or Slag.* This is the general process of metallurgy used in connection with steel, iron, copper, etc. All hearth furnace metallurgy, the Siemens furnace or the electric furnace is based on the use of slags which allow a charge entirely made up from scrap from any source; the use of soda ash brings about a rapid desulphurisation of cast iron.

All the reactions are, generally speaking, considerably accelerated by movements giving an emulsion and thereby materially increasing the surface contact (Ugine-Perrin process). Moreover, it can be stated that the deterioration of metal during melting is the result of poor technique. Changes of a metal or an alloy due to atmosphere can take place during casting, and hence the casting processes carried out in hydrogen or other gases, as for example in the case of refined copper, which is beyond the scope of this Paper. To simplify matters, it is proposed to consider in what follows solely the melting in air or in the furnace gases under normal pressure with or without a flux.

B 3—Furnace Chamber or Melting Medium

Refractory materials used as furnace fabrics[8] such as crucibles, pans, hearths, etc., are either oxides or oxidised products (silica, alumina, silicates of alumina, magnesia, zirconia, beryllia, chromite, etc.) or carbon (graphite) or carbides (silicon carbide, etc.) or perhaps metals (iron, cast iron, etc.). They react on the molten metal and the metallic oxides formed during melting, as well as on the fluxes responsible for or accelerating the changes in the metal. A study of these reactions would require a complete chapter of chemistry to deal with it, so it is proposed therefore only to give some short and much simplified indications applicable to normal conditions of melting. These depend upon temperature and pressure, as has already been shown when dealing with melting *in vacuo*.

Generally speaking, it is necessary to distinguish between cases where the refractory is of an acid or basic character, carburising and oxidisable or reducible.[8a] Basic linings are used for metals giving basic oxides and for basic fluxes. These include magnesia, beryllia (except for the carbonates) and chromite (which is neutral). Acid linings are used when there are acid products, such as silica (except for the fluorides), zirconia, alumina (except for silica); recourse can also be had to chromite and silicates of alumina (neutral).

Neutral linings such as chromite and silicates of alumina or magnesia are fairly difficult to attack in both cases. Carburising and oxidisable materials oxidise in air at high temperatures (about 1,650 deg. C. for graphite and 1,700 deg. C. for silicon carbide). They will resist solid oxides, most are reduced by fusible oxides (of Cu, Fe and Ni). Silicon carbide, which is both carburising and siliconising, reacts not only on the easily reducible oxides, but on metals such as Fe, Co, Cr, Pt, all melting at high temperatures.[8b]

Iron can be used for melting metals immiscible with it, such as Na, Pb, Mg. Even Sn, which alloys with iron and iron alloys, can be so melted, under the condition that the cast iron used is of poor mechanical quality, that is to say, carrying large graphite flakes (which prevent further progress of the dissolution of the iron).

In the changes in metal during melting, which often show up in a lowering of the mechanical properties, it is necessary to remember the chemical rôle of the furnace chamber. For example, repeated remeltings of tin and antifriction metals give a fragile metal, designated "burnt." These changes are attributed to oxidation since they are due to the presence of a

definite compound $FeSn_2$ formed by the action of the iron in which the melting was carried out.

Here are shown all the complexities of changes during melting which dominate, as will be shown, the compounding of alloys. It is a veritable "introduction to the foundry" which can only be set out in general terms. Confining the subject to the normal conditions of the foundry, that is to say, without special atmospheres and using ordinary pressures, first of all, there will be postulated (1) the principles underlying the melting of industrial metals and this will be followed by (2) the principles of melting and the compounding of industrial alloys.

PART III—PRINCIPLES OF MELTING INDUSTRIAL METALS

The operation of melting a metal calls into play its calorific, physical and chemical properties. The *calorific* properties, specific heat, latent heat of fusion, are only to be considered in the light of choice of furnace from the angle of the requisite *speed of melting*, the importance of which has already been stressed. These factors have been the subject of determinations by various authors (Endo, Toepler, Vincentini and Omodei, Bornemann and Sauerwald, Wrightson, Saburo, Umino, Schwartz, etc.).[9] The consideration of physical constants, *melting temperatures* θ_f and boiling points θ lead with that of *chemical properties at high temperatures* to the conception of an *interval or margin of temperature* for *superheated liquid* $\theta_s - \theta_f$ for a *metal and fixed conditions of melting*—an interval in which it should be possible to hold it in the actual practice of the melting of that metal.

The lower limit is precisely defined and in absolute terms by the *melting* temperature. The upper limit θ_s or the limit of acceptable liquid superheating is a function of several phenomena and it is defined with very much less precision, due to the presence of a number of variable factors. The phenomena of limiting character which intervene are:—

(1) Physical: boiling and volatilisation.

(2) Chemical: consisting principally of the action of the gases of the atmosphere, either oxidation or absorption of gases (H, N, CO, etc.) and, secondly, of the reaction on the walls and the fluxes. To these could be added

(3) Crystalline, corresponding with the total disappearance of the crystalline organisation through melting and corresponding to the phenomena of crystalline superheating having their repercussion on the crystallisation after melting, but the few serious factors actually available in this respect correspond to relatively small temperature margins of which there is no need to take account in practice.

It is thus worth while to examine the consequences that may be deduced from boiling, from oxidation and from absorption of gas.

(1) *Boiling.* Primarily, it is obvious that the boiling point θ_e is in every case the upper limit of the admissible temperature $\theta_s < \theta_e$ which may represent the melting conditions. The difference $\theta_e - \theta_f$, the boiling and the melting points of metals, is most frequently the greater the more the metal is refractory.

R. Lorenz and Walther Herz[10] have shown that the ratio $\frac{T_f}{T_e}$, the absolute melting and boiling points, was on an average 0.5583 for elements; 0.7183 for inorganic substances and 0.62 as a general average for 412 substances—elements, organic and inorganic bodies. In one case only, that of tin gave a ratio well under 0.198.

On the other hand, Professor G. Longinescu[11] has established the ratio $T : d\sqrt{n} = K$, a constant, where—

T = absolute melting or boiling point.
d = density in the solid or liquid state.
n = number of atoms in the molecule.
K = 50 for the solid state and 100 for the liquid state.

As the relation of solid and liquid densities is ranged between 1 and 1.2, it therefore follows that $\frac{T_f}{T_e} = 0.5$ to 0.6.

It can be concluded that

$$\theta_e \cong 1.8\ \theta_f + 218.$$
$$\theta_e - \theta_f \cong 0.8\ \theta_f + 218.$$

In fact, taking into consideration the latest published values for these physical constants, it has been found that $\frac{T_f}{T_e}$ is:—

0.7 for Mo (a relatively volatile metal).
0.6 to 0.7 for W, Cr, Fe, Ni, Co, Mg.
0.5 to 0.6 for Ti, V, Mn, Au, Ag, Cu, Cd and Zn.
0.3 to 0.5 for Al, Sb, Pb, Hg.
0.2 for Sn (a metal notably stable in the liquid state).

As has been stated, vaporisation taking place before boiling limits the margin of liquid superheating, the knowledge of θ_e in addition supplying a point of the exponential curve of vaporisation ($\log p = \frac{a}{T} + b$) determined for a number of metals (Na, Zn, Mg, Ca, Al, Cu and Be) by various authors (Pilling, Rodebusch and Walters, Bauer and Brunner, Rudberg), the coefficient b of the formula being of the order of 7 to 9. For example, in air, under atmospheric pressure, the evaporation becomes noticeable

when the temperature exceeds 715 deg. C. for zinc, 626 for lead and 1,023 for silver (Krupkowski and Balicki), of which the boiling points are respectively 918, 1,740 and 2,100 deg. C. The margin of superheating is, however, notably restricted by the chemical changes.

(2) *Chemical Change.*—This may be due to α, the melting change expressed either by the oxygen content or impurity absorbed or, inversely, the loss of an element, or again the lowering of a property, a foundry property (such as running power), a mechanical property, soundness, etc. On the other hand, this change or quality-depreciation is a function of the temperature of the liquid metal θ, of the melting period t and of the surface S of contact with external surroundings.[12]

$$\alpha = f(\theta, t, S)$$

Again, the *admissable change* through melting depends not only on the *limit of change* laid down for the metal, but also in the case of quantity production on the re-use of scrap[13] of *mise au mille*,* M, and the proportion of scrap r. This question has been analysed by R. de Fleury[14] who, in dealing with this subject drew some remarkably simple conclusions by pointing out that change in quality through melting was independent of the initial state before melting, that is to say reproduces itself with the same intensity at each remelting. Thus if N is the number of remeltings necessary so that constantly remelting the same quantity of metal of the initial quality Q_σ, one may cause this quality to fall to the lower level Q_l, there is

$$Q_\sigma - Q_l = N\alpha \quad . \quad . \quad . \quad (2).$$

If, on the other hand M is the *mise au mille*, that is to say the relation of the weight of the charge to be melted, or the charge, to the weight of the castings obtained, the number n of operations depreciating the metal to the lower limit of value Q_l will be given by the exponential equation:—

$$(1 - \alpha)^n \frac{(M - 1)^n}{M} = \frac{M - N}{M - 1} \quad . \quad (3).$$

and for an equilibrated manufacturing system taking back for remelting all the scrap made, might continue without reaching finality, thus

$$M \leqslant N(1 - r) \quad . \quad . \quad (4).$$

These formulæ demonstrate the interdependence of M, r, N, Q_l and α. M and r are essential to the conditions of technical and professional exploitation as upon them depend the conception and carrying out of moulding, notably in respect to feeding heads and the feeding of castings

* *Translator's Note.*—No equivalent expression has been found for this phase, which is the relationship between the weight of the charge to bemelted and the weight of the castings obtained.

Q_l is a limited quality which can on occasion be defined in particularly clear terms, but in other cases quite unprecisely and in an arbitrary manner dependent upon specifications and inspection conditions. For example with Alpax (aluminium-silicon approaching eutectic composition) there is a sharp drop in the mechanical properties when the iron content reaches 0.8 per cent. Again, for other alloys quite small variations in titanium have a very appreciable effect. Yet, most frequently, the change in properties is progressive and the limit is conventional.

Given a proper picture of the manufacturing conditions and the values Q_σ and Q_l, N and consequently α are thereby limited and thus for any given conditions of melting, notably the time of melting t, one can define from equation 1 a limited value θ_s for θ.

Putting aside contamination by solid contact (walls and tools) and if the chemical change by the free surface only be taken into consideration, that is to say, the atmosphere by oxidation or gas absorption, S becomes the surface of the bath, which it seems worth while to reduce, bestowing advantages from the point of view of furnace chambers or deep crucibles and even those narrowed towards the top.

The oxidation of metals in the liquid state has been the subject of a noteworthy research by Krupkowski and Balicki, who showed, so far as it takes place for the oxidation of metals in the solid state, the important part played by the physical state of the oxidised layer formed on the surface.

In the isotherm condition in air the rate of oxidation is low and constant if the oxide formed is insoluble and solid ($W^2 = Kt$).

The rate of oxidation is rapid if the oxide formed is soluble in the molten metal or is insoluble and liquid ($W = Kt$). In an unchanged atmosphere of air (as for example in a tall crucible) oxygen is absorbed and the speed is controlled by its diffusion in the air. The insoluble solid oxides therefore play the part of protectors, and this can be profitably used to protect metal during melting and during casting by small additions of oxidisable elements such as Al, Si, P, etc.

On the other hand there is a sharp increase in the rate of oxidation when insoluble oxide becomes liquid, that is to say, when the invariant temperature of the two phase liquid oxide-metal system is exceeded as, for example, in the case of $Cu\text{-}CuO_2$ at 1,200 deg. C. This often supplies a value to the limit of superheating θ^s but, moreover, this limit can also result in a rapid increase in the rate of oxidation resulting from the exponential amount of the phenomenon in relation to the absolute temperature T ($\log W = -\frac{K}{T}$).

Knowledge of the absorption of gases is less advanced; if various investigators (Sieverts, Iwase, Lückemeyer, Haase, Schenck, etc.) have given solubility values in relation to temperature, the rates of absorption are scarcely known. Seemingly they ought to be in relation to the temperature to conform to the corresponding laws for oxidation, everything connected with it being profoundly influenced by state—atomic or molecular—of the gas.[15] It is in this manner that the presence of water vapour or ammonia is responsible for a rapid absorption of H and N by various metals (Al, Fe, etc.), and that, on the other hand, it is important, from the point of view of the rapidity of the absorption of gases, not to exceed certain temperatures, as, for example, 900 deg. C. for aluminium in the presence of hydrogen. There is once again, from this point of view, an upper limit θ_s for the margin of liquid superheating.

Thus, under the triple aspect of vaporisation, oxidation,[16] gas absorption, there is an upper limit to the value θ_s of the temperature reached in the liquid state, but this temperature is a function, not only of the metal, but also of all the melting conditions (see Part II), and even of the very conceptions of manufacture and use. It is, moreover, to show the effect of these multiple factors that the subject has taken so long developing. It should be understood it is necessary to take the lower value of the temperature corresponding to these diverse phenomena to evaluate θ_s, the upper limit of the admissible margin for liquid superheating. This margin can in the end be very narrow; as for instance with manganese, because of its liability to oxidise, it cannot be melted in air. Its margin of liquid superheating is therefore nil. Under these conditions it is necessary to work in a controlled atmosphere. Again, for calcium, there is only a time margin when melting *in vacuo*, or still better in argon.

Generally speaking, by modifying the atmosphere, the pressure, the shape of the furnace chamber and above all by separating the metal from its external surroundings by fluxes or coverings, the admissible temperature limit θ_s can be considerably influenced. It must not be forgotten, that so far only the case of "change," $\alpha > 0$, has had consideration. Yet there can be, as has been stated, meltings without change $\alpha = 0$ or even with refining $\alpha < 0$.

In any case, under normal foundry conditions (melting in air or in furnace gases and at atmospheric pressure), the margin of admissible superheating $\theta_s - \theta_f$ is very variable with certain metals, and zero as has been pointed out for some, yet the margin becomes very wide for others as in the case of tin. This margin can also be increased if a refining after melting and before casting is practised.

Refining after Melting

The examination of the refining of metals is beyond the scope of the subject. It is felt, however, desirable to recall that it is done by additions (deoxidants, oxidants or grain-refining), by the action of fluxes and agitation, by bubbling gas through it, by settling and decantation, etc., not to speak of prior treatments of degasification by melting under pressure, slow presolidification, rapid remelting, etc. They are cited for the purpose of recalling that it is possible so to act indirectly on the margin of admissible superheating.

PART IV.—MELTING CONDITIONS AND THE COMPOUNDING OF INDUSTRIAL ALLOYS

Definitions

Apart from rare exceptions, the industrial alloys in common use are mainly composed of one metal in a predominant proportion with respect to the other metals and elements making up the alloy, the proportion of this major metal being usually of the order of 50 per cent. and frequently even exceeding 90 per cent. It is this metal which moreover enables technical alloys to be classified and described as alloys of iron, copper, aluminium, etc. This metal may be regarded as the principal or basic metal of the alloy, the other constituent metals being the secondary components or added metals.

The additions may be distinguished under the following heads:—

(1) *Constitutional, i.e.*, those metals whose proportion present is usually included in the ordinary chemical analysis of the alloy, such as tin in the bronzes, silicon in Alpax, etc.

(2) *Compensatory, i.e.*, those components added to make up for any deficit in composition due to melting losses caused by volatilisation or by any other change of the components added in the shape of alloys to the charge, such as zinc in the brasses, phosphorus in the phosphor-bronzes, silicon in pig-irons, etc.

(3) *Refining, i.e.*, those components added to facilitate the elimination or the dilution of certain impurities, such as O, S, N, gas, etc. Examples of these are deoxidants, desulphurising agents, etc.

(4) *Protective, i.e.*, those components added to prevent undesirable changes during melting or later during pouring. Examples which have already been cited are, Ca and Zr with Mg, P in the case of Cu, etc.

(5) *Grain-refining, i.e.*, those components, such as Na for eutectic mixtures of Al and Si (Alpax). Such grain-refining additions may become necessary owing to the presence of any of the afore-

mentioned components, *e.g.*, the addition of Zr may cause a coarsening of the grain of Mg, which must then be refined again.

Aspects of the Problem

The problem under consideration has a double object:—(1) To determine the method of adding or introducing the different components of the alloy; and (2) to establish the order in which these additions must be made. The first point may be considered from two points of view, either (*a*) according to the nature of the elements added; or (*b*) according to their form and quantity.

(*a*) As regards the nature of the components added, there are two extreme cases to be considered in practice, either the charge is prepared from metals and other components in the form of virgin metals, or it is prepared by starting with an alloy, either in the form of scrap or ingots of alloys specially compounded for this purpose (standard alloys of given analysis). Between these two extremes, there is the general case which is the most common in practice and in which the charge is made up of partly virgin metal and partly of alloys already compounded. The first extreme is necessarily encountered in the initial manufacture of any alloy, and this case will therefore be discussed first.

(*b*) As regards the form and quantity of the components, there are two points of view which lead to opposite conclusions, according to the prevailing conditions: the rate of solution results in fragmentation with reduction in thickness and consequent increase in the exposed surfaces of the fragments, which is the general case where constituent elements are added, or changes due to atmospheric action increase with the surface and tend towards the formation of larger aggregates or agglomeration, which occurs with scrap, such as turnings, powdery material, strip and wire cuttings, or the inclusion [or bonding] in a cement or a molten metal, as with oxidisable additions.

Alternatives are presented here very similar to those encountered when considering the part played by agitation, whether mechanical as produced by rabbling or mixing, or electromagnetic as produced in induction furnaces. The latter offer advantages in arriving at a chemical and thermal homogeneity by preventing local superheating, and the liberation of the gases in a state of supersaturation, although there are also disadvantages in inhibiting the pouring off of the insoluble impurities (inclusions) and intensifying chemical interaction by multiplying the number of contacts with the enclosing medium, either the gaseous phase (atmosphere), the solid phase (walls of the crucible or container), or the liquid phase (molten fluxes, slag). It is frequently difficult to separate the effects of the three non-metallic phases on the metallic phase, for, as already pointed out, they react conjointly and continuously, the action of the lining being associated with that of the oxidising atmosphere while the reaction products contribute to the formation of the slag.

Properties and Factors Operating

Various factors and properties have to be considered in the melting process and the compounding of alloys; the principal of these are enumerated below, and these will be considered from the point of view of the components as well as from the standpoint of the final alloys:

(1) Relative proportions of the components present.
(2) Relative densities of the components present.
(3) Heats of mixing or combination.
(4) Fusibility (and miscibility).
(5) Volatility.
(6) Chemical changes and particularly oxidisability.
(7) Absorption of gas.
(8) Velocity of mutual solution.

(4)–(6): Defining the range of superheat of the liquid for both the components and the alloy.

Before reviewing the various possible or recommended methods of compounding according to the relative importance of these factors, the available data regarding these phenomena and properties must first be studied.

Relative Proportions and Densities of the Components

The proportions of the components are determined by the chemical composition sought, with an accuracy or tolerance depending on the type of alloy and its subsequent duty. The densities are also known, either in the solid state or in the liquid state, with an accuracy usually adequate for all practical purposes under consideration here. It may be stated that the difficulties encountered in the compounding of alloys increase with the magnitude of the differences in the quantitative proportions and densities of the metallic components, since these differences adversely affect the ease with which the requisite homogeneity is obtained in the molten state. Moreover, when these differences are very large, certain artifices, to which reference will be made later, must be adopted.

Heat of Mixing and Combination

It has already been stated that the total heat which must be applied to the charge, including the heat of fusion, is interesting as a guide to the fusion mechanism of the metals in special relation to the rate or duration of melting. In the present case, they have to be considered as chilling the liquid bath by the introduction of cold, or solid, metal. It may be asked whether

the heat liberated during the formation of the alloy is able to balance this cooling action, either (*a*) by the heat liberated by mixing, solution or combination, or (*b*) by the heat of reaction due to the occurrence of reduction processes.

As regards the quantities of heat evolved during mixing, the researches of Masuo Kawakami (1930)[16a] indicate that for the binary alloys which he investigated: (1) those which do not yield intermediate compounds until the liquidus have negative heats of mixing, *e.g.*, Pb-Cu, Al-Sn, Sn-Sb, etc., while (2) those forming intermetallic compounds up to the liquidus have a positive heat of reaction, indicating that these compounds are not decomposed by fusion, *e.g.*, Al-Cu, Sn-Mg, etc.; (3) certain alloys, such as Cu-Au and Ag-Au, on the other hand, produce no change in temperature and represent examples of ideal solution.

These results concerning the presence of definite compounds may be reconciled to the forms of the liquidus, which are in relation with the degree of dissociation of the definite compounds according to which the maximum of the liquidus in a state of true equilibrium with the definite compound is either low and flattened or steep and high (as with Ni-Al). In industrial alloys, compounds of the latter type rarely occur; they are, moreover, not to be looked upon as master alloys, for both the benefit of the fusibility and that due to the contribution of the heat of reaction which facilitates the formation of the alloy are lost; at the very most their use can be envisaged in certain cases for equilibrating the melting points of the master alloy added and of the basic metal.

These heats of formation, however, which are usually relatively low, are augmented by the heats of reaction, mainly the quantities of heat due to reduction; *e.g.*, on the addition of the reducing metals Al or P to molten metals or alloys susceptible to more or less oxidation, such as alloys of copper or steels. This may be used advantageously to increase the fluidity of the molten alloy.

Fusibility and Liquid Miscibility

Solidification curves are of great value, if not indispensable, for the scientific preparation of alloys, since they furnish precise and essential information regarding the miscibility in the liquid state and of the fusibility of binary and ternary alloys and sometimes even of quaternary alloys.

(*a*) *Liquid Miscibility.*—The curves indicate the limits of concentration and temperature, the gaps in the miscibility process, and hence the regions of liquid heterogeneity, *i.e.*, of the non-alloyed state, in which the liquid alloy is not stable, particularly if there is a marked difference between the densities of the two phases. Examples of this are alloys of Cu-Pb with a high content of Pb as well as Pb bronzes. These data are also valuable in the choice and the use of the master alloys, *i.e.*, the auxiliary alloys for the compounding of a required final alloy. It is possible to alloy an addition of a metal B non-miscible with a metal A by using master alloys of B with another metal C which is miscible with both A and B, *e.g.*, to alloy Pb which is non-miscible with Al, an alloy of Pb with Mg may be used. Conversely, to add a metal B to A which is not readily miscible with it, an intermediate alloy of B with a third metal C which is not miscible with A may be used, so that C finally separates out. An example of this is afforded by the small addition of a sodium deoxidising agent to molten steel through the medium of an alloy with Pb, which is non-miscible with Fe and more dense than the latter, so that it acts merely as the vehicle for the introduction of the sodium.

(*b*) *Fusibility.*—For each alloy composition, the curves give the lower limiting temperature θ_f of the melting range or of the liquid superheating, these temperatures being moreover the lower limit of the zone or region of the homogeneous liquid phase, *i.e.*, the liquidus, except in the gaps of non-miscibility, at the liquidus horizontal, where θ_f follows the contour bounding the heterogeneous liquid phase.

Very little general information can be given regarding the variation of θ_f in alloys, since the liquidus is very variable and differs from alloy to alloy. The more common relationships encountered in industrial alloys may, however, be conveniently summarised as follows:—

(I) Liquidus descending uniformly from the metal with the higher melting points, *e.g.*, Cu-Sn bronzes, Cu-Zn brasses, Sb-Sn anti-friction alloys.

(II) Liquidus with a low eutectic point, *e.g.*, Al-Si Alpax, Fe-C irons, Sn-Pb soft solders.

(III) Liquidus with one or more maxima, sometimes higher than the melting points of the constituent metals. *e.g.*, Mg-Sn, Na-Sn, Al-Ni.

These considerations of fusibility are fundamental to the compounding of alloys and indispensable in the choice and use of master alloys (introduction of additions of high melting-point, volatile, oxidisable, etc.); a volatile and oxidisable addition such as P can thus be added in the shape of alloys with different melting points, Sn-P or Cu-P, while a high melting point and oxidisable metal, such as Cr, can also be added as a ferro-alloy with a suitable melting point, owing to the presence of C or Si.

Volatibility

The boiling point or θ_e of binary alloys have been determined by Leitgabel. The

more general shape of the curves plotted shows a very sharp drop on one side of the metal to the highest θ_e and a slow increase on the other slope for the more volatile metal. It appears that the addition of a volatile element or metal (*e.g.*, P, Na, Zn, Cd) to a molten metal with a high melting point usually entails considerable losses of heat and it becomes necessary to reduce the temperature of the molten bath by the addition of other alloying elements or alloys in the combined state, or to use master alloys.

In exceptional cases, where reference is made to refining additions before dispersal, *e.g.*, deoxidation of steel with Na, Mg or Ca, certain artifices must be used to promote their rapid mixing with the bath by attaching to a rabble, or better still by enclosing them in a cartridge or other suitable receptacle, which will either melt in the bath or require withdrawing again, or by encasing them in refractory cement.

As these additions are of low density (0.97 to 1.7) they must be weighted by another element already a constituent of the alloy or one immiscible with the latter.

To add sodium (θ = 97 deg., d = 0.97) to molten steel (θ_f = 1,600 deg., d = 7), Glasunov[18] used cylindrical cartridges with the upper end perforated and covered with paraffin, and the lower end closed with Pb so as to obtain a mean density higher than that of the molten steel; before the cartridge is melted, the Na escapes through the holes, forming jets of vapour which penetrate the bath. Light, volatile or combustible additions can also be introduced into the molten metal in the form of a projectile.

Although there may be a marked difference in density and they may be volatile and oxidisable, some very fusible elements such as tin can be added in small quantities by means of cartridges or containers to very hot baths such as molten steel, since they melt instantaneously and tend to volatilise if remaining on the surface of the charge. Little information is available of the volatility of alloys which in certain cases reduce the margin of superheating far below θ_e, as already indicated.

Chemical Changes, Oxidation and Absorption of Gas

There are hardly any quantitative data regarding the oxidisability of alloys; but it may be recalled that oxidation is selective, *i.e.*, it takes place first with the more oxidisable components present which act as reducing agents of the other oxides produced, and secondly, the oxide of a metal has only a very weak solubility in the other molten metals, although these may dissolve a fair proportion of their own oxides.

It follows therefore that the most oxidisable elements and metals will provide a protection against oxidation if their oxides are solid at the temperature of the molten charge, whence the interest attaching to the initial fusion in air of the principal metal or of the alloy already formed, by the previous addition of small quantities of deoxidising agents.

The solubility of hydrogen in alloys has been investigated by Sieverts, his results indicating that the solubility in a metal (copper or palladium) can be considerably increased or reduced by alloying with other metals. These results, however, relate to only two metals and moreover there is little information available on the rate of absorption of gases which will permit the deduction of any laws or general hypotheses in respect of the compounding of alloys from the point of view of the variations in the limit of admissible superheating θ_s. All that may be said is that this latter factor is closely related to the most volatile and more oxidisable element present in the bath. What appears most certain is that the range of superheating to the greatest extent appears to correspond with the eutectic alloys.

Compounding of Alloys from Component Metals or Virgin Metals

Assume that A is the principal or basic metal and B one of the metals or elements which has to be added. Consultation of textbooks of foundry practice or inquiry from practical foundrymen as regards general instructions for the order in which the constituent elements or metals of an alloy should be added, brings to light the most contradictory advice; according to some authorities the component with the highest melting point should first be melted, others favour starting with the component having the lowest melting point. The only point on which there is more or less general agreement is that the components to be added last are those which are the most oxidisable and the most volatile.

In this state of affairs, metallurgists must accept as a starting point that principle which appears the most simple from a practical point of view: First melt the principal metal and then add the additions in the order of their melting points and with decreasing margin of superheating. Hence in compounding a bronze, a Cu-Sn alloy, rich in Cu, the copper should first be melted and the Sn then added; in making an anti-friction metal of Sn-Cu rich in Sn, the tin should be melted first and the Cu then added. This process may be termed "working with constant heating and solid additions," for the variations in the temperature of the bath are principally due to the chilling effect (excluding exothermic reactions) of the additions.

The question of the relative quantitative proportions of the metals can therefore be set aside

for the moment, and primary consideration given to the "admissible margin of superheating." An examination will be made of the principal cases and phenomena with this method of procedure in order to arrive at the essential modifications and corrections.

Phenomena Occurring on the Addition of a Solid Component B to the Molten Metal A

If the principal metal A melts at a temperature θ within the temperature range $\theta_{A^1} - \theta_A$ and a metal B is added with a melting-point range $\theta_{B^1} - \theta_B$ in such small quantity that the temperature θ is not substantially altered (which depends as already stated on the thermal properties of the two metals), and if B rapidly acquires the temperature of A, a distinction can be drawn between the following cases:—

I.—The thermal ranges of superheat of the liquid metals A and B have a common range of temperature; the ranges can hence be said to be concordant. Take the temperature θ in this common range, when the metal B will melt and diffuse through charge A. Two separate cases can be distinguished here: I*a*—where temperature θ is above the maximum of the liquidus of the fusion diagram of A-B. The solution of the added component B is determined by the rate of diffusion of the two molten metals, which as a rule is very high. In addition, mechanical stirring will cause a rapid equalisation of the relative concentrations and result in the production of an alloy of homogeneous composition. The manufacture of this alloy is not difficult and will serve as a type to which it is desirable to reduce every practical case of alloy manufacture. *Examples*: Alloying of bronze to lead (Cu-alloy with 30 per cent. Pb), alloys of Al with Mg, Sb, Zn and Sn, Cu-Ag alloys.

Where certain deoxidising agents are added, such as Al, to oxidised metals, such as Cu, the particles of molten Al may be coated with a film of Al_2O_3, which prevents proper diffusion; agitated stirring is then necessary with the addition of a flux for dissolving the Al skin.

I*b*.—*Temperature θ is lower than the maximum of the liquidus in the A-B diagram.* As before, B will melt and diffuse through A and produce within the liquid an intermetallic compound A_mB_n corresponding to the maximum of the liquidus. This compound, which can be decanted, is responsible for heterogeneity during tapping, the first castings or ingots having a different composition from those cast later.

Examples: Manufacture of a Pb-Na alloy (in practice, the reaction is sufficiently exothermic to cause the temperature of the charge to rise above the maximum of the liquidus; advantage may be taken of this by pouring at this point).

II—*Margin of Superheating of A is Lower at the Melting Point of B.* In this case, the temperature θ of the molten bath does not reach the melting point of B, which therefore does not melt and must be dissolved in A; the state of superheating of B has thus also an important influence. Three different cases must be considered here:—

II*a*—Metal B is enclosed by a film of oxide which is very adherent and completely isolates B from A; B then cannot dissolve A.

Example: Al added in solid ingots to a eutectic of Pb-Sn (refining of "claire de soudure"*). Even when added to the bath at 600 deg., the Al does not dissolve.

II*b*—The metal is enclosed by a film of oxide which is eventually penetrated by A. Solution of B in A at first zero gradually increases (see below). The permeability of the oxide increases with an elevation of temperature. It is the higher, the further removed the temperature is from the melting point of A. The mechanism of this penetration has not yet been studied.

Example: Solution of copper additions in tin (manufacture of anti-friction metal), solution of Fe additions in certain special solders. The solution of these additions is zero at low temperatures if the surface of the metal has not been broken. This case is encountered with refractory deoxidants such as Si; also the melting point of the addition must frequently be lowered when working with a master alloy. Moreover, flux dissolving the oxide should be added while agitating.

II*c*.—There is no coating of oxide or if present it has no retarding action (*examples:* solution of Pb and Sn, the manufacture of solders), or its action is destroyed (see case II*b* above).

Where the A-B diagram does not disclose any definite compounds, there is simple solution of B in A governed by the velocity of diffusion in the liquid of the atoms of B contained in the liquid film, saturated with B, of the alloy (A + B) surrounding B; solution is rapid and accelerated by increasing the temperature, and fragmentation of the materials increases the area of the exposed surfaces, and above all mechanical stirring accelerates diffusion within the molten mass.

Examples: Solution of Zn and Sn (manufacture of special tinning alloys), solution of high melting-point elements in industrial metals, even those melting at a high temperature such as Fe, or elements less fusible in metals melting at moderate temperatures such as Al (alloys of Al with Cr, Cu, Fe, Mn, Mo, Ni, Si, Ti). This case is necessarily found where the means available for melting the metals do not allow the melting-

* *Translator's Note.*—This is thought to be a special type of solder.

point of B to be reached, when the alloy obtained by pure diffusion is frequently not homogeneous, *e.g.*, to alloy O_s with Fe, the former being the least fusible of the Pt family (θ_f = 2,700 deg. C.), Fallot[19] obtained solution in superheated iron by means of an induction furnace and operating *in vacuo* found it necessary to remelt three times to ensure proper homogeneity of the alloy.

This is not an industrial process and the question arises as to whether metals and elements with very high melting points, such as W, Mo, Cr., etc., should only be alloyed by means of master alloys with lower melting points, compounded in the electric furnace and used for many years under the general classification of

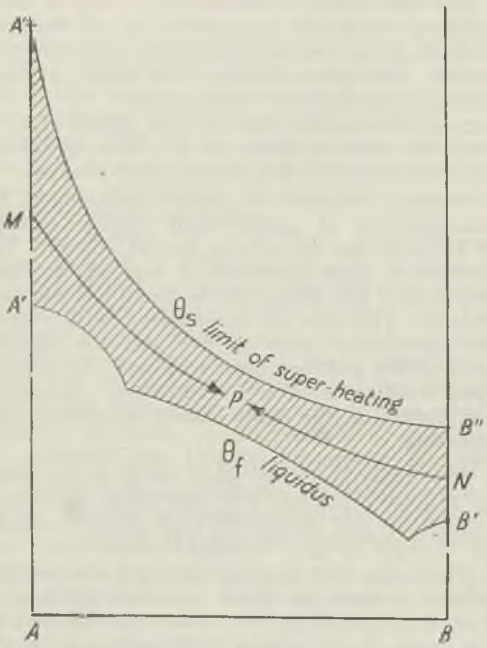

FIG. 1.—LIMIT OF SUPERHEATING = LIMITE DE SURCHAUFFE.

ferro-alloys. Where, however, these ferro-alloys are added to molten iron, at a temperature lower than that of molten steel, the melting point of these additions is further reduced by the incorporation of other elements; thus Si is added to Ni (θ_f = 1,260 deg. C. for 6 per cent. Si), to ferro-chrome (*e.g.*, 10 to 12 per cent. Si for 50 to 55 per cent. Cr), to ferro-molybdenum (*e.g.*, 10 per cent. Si for 40 to 45 per cent. Mo), to ferro-titanium and so on. Here again the state of granulation is of major importance from the point of view of the rates of solution and oxidation; the size of the grains must therefore be controlled[20] with each ferro-alloy if the additions are to be made in the ladle or in the tapping spout of the cupola (in the latter case, the grains must be distributed with a uniform velocity in all directions where they will agitate the metal by eddying, *e.g.*, at the mouth of the spout or where the stream of metal enters the ladle).

In these cases of more or less rapid solution, the differential density factor may enter, for if the density of B is much less than that of A, B will rise to the surface; lumps of B must then be enclosed in perforated containers, either of metal or refractory materials, such as graphite, according to the conditions ruling, and a handle of suitable length used to keep them beneath the surface of the molten bath.

In all cases, there is a tendency in favour of the compounding of master alloys formed by the addition element and the base metal and with a margin of superheating conforming with the latter so that the conditions obtained are as set out in case I above.

It should be noted that where the A-B diagram indicates the formation of a definite compound, the surface of B in contact with A will become covered with a film of the latter. The velocity of solution will then depend on the diffusion of the atoms of B with respect to A (or inversely) within this film of the solid compound. The solution of the addition is slow (Ni in Sn, Fe in Sn), at least when the temperature is raised above that of the melting point or the dissociation point of this compound (*e.g.*, addition of Sb in anti-friction alloys, solution which is very slow at 300 deg. becoming very rapid at 500 deg.). Solution can be accelerated in this case by using B in small lumps.

Summarising, it may be stated that the use of ferro-alloys is not essential in principle in cases Ia, Ib and IIc where no film liable to retard solution is formed, either in the form of a definite compound or as an oxide.

On the other hand, in case IIa, it is an advantage to use a master alloy above the melting point of B. *Example*: Refining of solders with Al, which is melted separately and alloyed with three times its weight of solder. The solder thus obtained will dissolve more quickly (for reasons of economy the temperature of the solder bath cannot as a whole be raised to the melting point of Al).

In cases IIa with slow solution (additions with high melting points), IIb and IIc (with the formation of a retarding coating), some change in the bath may take place, *i.e.*, reduction of θ_s by increasing the duration of the melting process; this may be avoided with heavy metals little susceptible to the absorption of gases, by the addition of protective fluxes. This will,

however, not apply to volatile additions, where θ_s is depressed in spite of the addition of fluxes and it is preferable to use a master alloy. *Example*: In making alloys of Cd and Ni, there is a considerable loss of Cd if the bath even when carefully covered is only 50 deg. above the melting point of Cd. The use of master alloys may also be favoured in the following case, which is derivable from case I.

III.—*Melting Point of A is above the Margin of Superheating of B.* This case arises where the addition B is either very volatile or very oxidisable; recourse can again be made to various artifices for introducing these additions, as already outlined above. Examples are the addition of P, Na, Zn, Mg, to the high melting-point metals Cu and Fe.

The component B may be melted within its margin of superheating, adding little by little to the molten metal A and[21] owing to the elevated temperature in such a way as to increase progressively both the concentration and the temperature, while remaining within the margin of superheating of the alloys in the diagram (elevation of temperature may be avoided by adding B in the solid state). The thermal curve of the operation is MP between θ_f and θ_s on the diagram. This variation in temperature is, however, not feasible in current foundry practice, but may be employed for corresponding master alloys, such as Al-Cu, P-Sn.

The same applies to the inverse process in which increasing amounts of the more fusible metal are added in the solid state to the higher melting-point metal when molten, so as to increase progressively the concentration by reducing the temperature and to remain within the margin of superheating in the diagram; the thermal curve of this operation is MP in the diagram, although this much easier method must also be considered.

Compounding Alloys from Previously-Prepared Alloys

In this case the charge is entirely made up of scrap and ingots already having the final composition sought. The only precaution to be taken is to reduce to a minimum the losses in oxidisable and volatile elements and to make up for any losses and chemical changes sustained,[22] either by: (1) Reduction to a minimum of the exposed surfaces, by previous briquetting or covering with cement; (2) employing a flux for fusion and protection which dissolves the oxides formed on the surface and prevents atmospheric attack, the more so in view of the high state of division of the materials (turnings, wire, thin sheets, etc.); additionally, there is the potential use of charcoal on surfaces, and (3) protective additions with deoxidising and compensating action.

The simplest case in foundry practice, which requires the least number of precautions and technical skill, is the melting of standard ingots, *i.e.*, of ingots specially prepared as regards composition and shape, reducing to a minimum the difficulties of processing. This is the limiting case of a master alloy extended to all alloys, instead of being restricted to the introduction of certain elements.

This initial ingotting represents a first solidification of the alloy, a solidification which can be carried out at will, instead of being dependent on actual casting operations in the foundry. It is thus possible to control the conditions of this solidification to effect degassing and with the minimum of segregation. The preparation of an ingot is thus frequently valuable from the point of view of soundness and final heterogeneity.

If the charge is partly made up of component metals and partly of alloys already formed, the latter should be considered as an element of the charge with a proportion, density, melting point and a margin of superheating all determined, and in consequence the considerations and rules enunciated above will apply here.

PART V.—SUMMARY AND CONCLUSIONS

I.—Compounding of Alloys in the Foundry

The two simplest cases permitting constant heating of the charge and dispensing with the need for a special atmosphere, with or without a flux, are as follows:—

(1) Remelting of alloy ingots with the required composition (standard alloy ingots).

(2) Preparation of alloys starting with metals and alloys with concordant ranges of melting or superheating. (It should be remembered that the use of a flux and the melting rate enable the margin of superheating to be considerably increased in this case.)

All cases can be reduced to one or other of these types or at least very close to either. This may be done either by (1) making initial ingots, or (2) by using master alloys chosen with margins of superheating in agreement with those of the other elements in the charge (metals or alloys). It appears that this method of interpretation actually only begs the question, since it is still necessary to compound alloys either as ingots of the required composition or as master alloys; this is actually what takes place. The difficulties of an alloy are related to a previous operation, which may be outside current manufacture, or again be carried out by specialists.

Recourse can usually be had, for the obtaining of master alloys, to all sorts of conditions of compounding, which are either unusable or too complicated for ordinary foundry practice. It is

beyond the scope of this Paper to enter deeply into the question of the manufacture of master alloys, and the subject has been confined to outlining some fundamental principles.

II.—Choice and Compounding of Master Alloys or Additive Alloys

The choice of the composition of a master alloy designed for incorporating an alloying element M is determined by the following considerations:

(1) A melting point close to that of the base metal or alloy and a margin of superheating comparable with it.

(2) Chemical homogeneity, *i.e.*, absence of segregation, demanding the use of eutectic alloys and pouring in thin seams.

(3) Proportion of M sufficient to reduce the proportion of the master alloy to be added.

(4) Adequate chemical stability.

(5) If possible having a composition in which the components are in simple proportions to each other ($\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, $\frac{1}{10}$), taking into consideration any subsequent losses to simplify and accelerate calculation.[23]

(6) Permit easy fragmentation for adjustment of the weight of material to be added to the charge. This may be done either by casting notched ingots or by getting samples capable of being split up by drilling or shearing or by previous breaking up to the required size, or by making fragile alloys which can be broken with a hammer (tending towards materials defined as compounds of a non-metallic character).

This may be done through the use of binary, ternary and more complex alloys formed by the element M, either with a base metal, or with other elements of the alloy, or even with additional elements which do not adversely affect the qualities of the final alloy.

In all cases, the diagrams form the starting point and provide the indispensable basis for the choice of the master alloys. The frequently important part played by certain impurities or elements, however, in respect of fusibility and solubility, such as carbon in the ferro-alloys, should also be kept in mind.

In one case, fusible phosphorus or refractory silicon is supplied to the foundry in the form of alloys with different melting points and with different base metals, *e.g.*, P with Sn, Zn, Cu, Fe, etc., and Si with Al, Cu, Ni or Fe.

Compounding of Master Alloys

For this purpose all kinds of processes can be employed for compounding the alloys which may prove too complex for ordinary foundry use or even quite useless in foundries. The margin of superheating must be considerably extended by using specific atmospheres, or melting *in vacuo*, etc., which enable the temperatures and duration of superheating to be increased, thus promoting the rate of solution.

Various methods of compounding may be used: Mixing metals already in the liquid state, melting at temperatures which are varied during compounding, *e.g.*, in the electric-arc furnace, the resistance furnace, the induction furnace, for compounding, for reduction with C, Si, and master alloys containing high melting-point elements (Si, Cr, Ti, Zr), or even volatile constituents (ferro-phosphorus); by cementation to avoid impurities, as in a cemented bar as used to be used for crucible steels[24]; by the compression and sintering of powders; by electrolysis in the molten state (example of borides of alkaline metals, alkaline earths of normal or special refractory composition) or in the aqueous state; by aluminothermy and silico-thermy, etc.; by the reduction of salts such as chlorides, metals such as Al (preparation of master alloys of Al with Co, Mo, Ti).[25] More generally all chemical processes for the preparation of elements can be used with advantage. The use of these master alloys has been widely developed in steel-foundry practice and in non-ferrous foundries handling Cu, Ni and Al.

In general, the practical rule followed in the majority of these various types of foundries regarding the order of adding the components to the bath is as follows:—(1) Principal metal or base alloy; (2) master alloys; and (3) before pouring, volatile elements or final additions (except where the interaction of the latter must be completed to permit quiescent pouring).

To complete this outline of the principles for compounding alloys in foundry practice, reference should also be made to the choice and use of melting fluxes and slags, but this subject merits separate discussion on broad lines and for this reason will not be discussed here.

Conclusion

In this study of the general principles applicable to the compounding of alloys, an attempt has been made to regard the whole subject from its various aspects and to enumerate the different factors and conditions entering, without losing sight of the incompleteness of the investigation and the extreme generalisations which have been made to effect simplicity; the present Paper does not advance a doctrinaire theory, but is only a tentative attempt to arrive at a systematisation, incomplete as well as imperfect, in order to promote observations, comparisons and criticisms as well as a discussion which it is hoped will lead to a more satisfactory analysis and synthesis of this important problem on more concrete and more concise lines.

REFERENCES.

1 Lessons by R. Lemoine on the compounding of copper alloys, and by P. Bastien on the compounding of aluminium alloys. Worthwhile reference has been made to M. Dannenmuller on compounding antifriction alloys.

2 "Purity" should perhaps include elements not usually analysed, such as gases. Gases may be more abundant in certain types or under certain conditions of compounding. For example, the gas content of aluminium depends on the electrolysing conditions.

3 The classification of scrap has been well set out for aluminium alloys, both from the mechanical and physical aspects, by Bosshard, and rules for admissible and inadmissible mixes have been formulated by Irmann. Their results are worth studying and amplifying.

4 See Herenguel, Lille Thesis, 1936, p. 10.

5 Under certain conditions, charcoal ash can react with the metal. For instance, in lead baths, it forms silicates from its ash.

6 See W. Kroll, Zeit. Elektrochem., Vol. XLII, 873, 1936.

7 Keeping aluminium in a stand-by furnace before casting, formerly carried out, should have resulted in a decantation, not of the alumina, as would be thought (an illusory decantation because of too small a difference in density), but of gas inclusions.

8 Everything written in connection with furnace chambers naturally applies to all solid materials in contact with molten alloys, such as those used for stirring or for the introduction of materials forming the charge.

8a Data upon the attack of refractory-lined furnace chambers by metal, oxides and molten salts are to be found in the research work of R. Winzer (Angewandte Chemie, 1932).

8b The action of silicon carbide on the metallic oxides of Al, Ca, Co, Cu, Cr, Fe, Mg, Mo, Mn, Ni, Ti, W has been dealt with by L. Baraduc-Muller (Rev. Met., VII, p. 683, 1910).

9 Résumés are to be found in the Appendices to the Metallographic Course of the French Foundry School, pages 1 to 5, 1936 edition.

10 Zelt. an. allg. Chemie, **94**, 1 and 24 (1926); **122**, 51 (1922).

11 Journ. Chim. Phys., (1903), p. 289, 296, 391; Bull. Chim. Soc. roumaine Sci., XXVI, Dec., 1923.

12 In this connection it is germane to point out that the change, everything being equal and for furnace chambers geometrically the same, decreases with the mass of metal to be melted, since it increases with the surface S, which should be in relationship with the mass unit M and that the ratio $\frac{S}{M}$ decreases as one of the linear dimensions, depth or width of the liquid bath. Also, unless special precautions are taken, there is no advantage to be gained from laboratory meltings using small masses for the study of alloys.

13 It is to be understood that no regard is paid to the contamination resulting from the introduction into the bath of foreign substances mechanically entrained, such as metallic powders, oxides, slags, sands, which result from carelessness.

14 Fundamental importance of *mise au mille* in foundry practice. Bull. A.T.F., XII, p. 2, Jan.-Feb., 1938.

15 As a natural consequence for the melting of metals prone to the absorption of gas, there is a series of practical precautions: Melting as rapidly as possible; thus charge the materials into the furnace and the furnace chamber as hot as possible; avoid reducing atmospheres in pan furnaces; in crucible practice avoid dampness in the fuel, atmosphere or tools; reduce the time of contact with the atmosphere whenever dealing with liquid metals.

16 For some metals, sulphurisation can be added.

16a Reference should also be made to the thermo-chemical researches on the direct determination of the heats of formation of binary and ternary alloys of Co-Al, Co-Sb, Co-Si, Co-Sn, Cu-Al Cu-Sn, Cu-Zn, Fe-Al, Fe-Sb, Ni-Al, Ni-Sb, Ni-Sn, Sb-Zn, Fe-Ni-Al, Fe-Co-Al, Cu-Ni-Al, Fe-Al-Si, by Fr. Koerber, W. Oelsen, W. Midde, and H. Lichtenberg (Mitt. K.W.I., vol. xix, No. 1, pp. 1–26; No. II, pp. 13–159; No. XV, pp. 209–219).

17 Sieden von Metallen und Legierungen bei Atmosphärendruck. Zelt. f. anorg. u. allg. Chemie, 202, p. 305, (1931).

18 R.U.M., 8th Series, IV, October, 1930.

19 Annales de Physique, 2ème Série, vol. 10, p. 312, October, 1938.

20 Cf. P. F. Viandon. L'emploi des ferro-alliages en fonderie. Bull. Assoc. Techn. Fonderie, X, p. 326, Sept., 1936.

21 Previous oxidation of the metal A may take place when B is a reducing agent, such as Al, in order to prevent violent exothermic reactions.

22 We shall not here recall the considerations advanced regarding the classification of scrap referred to previously.

23 Thus a proportion of 50/50 is used for master alloys of Al-Fe, Al-Cu, Cu-Mg, Cu-Ni, and 75/25 for Al-Ti, Cu-Si.

24 It is possible to extrapolate for high melting-point metals with volatile chlorides or halides (Si, Mo, Ti).

25 Certain chlorides and fluorides can in fact be used directly for introducing the elements to the bath, such as Ti to a bath of an Al alloy.

DISCUSSION

Professor Portevin, introducing his Paper, said that the work discussed therein arose from the French proposal at the Warsaw Congress to study the compounding of alloys. Being a Professor, he had felt it his duty as a student of the subject to collect and collate all available knowledge. The Paper was, however, the first review of the subject and was necessarily incomplete. He hoped that discussion might enable him to improve on his methods and results. The Paper, he said, was perhaps somewhat doctrinaire and absolute and he asked particularly that those who had practical experience of foundry work would give him the benefit of their criticisms, which would help his students and himself to modify and improve upon the results already obtained.

Professor E. Piwowarsky (Germany), in thanking Professor Portevin for an exceedingly valuable report, said that the materials covered therein were perhaps the most important of all which were before industry at the present time. When using metals, it was necessary to ensure that they were melted properly and that the correct after-treatment was carried out; all the various operations must be subject to close control, and that control must be exercised by someone who combined industrial knowledge of practical conditions with a scientific metallurgical background, such as Professor Portevin had supplied. Speaking metaphorically, he said it was a question nowadays not merely of making bricks, but of building the bricks into a wall by means of a mortar which was represented by the kind of knowledge that Professor Portevin had brought forward. Only in that way could the requirements of modern conditions be fulfilled.

The Chairman (Major Miles) highly commended the logical way in which the Paper had been presented, particularly as it involved so many practical details.

Preventing Sulphur Pick-Up

Mr. R. Chavy (France) pointed out that alloys of high nickel content absorbed sulphur gases very easily, and inasmuch as very high sulphur content oils were now being used in melting furnaces in France, some difficulties were encountered due to some of the castings produced being

very brittle. In order to overcome that difficulty, some silicon was added at the beginning of the melting to reduce the sulphur pick-up by the metal, and as a result much better castings were produced. It would be preferable to add the silicon at the end of the melt, but it was done at the beginning to protect the bath against the atmosphere.

Professor Portevin's Reply

PROFESSOR PORTEVIN also commented that the example given by Mr. Chavy was one in which an addition was made at the beginning of the fusion; it is an example of "protective" addition against alterations due to the atmosphere; it is consequently different from the case of final deoxidising or desulphurising additions.

Paper No. 678

Control of the Solidification of Castings by Calculation*

By N. CHVORINOV, Met. Eng.

The mechanical properties of a sound cast steel compare favourably with those of a forged steel. If steel castings are to be placed on the same plane as forged steel, then the first condition to be considered is their soundness. From the point of view of service stresses the fatigue limit is often a deciding factor. According to Moore[1] the ratio of the endurance limit to the tensile strength of cast steels varies from 0.4 to 0.5, which corresponds pretty well with the same ratio for forged or rolled steel, equal on an average to 0.47. From the designer's point of view, a cast steel is an inferior material as compared to a forged steel, first because of the lower specified values, and secondly because of a possible occurrence of unobserved flaws and unsoundness.

In Fig. 1 are given the mechanical properties of two steel castings across their section. The influence of microscopic unsoundness, caused no doubt by freezing conditions, is manifested in the fluctuation of the elongation and reduction of area values. The highest values are always obtained in the outer layer. In the process of solidification it is the feeding that is chiefly responsible for the soundness of a cast metal. On the other hand, feeding conditions depend also on the character of the crystal growth. Other factors beside the character of crystallisation also influence the feeding process. Capillarity, fluidity of liquid metal, gas evolution, pressure conditions, etc., all play some part in the process of feeding and the resulting soundness.

Variables Influencing Crystallisation

No quantitative laws have so far been defined to cover the phenomena of primary crystallisation of metals. The size, form and number of crystals are governed not only by the rate of cooling but also by the temperature gradient, by preferential crystallisation along crystallographic axes, by chemical composition, by purity of metal and even by gravity. As an illustration, a sulphur print of a horizontally-cast cylinder 400 mm. (16 in.) in diameter is reproduced in Fig. 2. The top portion exhibits pronounced columnar dendritic structure whereas the lower part, which solidified under the same temperature conditions, exhibits a fine-grained primary structure. Two long crystals are seen in the upper half with distinctly curved main axes. These two crystals were bent obviously due to the gravity effect of specifically heavier solid crystals in the liquid medium. The gravity effect manifests itself on the same sulphur print in a fine-grained primary structure of the lower portion. Evidently small

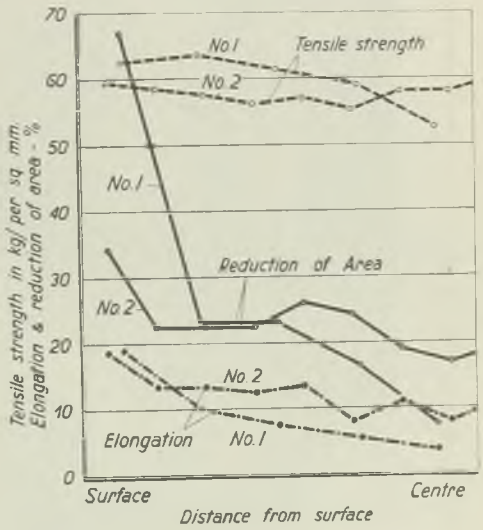

Fig. 1.—Variation of Mechanical Properties of Steel Castings from Surface to Centre of Section.

undeveloped dendrites fell down from the upper portion, leaving there only well-rooted crystals which gave a dendritic structure of long hanging crystals.

Progressive Solidification

From a practical point of view, the complicated relationships of different crystallisation phenomena are of minor importance when a casting first solidifies fully in the portion remotest from the feeding head and the solidification progresses towards the head. The concep-

* Presented on behalf of the Ceskoslovensky Odborny Spolek Slevarensky.

tion of progressive solidification was defined by Batty[2] and Briggs[3] as directional solidification. Though solidification is the main physical process of casting, it did not receive until recently the full attention of research it deserves. In 1936, however, Briggs and Gezelius[4] presented in their study on the rate of skin formation the first quantitive research on the mechanism of solidification in sand castings. Their investigation discloses very valuable quantitive information and registers a distinct advance in the knowledge of the freezing process.

The present author must point out, however, that some statements, and the method of determination of the rate of skin formation itself, can be criticised. In his opinion, the rate of skin formation as observed with bleeding castings is greater than the amount of metal actually solidified, *i.e.*, molten metal is retained by capillarity and surface tension between the network of dendrites up to as much as 20 to 30 per cent. of the supposedly solid skin. This can be proved quite definitely, both mathematically and from results of experiments carried out by the author

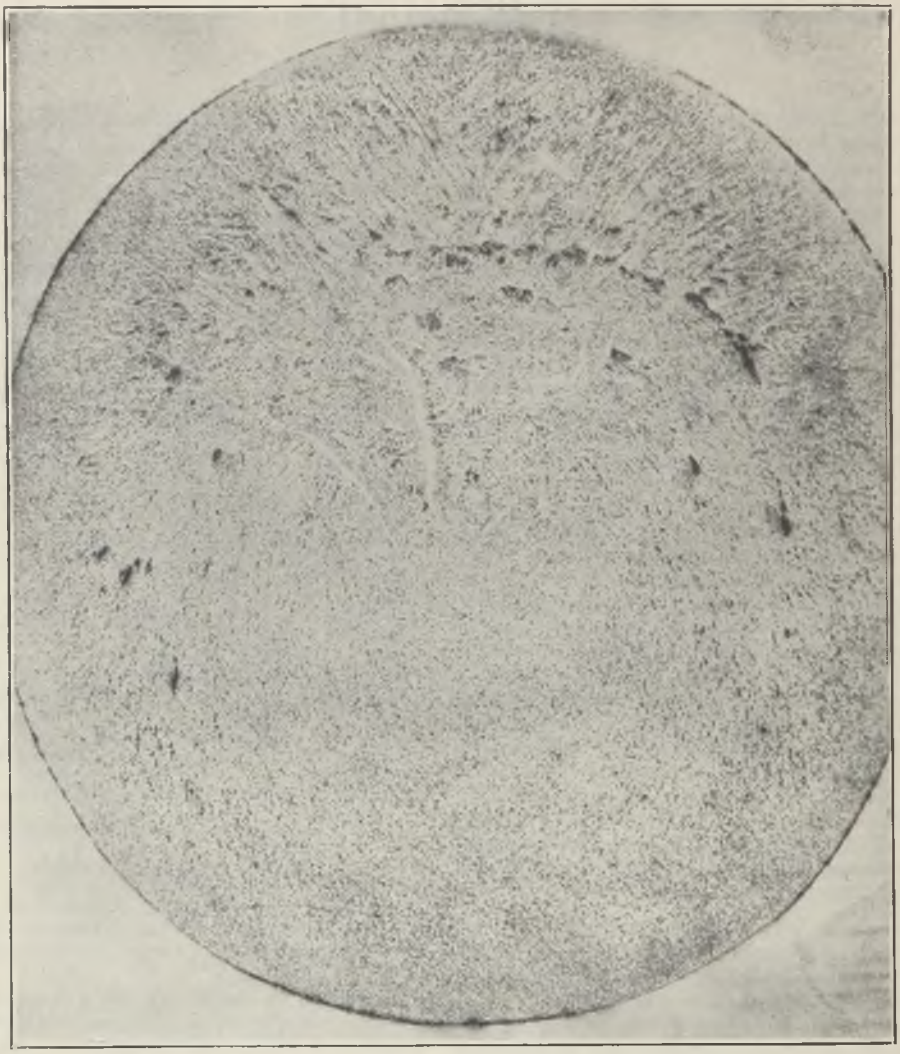

Fig. 2.—Sulphur Print of Horizontally-Cast Cylinder, 400 mm. (16 in.) dia.

as well as from the results of Briggs and Gezelius themselves. The author hopes to supplement and correct the results of these workers in a later publication.

How Castings Solidify

For the sake of illustrating the actual conditions of solidification of castings, some experimental results are given in Fig. 3. In the lower diagram the temperatures of a sand-cast plate during solidification are given for different time intervals after casting and for various distances starting from the surface. Special arrangement of the thermocouples was necessary to obtain a true temperature, since the currently-used type of thermocouple with parallel wires and a joint at the end cannot give correct temperature unless a certain length of the tube is heated to the same temperature. With the arrangement used the error was probably less than ± 5 deg. C.

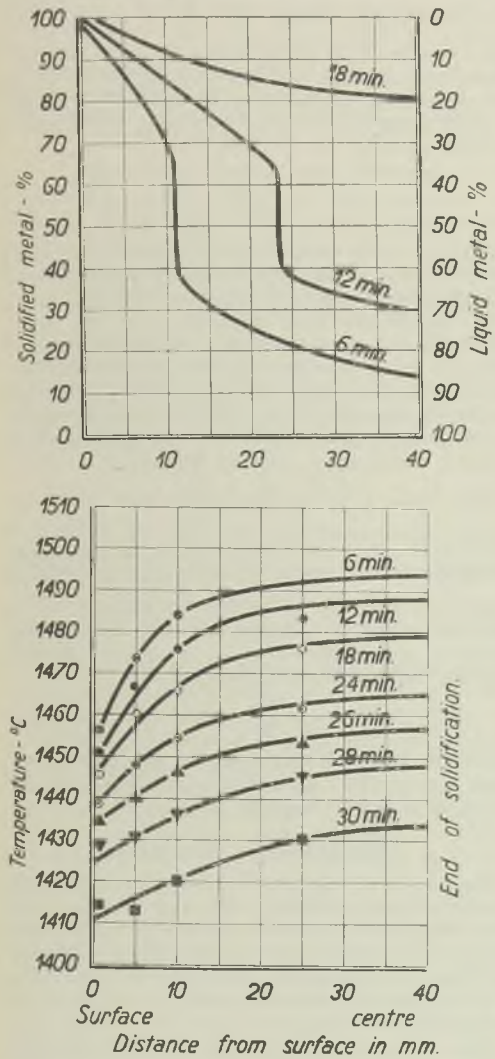

Fig. 3.—Top: Distribution of Solidified Metal in Cross-Section of Sand-Cast Plate related to Time Intervals after Casting. Bottom: Temperatures during Solidification at Various Time Intervals after Casting and at Varying Distances from Surface.

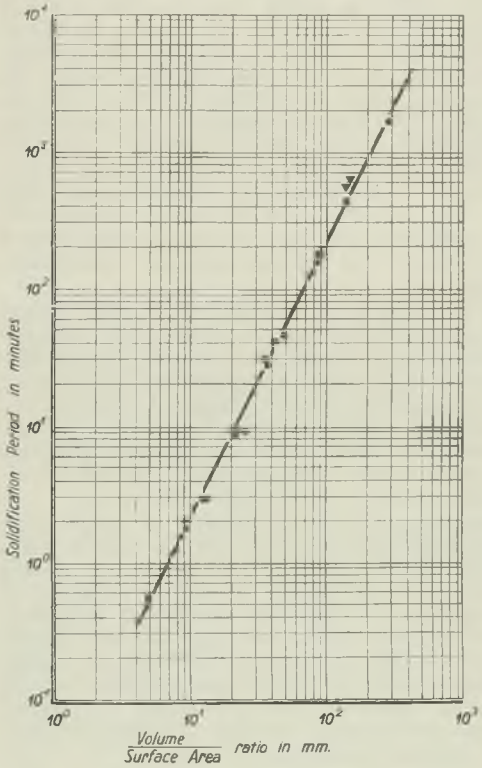

Fig. 4.—Solidification Period related to Ratio of Volume to Surface Area.

It will be seen from Fig. 3 that the surface temperature remains approximately constant during the whole period of solidification. The temperature gradient $\frac{dT}{dx}$ at the mould-metal interface for any time during the solidification period gives the rate of heat loss, which is in perfect accord with the parabolic law of heat diffusion. The deviation of temperature-gradient curves from the theoretical shape is in accord with the actual solidification range of a

steel with 0.24 per cent. of carbon which was used in this experiment. The distribution of solidified metal in the cross-section is given in the upper part of Fig. 3 for corresponding time intervals. The ratio of solid and liquid phases is calculated from the iron-carbon equilibrium diagram.

A number of observations of the temperature at the mould-metal interface, carried out by means of thinly-isolated thermocouples arranged to give true temperature, has shown that the average surface temperature of steel castings irrespective of their size varies within the range 1,470 to 1,420 deg. C. and remains fairly constant during the whole period of solidification. Only at the very beginning—depending on the casting temperature and the amount of metal flow during casting—it may be higher. The average temperature at the surface of castings, as has been theoretically calculated by the author for the average solidification temperature of 1,486 deg. C., must be 1,457 deg. C. The actually observed average temperature of 1,450 to 1,460 deg. C. is in perfect accord with theory and can be considered as definitely correct.

The problem of cooling with a simultaneous evolution of the heat of fusion had been investigated by mathematicians[5] and applied during recent years to the problem of solidification of steel ingots by S. Saito, A. Feilds[6], N. Lightfoot[7] and C. Schwarz.[8] These investigations have shown that the freezing of metal in ingot moulds can be treated mathematically under certain simplifying assumptions. An accurate mathematical solution of simple form was found only for a semi-infinite mass of metal or for a plate of finite thickness if the casting temperature is equal to the temperature of solidification. A general solution of this problem in simple form for ingots of finite dimensions has not been found. C. Schwarz treated separate cases of round ingots using a mathematical method of heat-source functions. Numerical solution requires, according to him, an immense amount of calculation.

Mathematical Relationship with Ingots

The problem of the solidification of sand castings is mathematically the same as the problem referred to in the case of ingots. In practice, however, because of a small temperature differential and the absence of surface gap, it is really quite different. The mathematical solution of the progress of solidification of a semi-infinite mass of metal is given by the formula

$$x = M\sqrt{t} \quad .. \quad .. \quad \text{(i)}$$

where x represents the thickness of solidified metal

t the time after casting,

and M is the solidification constant that must be found from an equation of solidification.

For plates of finite thickness the given solution cannot be applied unless the casting temperature equals that of solidification, which is practically impossible. Yet if M be considered as a function of other variables, then for certain cases M can be used as a constant. The author has found that for $x = \frac{s}{2}$, *i.e.*, for the end of solidification, the same relationship exists for plates of various thicknesses for any superheat of metal. This relationship for a certain metal of definite casting temperature is expressed by the formula:—

$$t = \frac{\left(\frac{s}{2}\right)^2}{M^2} \quad .. \quad .. \quad .. \quad \text{(ii)}$$

where t is the solidification period, *i.e.*, the period from filling the mould to the end of solidification of the last portions of metal,

s is the thickness of plate

and M is the solidification constant which is obtained by a modified solution of the equation of solidification, *e.g.*, its value differs from the normally calculated M. The value of M represents in formula (ii) half the thickness of such a plate, which takes 1 hr. to solidify.

The value $\frac{s}{2}$ of an infinitely large plate expresses simultaneously the ratio of volume to surface area. If in the formula (ii) $\frac{s}{2}$ is substituted for the ratio of volume to surface area of castings of finite dimensions, the relationship remains practically true. A more general formula can be therefore written:

$$t = \frac{R^2}{M^2} \quad .. \quad .. \quad .. \quad \text{(iii)}$$

where R is the given ratio of volume to surface area. (The mathematical solution of the constant M is here omitted.)

Establishing a Constant

For steels of the usual chemical compositions (plain carbon and alloy steels) and average pouring temperature cast in dried moulds at room temperature, the value of the constant M was calculated by the author to be equal to 0.053 m., if R is expressed in metres, or M = 2.09 in. if R is expressed in inches.

The value of M calculated from the heat balance between metal and mould, both theoretically and as determined by actual measurements of mould temperatures during solidification, is exactly the same as that recorded by the solution of the equation of solidification. The theory of heat diffusion is likewise fully corroborated by exact measurements of mould temperatures during the solidification period.

In Fig. 4 the line representing the above relationship (iii) is drawn in logarithmic scale. The values of freezing periods actually found for different steel castings, mostly of simple geometrical form, are plotted in the same diagram as points and correlate with the theoretical values. The practically ascertained values of the solidification period embrace the whole range of castings as regards both shape and size, from a 10 mm. thick plate up to a massive casting weighing 65 tons. (Two points from the investigation of Briggs and Gezelius are also included.) The range of the solidification periods observed extends thus from less than 1 min. up to 27 hrs.

Application to Intricate Castings

For complicated castings with sections of changing thickness, the mutual influence of differently proportioned sections has to be considered since such castings are of normal occurrence. In such cases, the following relationship was found: (*a*) the solidification period of the thinnest section of a casting is practically independent of the size of other sections; (*b*) a section adjoining a thinner one is affected by the latter. To account for this influence the following correction of the size ratio R is necessary: corrected ratio

$$R = R\left(1 - \frac{R - R_0}{L}\right) \quad \ldots \quad \text{(iv)}$$

where R is the size ratio of volume to surface area or of cross-sectional area to enveloping circumference of the section to be corrected.

R_0 is the size ratio of the thinner adjoining section.

L is the distance between the central points of the two sections under consideration. For sections with continuously changing thickness, L is the distance between the thinnest section and the cross-section in question.

The solidification period of any portion of a casting is found from formula (iii) by substituting for actual R the corrected value according to formula (iv). The formula affords a means for correcting the solidification periods in different portions of one casting that influence each other and allows therefore the previously deduced relationship for castings of simple geometrical forms to be applied for irregularly shaped castings of various sizes. Direct measurements have confirmed the practical validity of formula (iv). The mutual influence of differently proportioned sections of a casting is not so pronounced and can be often neglected.

At the places of abrupt changes of thickness or shape, *e.g.*, at junctions, angles are formed. Such angles are very insufficiently cooled, and therefore the full cooling capacity of the mould in such locations cannot be included in the calculation. For such a junction an imaginary one must be taken for which the ratio of volume to surface holds true. Such a junction is one with a fillet of a radius equal to the thickness of the thinner section. By means of such assumptions the formulæ detailed above can be successfully applied to any castings.

Application to Cores

So far as the incidence of cores is concerned, the problem has not been tackled. Two extremes can be provisionally set as guiding principles. Cores of a thickness over four times the thickness of the cast sections which surround them may be considered in the same manner as moulds, their cooling capacity being fully adequate so far as solidification is concerned. Cores of a thickness under the size of the surrounding sections must be considered as exerting a diminished cooling capacity. With such cores the surface layer of metal may not solidify fully until the end of the solidification period, so that some defects may possibly arise.

Extended Applications of Mathematical Treatment

The numerical evaluation of the solidification constant from the equation of solidification involves considerable labour, and is not sufficiently practical if M (the solidification constant) is to be calculated for different metals and for different thermal characteristics of moulds. An approximate solution can be found from the following formula:—

$$M = 1 \cdot 158 \frac{T \cdot b}{Q \cdot s} \,* \quad \ldots \quad \ldots \quad \text{(v)}$$

where M is the solidification constant to be found; T is (for first approximation) solidification temperature of metal; b is the heat diffusivity coefficient of the mould equal to $\sqrt{K \cdot c \cdot s}$ (where K is the heat conductivity, c the specific heat and s the volume weight of mould); Q is the heat content of the metal evolved on solidification (for the first approximation the sum of the heat of fusion and the heat content above melting point); s is the specific gravity of the metal at the temperature just after solidification, and the numerical value 1.158 represents the evaluation of the function

$$\Phi = \int^{\infty} \left\{1 - G\left(\frac{-x^2}{2}\right)\right\} dx$$

where G is the error of the function integral.

If an accurate value of M be desired, it can be calculated from formula (v), provided that, for the first approximate value of M, the temperature gradient is found and the values of T and Q are corrected for it. For mould materials with the values of b greater than 35, this is necessary, as the error rapidly increases for

* Dimensional units: metres, calories, kilograms and hours.

greater values of b. For high values of b two or more corrections may be necessary if an accurate value of M be required.

Formula (v), besides being very simple, discloses the meaning of the heat-diffusivity coefficient b. It shows that the solidification constant, *i.e.*, the amount of metal solidified after a certain time, varies directly with the heat-diffusivity coefficient of a mould, and thus a quantitive relationship is found between the rate of solidification and the thermal properties of the mould material.

It has been shown by different metallurgists that a sound casting is produced when the condition of what is termed by Batty and Briggs as directional solidification is attained. Batty attains this by bottom-pouring a casting with heavier section at the bottom and reversing it after casting. It is known a plate of an equal thickness cannot be cast fully sound if bottom-poured, microscopical cavities resulting in the inner portion. If, however, the cooling capacity of the mould is progressively increased towards the bottom, the condition of directional solidification is attained and a sound plate results.

Controlled directional solidification can obviously be attained if the thermal properties of a mould are suitably changed. For a given casting the required thermal properties can be calculated from formulæ (iii), (iv) and (v).

Application to Practice

The possibility of controlled directional solidification depends naturally on the available practical means, *i.e.*, on the possibility of varying the cooling capacity of a mould in its different portions. The first problem is therefore to seek materials with higher cooling capacity, *i.e.*, with higher coefficient of heat diffusion, that may be used in moulding. Such materials must fulfil the following requirements:—

(*a*) Must be adequately refractory for conditions prevailing during the casting and solidification of a casting.

(*b*) Should not produce casting difficulties, *e.g.*, should not chill too vigorously during the pouring and should not spall when suddenly heated by contact with molten metal.

(*c*) Should be easily produced as parts of a mould, preferably by moulding methods.

(*d*) Should not present difficulties for cleaning the castings and should not contaminate the sand to any perceptible degree, if full separation were not practicable.

The thermal properties of refractory materials alter with temperature. In Table I data on thermal properties of chamotte and magnesite bricks are given to illustrate this influence. Average data from literature are compiled; it should be noted, however, that data on the heat conductivity of magnesite brick differ widely.

TABLE I.—*Thermal Properties of Chamotte and Magnesite Brick.*

	Temp. Deg. C.	Heat conductivity. Cal. / m./deg. C.	Specific heat.	Volume weight. Kg. / cub. m.	Coeff. of heat diffusivity.
Chamotte	20	0.7	0.20		15.9
	200	0.78	0.21		17.2
	400	0.87	0.24		19.4
	600	0.96	0.28	1,800	22.0
	800	1.06	0.30		23·9
	1,000	1.15	0.36		27.3
	1,200	1.25	—		—
Magnesite brick ..	20	4.0	0.20		45.7
	200	4.0	0.24		50.0
	400	3.8	0.26		50.7
	600	3.6	0.27	2,600	50.3
	800	3.2	0.25		45.6
	1,000	2.9	0.25		43.3
	1,200	2.6	0.25		41.2

Heat-Diffusivity Constants

It will be seen from Table I that the heat-diffusivity coefficient varies considerably with temperature. The effective value that interests us can be ascertained only by experiment. Such an effective value is really a composite one, but roughly it may correspond to some value from about 700 to 1,200 deg. C.

The thermal properties of some refractory materials and steel are given in Table II for comparison with the effective values of an average chamotte moulding sand.

Direct Chilling Means

From Table II it will be seen that both magnesite brick and silicon-carbide have great cooling

capacity compared with normal moulding sand. Steel (or iron) used as a chill has of course the greatest cooling effect. Iron or metal chills for the cooling of such portions as otherwise take a longer time to solidify and produce internal unsoundness or show inclination to tear are currently used. The use of chills to attain directional solidification has been recommended. The use of chills in a steel foundry is generally more limited than in non-ferrous and grey-iron foundries for the obvious reason that iron chills unless massive cannot be often used because of the high temperature of steel. Massive chills produce rather too vigorous an effect and may give rise to surface defects. On the other hand, small chills are easily heated throughout during the pouring and lose a greater part of their cooling capacity. Likewise they are prone to give trouble by becoming welded to the casting. The use of iron or steel chills on a quantitative basis requires a study of heat balance, both the thickness ratio and the filling time being considered. The foregoing disadvantages of metal chills lead to a search for other materials and methods to supplement or replace them.

From Table II it appears that magnesite brick presents a very attractive characteristic, on account of its cooling capacity being 2 to 2.5 times greater than that of an average moulding sand. Compared with steel or iron, magnesite has not such an initial chilling effect and can consequently be used for chilling much larger areas than is practicable with iron chills without the danger of surface casting defects. Magnesite used at re-entrant angles exactly fulfils the cooling conditions required to attain the same solidification period in junctions as in the adjoining sections. The possibility of using magnesite bricks has been confirmed with distinct success. The cooling ratio found experimentally with the grade of magnesite used was equal to about 2, *i.e.*, a double cooling capacity as compared with a moulding sand.

The behaviour of magnesite bricks was found to be excellent. Castings of over 20 tons weight were cast with large areas built in magnesite bricks without the least deleterious results, the desired effect on solidification being fully attained. As an alternative to burnt magnesite bricks, crushed magnesite may be used with a suitable bonding material. This gives a cheaper means of controlled solidification when the importance of the castings warrants it. Another material that would probably lend itself to the same purpose is silicon-carbide. There are silicon-carbide plastic materials used for lining and patching crucible furnaces in non-ferrous foundries. Similar materials could be worked out for use as chilling media of definite thermal properties.

Semi-Metallic Chills

A further possibility is the use of a mixture of steel turnings (known to be used) or granulated steel with suitable bonding material. Mixtures of over 50 per cent. of steel must be considered, since a mixture of equal parts of steel and sand can be roughly estimated to give the coefficient of heat diffusivity of only about 22.

TABLE II.—*Roughly-estimated Effective Thermal Properties of Materials if Used as Moulds.*

	Heat conductivity. $\frac{\text{Cal.}}{\text{m./deg. C.}}$ K	Specific heat. c	Volume weight or specific gravity. s	Temp. diffusivity coeff. $a = \frac{K}{c.s}$	Heat diffusivity coeff. $b = \sqrt{K.c.s.}$
Steel	25.0	0.15	7,700	0.022	170.0
Moulding sand for steel castings ..	0.65	0.26	1,730	0.00145	17.1
Chamotte brick ..	1.10	0.26	1.800	0.00235	22.7
Magnesite brick ..	3.0	0.25	2,700	0.00445	45.0
Silicon-carbide—					
Solid	12.0	0.26	2.200	0.021	82.8
Bonded with clay	3.0	0.26	2,000	0.0058	39.0

Indirect Chills

Cooling materials that can be moulded may be considered as a "facing." The thickness of such a facing need not exceed the thickness of the cast section, but should not be less than half its thickness if a full cooling capacity is to be realised. In large and heavy castings cooling materials may be supplemented by the use of *indirect chills,* by which is meant iron chills that are not exposed directly to contact with cast metal, but which are protected by a layer of normal moulding sand or a cooling moulding material. The effect of an indirect chill is therefore retarded and diminished according to the thickness of the protective layer and its heat conductivity.

The effect of such an indirect chill plate is illustrated graphically in Fig. 5. The curve 1 in Fig. 5A (upper part) gives the cooling rate

of a steel plate cast in sand expressed in calories per square metre per hour. In Fig. 5B the corresponding curve for the total amount of heat lost by casting per square metre is given. The rate of solidification and the solidified amount of metal are roughly proportional to the loss of heat. The curves 2 represent the

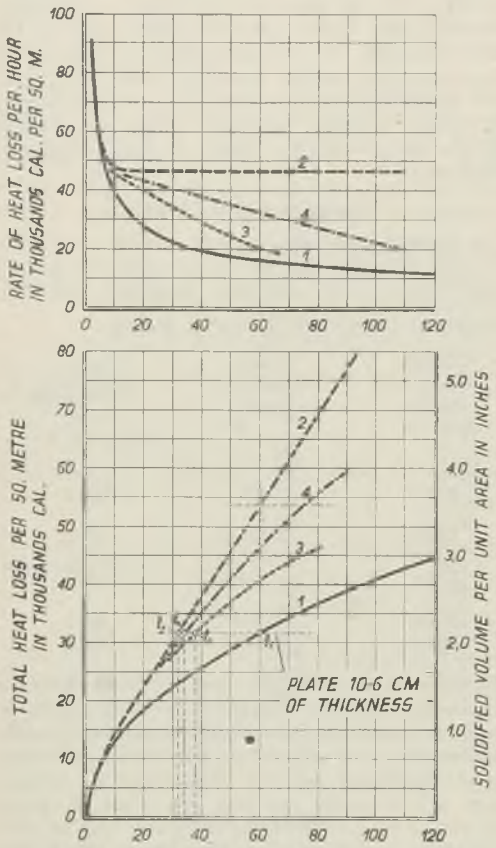

FIG. 5A (TOP) AND B (BOTTOM).—EFFECT OF INDIRECT CHILLS.

corresponding rate and the total amount of the heat loss for an infinitely thick chill plate with a 2-cm. moulding-sand layer between it and the cast plate. Curves 3 and 4 give the cooling conditions for chill plates of finite thickness, 5 and 10 cm. respectively.

A quantitive decrease of solidification period can be easily determined for any thickness of casting. A greater cooling effect can be attained if a facing material of a greater heat conductivity be used instead of an ordinary moulding sand. If the thickness of the facing layer is changed, the cooling effect also changes. For the sake of simplicity let us consider a cast plate and another plate as an indirect chill. The thickness of the intermediate layer can be continuously changed by inclining the chill-plate in relation to the surface of the cast plate. Thus a continuously changing cooling effect is attained and progressive or controlled directional solidification can be effected. Such a plate would solidify, not as a plate of equal thickness, but as a wedge, thus assuring the internal soundness of the casting.

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Paper No. 679

Copper and Copper-Alloy Castings for Electrical and Thermal Conductivity Applications

By H. J. MILLER, M.Sc. (Member)

Introduction

One of the outstanding features of copper is the possession of high electrical and thermal conductivity, and on this account the metal finds extensive industrial application, especially in wrought forms such as strip, sheet, wire, rods and sections. The demand for high-conductivity castings is, however, limited, and, indeed, when it is desired to employ castings for electrical and thermal conductivity applications, there are many difficulties both in the choice of composition and in founding.

The production of foundry castings in essentially pure copper has always presented great difficulties, and it is perhaps true to say that the problem has been mastered only by a few specialists. Certainly the project has not been undertaken by the average foundry, and the reasons for the limited interest in copper castings are not far to seek, since, in addition to the founding troubles, it is to be noted that cast copper is not characterised by good mechanical properties, these being, in fact, inferior to those of all copper alloys.

For this reason, it is only in cases where, primarily, high conductivity (thermal or electrical) is required that copper castings are seriously considered. One important application of a thermal character is that of blast-furnace tuyeres, for which copper containing about 1 per cent. tin is generally used; the main application involving electrical conductivity is in connection with various parts for switchgear and other plant in the electrical trades. In practice the range of alloys used for electrical castings is extremely wide and includes brasses, bronzes and other copper alloys. One of the objects of the present Paper is to summarise the alloys now being regularly employed or which are now available for special-purpose castings; this has been undertaken because of a general desire on the part of users for a summarised statement on the latest developments pertaining to the special high-conductivity and high-strength alloys which have become available within recent years.

The Paper is divided into several sections as follows:—

PART 1.—Tough pitch copper—effect of oxygen—effect of hydrogen—reactions on solidification—properties of tough pitch copper—oxygen-free copper.

PART 2.—Deoxidised copper—consideration of deoxidants—properties of deoxidised copper castings.

PART 3.—Commercial copper-rich casting alloys.

PART 4.—Modern high-conductivity high-strength casting alloys—copper containing chromium additions—other alloys.

PART 5.—Foundry technique.

PART I.—TOUGH PITCH COPPER

For an appreciation of the factors involved in the casting of copper, it has been considered advisable to outline briefly the present state of knowledge with regard to the reactions occurring in the production of "tough pitch" copper. Such copper always contains a small amount of oxygen—generally within limits of 0.02 to 0.08 per cent.—and it is the conventional form of copper for casting into billets, cakes, ingots and other shapes in which the metal is marketed for fabrication purposes. In the course of the usual refining of the metal for such purposes, it is exposed to the various gases which are present in the furnace atmosphere, and there is consequently a considerable absorption of certain of these gases, notably oxygen and hydrogen. These subsequently give rise to reactions on solidification of the molten metal, with some resulting unsoundness in the final cast shapes. With this tough pitch copper, the unsoundness is always of a controlled order, and, in fact, the term "tough pitch" is applied to products which exhibit unsoundness only to such an extent that the evolution of gases exactly counterbalances the natural shrinkage effect; this unsoundness has no deleterious influence in the case of cast products for fabri-

cation, since the porosity is removed in the hot-working stages.

The elucidation of the actual effects of oxygen and hydrogen in the casting of copper is largely due to Allen and his colleagues[1] in this country and to the American Metal Company[2] in the U.S.A., and in this Paper only a brief description of the reactions will be attempted. Further, it is not possible to consider here the related factors of pouring temperature of metal, temperature of moulds, shape of moulds and cooling rates, all of which affect the rate of gas evolution.

While it might be thought that there would be little similarity between melting conditions existing in large-scale refining furnaces and those in small foundry furnaces, there is no fundamental difference, and the need for appreciation of the gaseous reactions is certainly necessary in both cases.

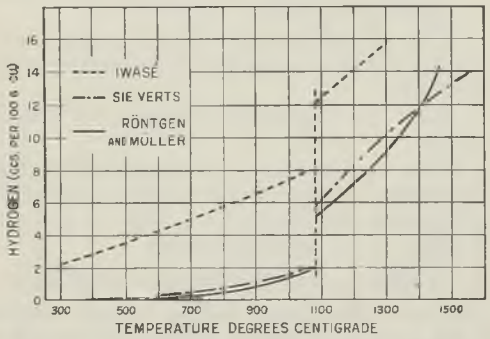


FIG. 1.—SOLUBILITY OF HYDROGEN IN COPPER.

Effect of Oxygen

Oxygen enters into chemical combination with molten copper, forming cuprous oxide, and in cast metal practically the whole of the oxide exists in the form of a copper-cuprous oxide eutectic, since the solid solubility limit is extremely low; the eutectic composition corresponds to approximately 0.39 per cent. oxygen. In wrought products, the eutectic type of structure is broken up, so that the oxide then exists in the form of separate particles of cuprous oxide. Within the usual commercial limits the oxide, as present in wrought tough pitch copper, has little or no effect on mechanical or other properties, although copper which is free from such oxide is characterised by slightly superior ductility.

Effect of Hydrogen: Reactions on Solidification

Hydrogen is simply absorbed or dissolved by copper so that it exists in the uncombined state; the extent to which it is soluble depends both on the temperature and the oxygen content of the metal. On heating, there is a gradual increase in the amount of hydrogen absorbed by the solid metal and on reaching the melting point there is a marked increase in solubility, while at higher temperatures a further increase in solubility is encountered. Some results by various investigators are reproduced in Fig. 1, from which considerable differences will be noted; the curve shown as a continuous line is the most recent determination.[3]

The amount of hydrogen which can dissolve in molten copper at any temperature is also a function of the oxygen content, and with molten copper which is high in oxygen, only a limited amount of hydrogen is dissolved, owing to the fact that immediate reactions occur with some of the oxygen present; with molten copper of low oxygen content it is possible to obtain an

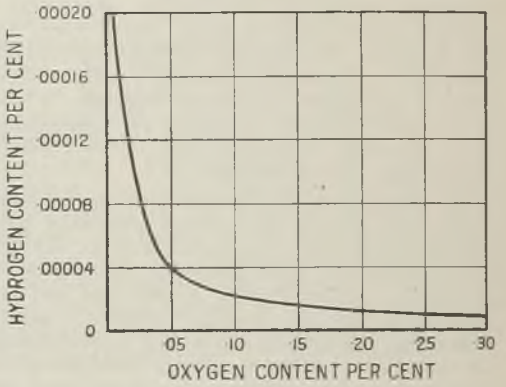


FIG. 2.—VARIATION OF HYDROGEN CONTENT OF MOLTEN COPPER AT 1,150 DEG. C. WITH OXYGEN CONTENT.

appreciable solubility of hydrogen in accordance with Fig. 1. A curve reproduced from Allen's Paper is given in Fig. 2, and this expresses the general change in solubility at 1,150 deg. C. of hydrogen in copper containing various amounts of oxygen. The change in the curve of hydrogen solubility when the oxygen content is of the order of 0.05 per cent. is especially noticeable, and the refiners' art in obtaining the tough pitch condition in copper is thus seen to be related to the balance between oxygen and hydrogen contents. The curves given in the Patents of the American Metal Company are very similar in character, although quantitative results were not given, only the fundamentals attaching to the influence of gases on molten copper being established, these being based essentially on principles enunciated by Hofman[4] in 1914.

The liberation of the excess hydrogen from solution on solidification of the metal is accom-

panied by a reaction with cuprous oxide according to the equation:—

$$Cu_2O + H_2 \rightleftharpoons 2\ Cu + H_2O.$$

This reaction, occurring during solidification, results in disturbance and expansion of the metal. The extent of the reaction depends mainly on the amount of hydrogen contained in the molten copper, since there is usually sufficient cuprous oxide present to react with the whole of the hydrogen liberated; however, certain other factors are also involved. The tough pitch state—with expansion due to gas evolution equalising the natural shrinkage—is normally obtained within an oxygen range of about 0.025 to 0.08 per cent. With lower oxygen contents a more extensive reaction is encountered, giving markedly unsound products, simply on account of the greater quantities of hydrogen which were in solution in the first place; with higher oxygen contents the casting surface sinks in the mould, but the metal is then deficient in ductility.

TABLE I.—*Properties of Tough Pitch Copper.*

	Cast.	Lightly-forged castings.	Worked and annealed.
Density	8.4	8.85	8.93
Tensile strength, tons per sq. in.	9	13	13.5
Elongation, per cent. on 2 in.	20	40	60
Reduction of area ..	20	40	75
Brinell hardness ..	32	35–40	45
Electrical conductivity, per cent. ..	80–85	95	100–102

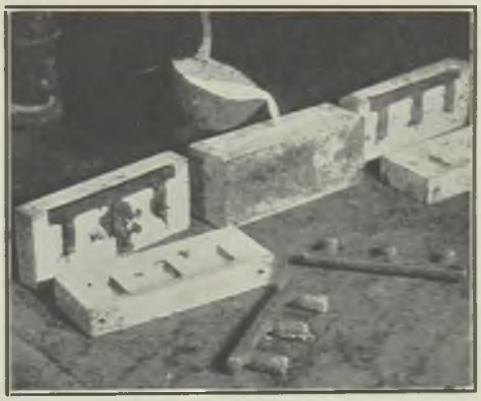
Properties of Tough Pitch Copper

It will be appreciated from the foregoing that "tough pitch" copper is not completely sound, although the porosity, amounting to 2 to 5 per cent. by volume for most simple cast shapes, is, as already explained, removed in the early stages of hot-working. For ordinary castings, however, it is obvious that the gas reactions associated with tough pitch copper will be most undesirable, and attempts to cast such copper into sand moulds almost invariably culminate in disaster.

It must be pointed out, however, that many simple cast shapes are made in tough pitch copper by pouring into chill moulds. These should preferably present an open surface and, if maximum density and mechanical properties be required, the castings should afterwards be forged. By this means it is possible to obtain small products having good density and an electrical conductivity ranging between a minimum of 90 per cent. and about 97 per cent. Figs. 3 and 4 show some products made in this manner. The properties of cast tough pitch copper are summarised in Table I and, in order to appreciate the effects due to porosity, figures are also quoted for this material in a lightly-forged and in the usual heavily-worked annealed condition.

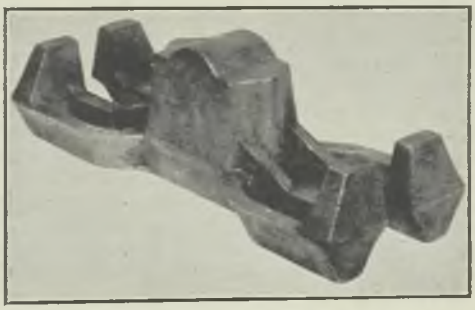
Oxygen-Free Copper

To obtain molten copper in such a condition that gas reactions on solidification are avoided, it will be clear from the foregoing consideration that the courses open to experiment are



(Courtesy T. Bolton & Sons, Limited.)

FIG. 3.—CASTING TOUGH PITCH COPPER FOR PRODUCTION OF TERMINAL CASTINGS.



(Courtesy T. Bolton & Sons, Limited.)

FIG. 4.—LIGHTLY-FORGED TOUGH PITCH COPPER CASTING FOR ELECTRICAL SWITCHGEAR.

(1) elimination of oxygen or (2) elimination of hydrogen. The latter method is generally impossible of fulfilment owing to practical difficulties following on the fact that hydrogen can be derived from water vapour present in the furnace atmosphere. Hence, the general course is to attempt the elimination of oxygen by the addition of elements which are capable

of reacting with cuprous oxide, thereby forming liquid or solid products which may be slagged-off; this method is dealt with in Part 2.

In the Patented process which has been commercially developed for the production of oxygen-free high-conductivity copper billets and vertically-cast cakes, melting of the copper is performed in inert gas atmospheres (carbon monoxide and nitrogen) and the molten metal is conveyed into the moulds under cover of the same gases. The resultant cast shapes are free from both oxygen and porosity due to dissolved gases, and they thus have a high density (an average of 8.9); on account of freedom from gas reactions on solidification, the normal shrinkage of gas-free molten metals is exhibited, while another feature is the possession of a relatively coarse structure. Although a considerable tonnage of copper is cast into simple shapes for fabrication purposes, it is not possible to envisage the application of this technique to the production of miscellaneous sand castings. However, the time may yet arrive when non-ferrous foundries will be in a position to conduct melting and casting processes *in vacuo* or in inert atmospheres; such equipment would eliminate hydrogen absorption, which with present methods of producing deoxidised copper remains as a potential cause of porosity.

PART 2.—DEOXIDISED COPPER

A consideration of the fundamental requirements of a deoxidant will not be attempted, but in addition to the usual factors, special attention must be given to the effect of residual quantities of deoxidants on both electrical and thermal conductivities, which are closely allied. The fact that small quantities, *i.e.*, about 0.1 to 0.2 per cent., of certain elements may reduce conductivity to one half of the original value is not always fully appreciated, although it is obviously of prime importance in connection with castings for conductivity applications. In order to clarify the position from this aspect some results of conductivity determinations are graphically presented in Fig. 5.

From the point of view of materials the principal points to be noted in the production of castings having maximum conductivity are:—

(1) The use of high-grade copper (H.C. quality) and avoidance of contamination with impurities.

(2) The choice of a deoxidant having little adverse effect on conductivity or alternatively the use of minimum quantities of more harmful deoxidants.

A surprisingly large number of recommendations concerning deoxidants for high-conductivity copper castings have been advanced over a period of many years, and in some cases extravagant and unsubstantiated claims have been put forward. This might perhaps be taken as an indication of the difficulty of the problem. At any rate, the choice of deoxidants was being vigorously discussed about thirty years ago, when it is interesting to note that boron carbide was first used[5] and that calcium was patented for deoxidation purposes.[6] During the intervening years other special deoxidants have been introduced so that to-day the choice is extremely wide; the practice advocated by different investigators has been so varied as to cause much confusion, and hence it is difficult to deal with this matter in a completely satisfactory manner.

Deoxidants which have received some consideration include aluminium, beryllium, boron,

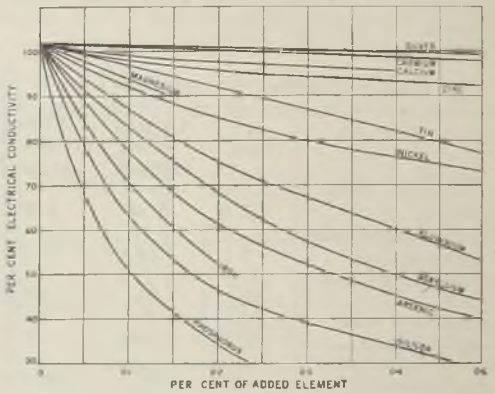


FIG. 5.—INFLUENCE OF ADDED ELEMENTS ON ELECTRICAL CONDUCTIVITY OF COPPER.

boron carbide, cadmium, calcium, calcium boride, lithium, magnesium, phosphorus, silicon, titanium and zinc, although not all of these have been used on a commercial scale. Quite frequently a combination of two deoxidants is recommended.

A fact which must not be forgotten when making deoxidised copper castings is that hydrogen can be present in considerable quantities in the molten metal; it is believed that this accounts for many of the variable results which have been reported. Even at the present time it must be confessed that everything is not known concerning the solubility of hydrogen in various deoxidised coppers in the molten and solid states. For instance, there is some indirect evidence leading to the conclusion that the presence of deoxidants (or certain of them) results in diminished hydrogen solubility in the liquid state, or that the solid solubility is much greater, while an alternative idea is that the evolution

of the gas on solidification takes place without any harmful results. The number of occasions on which "hydrogen unsoundness"—as apart from the "reaction unsoundness"—is obtained with deoxidised copper are relatively few, but this possibility must not be overlooked.

Consideration of Deoxidants

Of the previously mentioned deoxidants, phosphorus is by far the most important as it is cheap, convenient and very effective, although it suffers from the disadvantage of adversely affecting conductivity when present in amounts exceeding mere traces. It is certainly the only deoxidant which need be considered when maximum conductivity is not a prime important factor, although a strong theoretical case can be presented on behalf of silicon, as, for instance, in wrought copper for welding, on account of the reduction of hot-cracking tendencies.[7]

For general castings, a residual phosphorus content of 0.05 per cent. may be regarded as a satisfactory figure to be aimed at, this amount normally being sufficient to ensure complete deoxidation. However, for pressure-tight castings, such as tuyeres, copper containing this amount of phosphorus does not appear to be entirely suitable, since porosity has been reported with products made from such material; the reasons for this are not too clear, but the trouble is most probably due primarily to excessive gas absorption during melting.

For blast-furnace tuyeres and other castings which are required to withstand a hydraulic test at a pressure of 60 lbs. per sq. in., most founders express preference for copper containing 1 per cent. of tin and about 0.05 per cent. phosphorus, and production practice with this alloy has been described by Blakiston.[8] The conductivity of products made in this alloy is naturally low, frequently falling below 40 per cent., as indicated in Table II, presenting observations on various specimens; the conductivity of ordinary commercial phosphorus-deoxidised copper is frequently very little better.

Hence, for conductivity applications where an electrical conductivity value of 80 per cent. might be regarded as the minimum specification figure, such materials are not allowable. With care in melting practice so that the oxygen content of the metal prior to deoxidation is maintained at a constant figure, it is possible to deoxidise copper with phosphorus so that less than 0.01 per cent. of phosphorus remains in the final product; this amount effects a reduction of about 10 per cent. in conductivity. Naturally, this technique calls for considerable skill and experience and, indeed, the whole subject of copper casting can be said to be one requiring continual practice with more or less constant materials and products under accurately controlled conditions.

Cadmium in amounts of the order of 0.5 to 1 per cent. is frequently used in conjunction with approximately 0.01 per cent. of phosphorus; likewise 1 per cent. of zinc is sometimes used in conjunction with minimum quantities of phosphorus. Both of these elements are very mild deoxidants, but there seems little doubt that they are helpful in obtaining satisfactory castings, probably due to assistance in gas removal and the fact that the zinc and cadmium vapours given off from the stream of molten metal as it is being poured have a protective influence against oxygen pick-up at this stage; in addition the cadmium and zinc permit of greater control over the phosphorus content. However, it might be noted that a 1 per cent. cadmium-copper alloy is not regarded as an easy material to cast in a copper refinery.

Aluminium and magnesium are undoubtedly excellent deoxidants for copper, but the oxidation products are not readily removed and tend to make the molten metal sluggish; in addition, with excess quantities present, there are casting difficulties on account of the oxide films formed on the stream of metal as it is poured. Consequently these deoxidants are not generally employed for these particular products, although Vickers[9] has recorded satisfactory results when using 0.025 per cent. magnesium in conjunction with 0.05 per cent. chromium.

TABLE II.—*Average Properties of Deoxidised Copper Castings.*

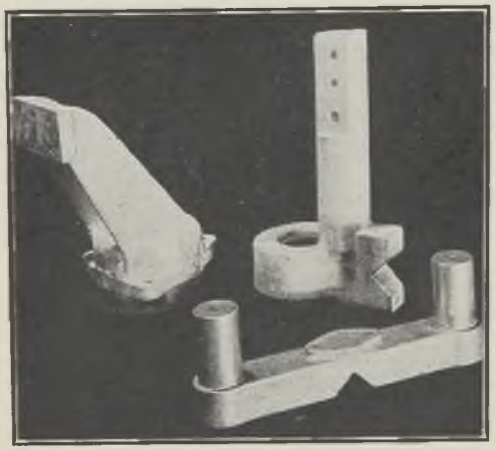
Composition.	0.15 per cent. proof stress. Tons per sq. in.	Tensile strength. Tons per sq. in.	Elong. Per cent. on 2 in.	Brinell hardness.	Electrical conductivity. Per cent.	
					Cast.	Wrought (annealed).
1 per cent. Sn, 0.03 per cent. P	2	10	25	40	39	—
0.05 per cent. P	2	10	25	35	60	67
0.9 per cent. Cd. 0.005 per cent. P ..	2	11	30	35	85	94
0.03 per cent. Si	—	—	—	—	75	—
0.02 per cent. Si added (residual amount unknown)	—	—	—	—	90	—

Beryllium presents very similar characteristics to aluminium and magnesium; its suggestion for deoxidation purposes followed from the wide research of beryllium alloys by Masing and colleagues.[10] Results attending the use of beryllium in the production of wrought deoxidised copper have been given by Schumacher and Ellis,[11] who found that a residual amount of 0.05 per cent. reduced the conductivity by 10 per cent. Beryllium is of much more interest in the production of alloys of superior mechanical properties than it is as a deoxidant.

In 1931 lithium was suggested as a deoxidant for copper by two independent groups,[12 13] and as it seems to possess practically all the attributes required of a deoxidant, it would undoubtedly be used to a greater extent if its cost was not so great. To conserve the quantities of lithium required it is usual to employ a calcium-lithium alloy, and as extremely small quantities only are essential, deoxidation is not entirely a prohibitively expensive matter. The recommended addition of 50:50 lithium-calcium alloy is 0.025 per cent., and this has a negligible effect on conductivity; it might, however, be noted that with the addition of excess quantities of lithium, say of the order of 0.08 per cent., a reaction with oxides present in refractories may occur, thus resulting in inferior conductivity of the metal. According to Schumacher and Ellis,[11] alloys made in fused-silica crucibles and alundum-lined crucibles were contaminated with silicon and aluminium, so that the conductivities of hard drawn wires were below 80 per cent. Other experience with lithium has been recorded by Masing and Haase,[10] Schumacher, Ellis and Eckel,[14] Burkhardt and Sachs,[15] and Osborg.[16 17] In addition to its deoxidation features, lithium can also remove hydrogen by chemical reaction, yielding hydrides and hydroxides if oxygen be present, and in recent times some further attention has been devoted to lithium on this account; one instance is in connection with the degasification of copper-lead alloys for bearings.

Calcium has, from the theoretical point of view, strong claims as a deoxidant, and it is difficult to appreciate why it has not been used to a much greater extent in the production of high-conductivity copper castings. For systematic data on the effect of calcium on conductivity, the publications of Schumacher and colleagues[18 11] and Zickrick[19] should be consulted, as there are considerable discrepancies in the results; according to Schumacher, a residual calcium content of 0.1 per cent. depresses the conductivity of wrought products by less than 3 per cent., but Zickrick reports a much greater adverse effect. A factor tending to deter the use of calcium is its acknowledged tendency to give rise to dross inclusions in the surface of castings.[10]

The use of silicon as a deoxidant dates back for a considerable period, and it would seem that the practice of adding this element to copper for electrical castings was in the first place founded



(Courtesy Brookhirst Switchgear, Limited.)

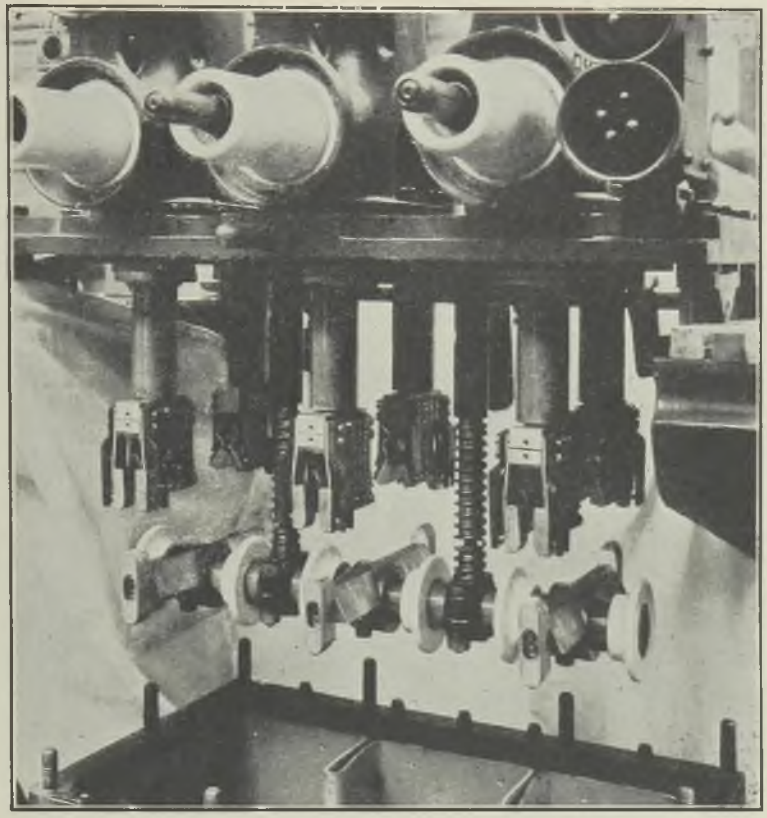
FIG. 6.—GROUP OF MACHINED AND SILVER-PLATED COPPER CASTINGS.

(Courtesy A. Reyrolle & Company, Limited.)

FIG. 7.—CONNECTOR AND CONTACT BLADES AND BLOCKS CAST IN DEOXIDISED COPPER OF 80 PER CENT. MINIMUM CONDUCTIVITY.

on the belief that it did not adversely affect conductivity; however, it is now known that silicon is second only to phosphorus from the point of view of its depression of conductivity. In spite of this, castings having quite good conductivity properties can be produced by means of silicon additions, and a typical production practice was recently described by Phillips[20] who added 0.02 per cent. silicon in the form of a 15 per cent. master alloy; the resultant castings possessed a conductivity approaching 90 per cent., which is a highly satisfactory figure and bears testimony to the care taken at all stages.

Silicon does not impair the fluidity of the molten metal, although it does not confer the same free-running properties as phosphorus additions. There is some indirect evidence that the strength of copper at temperatures just below the melting point is much greater when silicon is present in the metal than when phosphorus has been employed as the deoxidant; this point has only recently arisen from a consideration of the most suitable type of copper for welding.[7] Accepting the validity of this finding, it would seem that the chances of hot-cracking of castings would be less with the use of silicon as a deoxidant, but it is extremely doubtful whether any observations have ever been made on this point.



(Courtesy A. Reyrolle & Company, Limited.)

Fig. 8.—Circuit Breaker, showing Use of Cast Copper Contact Blades.

"Boronised copper" is a term which is frequently encountered, but little information is available concerning the properties of copper-boron alloys; there is, for instance, a dearth of information on their conductivity properties. Both calcium-boride and boron-carbide have been advocated as deoxidant additions, and results have been reported by Zickrick.[19, 21] A feature of the practice with boron-carbide is that, owing to the stability of this compound, it is necessary to heat the copper to at least 1,300 deg. C.; such

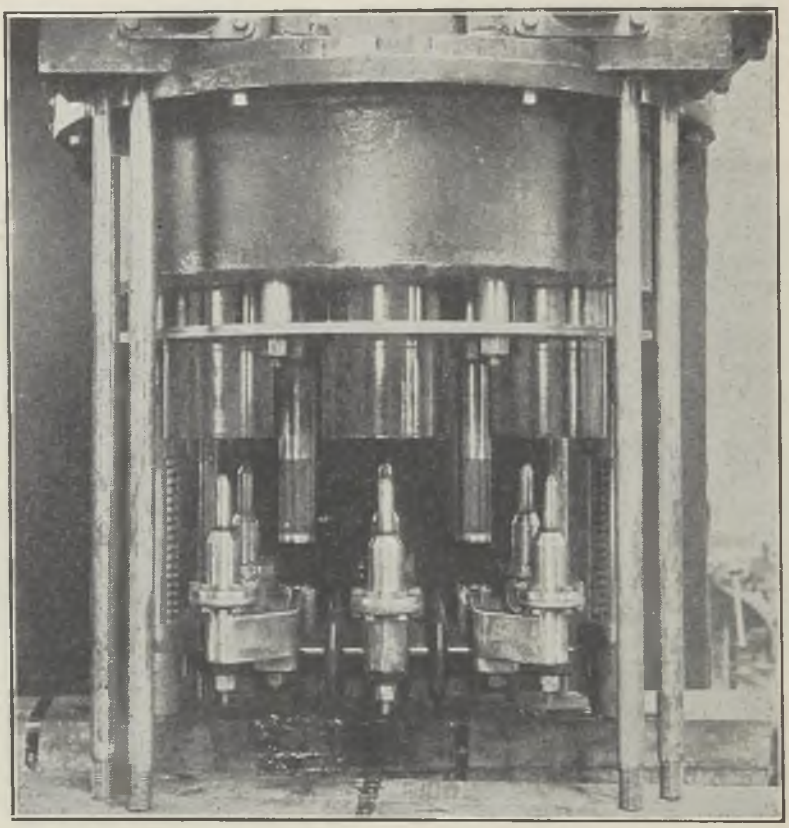
a practice must tend to give excessive absorption of hydrogen, and is consequently open to theoretical objections.

Properties of Deoxidised Copper Castings

It is possible to add but little information to that already outlined regarding electrical properties of cast products, and indeed the general run of results should by now be appreciated. As is the case with other properties, such as tensile strength, production technique has an enormous influence; it is possible to envisage variations between about 75 and 90 per cent. conductivity in products of a given nominal composition according to their density and production history, while the same composition in the wrought state might even show 95 per cent. conductivity.

However, it has been effectively proved by many firms that the electrical conductivity of castings may be held within limits of 85 to 90 per cent., but this calls for extremely close control at all stages. The strength and hardness of copper castings are inevitably rather unimposing, as will be apparent from the few figures given in Table II.

Parts cast in deoxidised copper of 80 per cent. minimum conductivity are illustrated in Figs. 6 and 7, while Figs. 8 and 9 show applications of such castings in switchgear. The three castings shown in Fig. 6 are used for circuit-breaker parts, while of those shown in Fig. 7 the casting at the back is a connector, the other four being contact blocks and blades. Fig. 8 shows a circuit breaker (with oil tank removed) which incorporates cast copper contact blades of the type shown to the left in Fig. 7. Fig. 9 shows a high-voltage circuit breaker (also with the oil tank removed); the cross-arms carrying the contacts are copper castings.



(Courtesy Brookhirst Switchgear, Limited.)

FIG. 9.—HIGH-VOLTAGE CIRCUIT BREAKER, THE CROSS-ARMS OF WHICH ARE HIGH-CONDUCTIVITY COPPER CASTINGS.

PART 3.—COMMERCIAL COPPER-RICH CASTING ALLOYS

Owing chiefly to their low hardness and strength, together with the fact that such machining processes as tapping and screw threading can only be accomplished with some difficulty, copper castings have conventionally been used by the electrical industries only in essential applications. For most conductivity parts, especially those subjected to mechanical stress or wear, it has been customary to use castings of comparatively heavy cross-section, made in copper alloys of much inferior conductivity but possessing such other desirable attributes as greater strength and ease of machining. It will be shown in Part 4 how new alloys have been developed to meet conductivity and strength requirements, and the purpose of the present section is to summarise the properties of the general copper alloys which in the form of castings find quite extensive applications for electrical purposes.

Most of these alloys are of a bronze basis, although in some cases brasses and aluminium bronzes are also employed, the former in sand-cast, die-cast and wrought forms and the latter notably as die-castings. The standard bronze alloy used for electrical castings has a composition of 87 per cent. copper, 7 per cent. tin, 3 per cent. zinc, and 3 per cent. lead, and is known as "electrical bronze"; the lead content ensures good machinability but it impairs strength and ductility, and, under impact stresses, the alloy is particularly weak. Consequently for highly stressed cast parts Admiralty gunmetal (88 per cent. copper, 10 per cent. tin, 2 per cent. zinc) is often specified. Properties of these materials are summarised in Table III, and this shows the extent of impairment of conductivity due to the presence of tin and other alloying elements. Also in this Table are typical properties for other copper-base alloys which are commonly used as castings.

Of these other alloys, brasses are of most importance, and it seems to be overlooked by many electrical engineers that they possess better conductivity properties than do the bronzes. The resistance to wear may, however, not always be as satisfactory, as their "bearing properties" are not so good. Brasses used for casting purposes vary considerably in composition and in purity, and there is little uniformity in the specifications of different users. Sand castings may be made from any brass with a copper content between about 55 and 80 per cent. Recognition might be given to a high-quality brass containing about 75 per cent. copper and 25 per cent. zinc, a common quality brass containing about 60 per cent. copper, 2 per cent. of lead (which improves machining properties), balance zinc, and the group of high-tensile strength brasses (manganese bronzes). In the case of the latter group, particular care should be exercised over the alloy composition if tinning or soldering is to be performed, because the alloys possessing a beta structure are prone to fail by intercrystalline penetration of the tin or solder.

In the case of cast parts as exemplified by overhead-line clamp fittings, which are subjected to atmospheric exposure, all the brass alloys do not function equally satisfactorily; alpha-beta brasses have in some instances given poor service owing to dezincification of the beta phase. Hence alpha brasses such as the afore-mentioned 75/25 alloy are preferred for such service, or alternatively the bronzes or other alloys may be used.

In Fig. 10 a group of 88/10/2 gunmetal and 75/25 brass castings is shown. Of these castings, the two at the back might be called breach holders; the hollow casting in the centre, a contact holder; the heavy casting to the left of this,

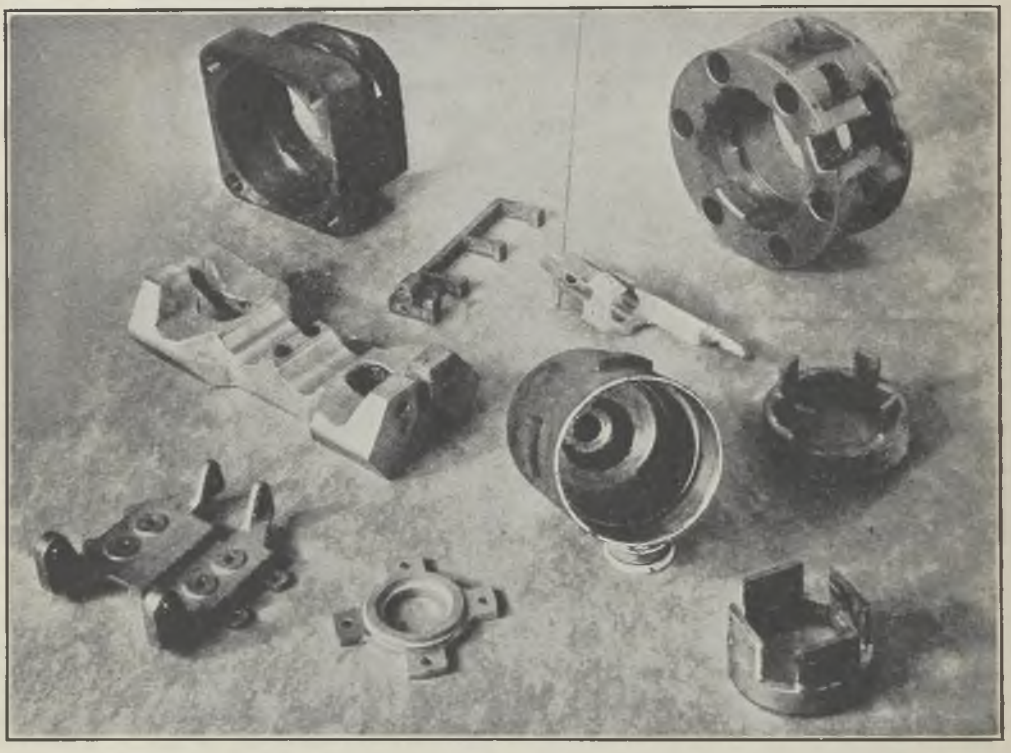
TABLE III.—*General Casting Alloys.*

Alloy.	Composition.			Other elements.	Electrical conductivity (cast).	Tensile strength. Tons per sq. in.	Elong. Per cent. on 2 in.	Izod impact strength. Ft.-lbs.	Brinell hardness.
	Cu.	Sn.	Zn.						
Electrical bronze ..	87	7	3	3 Pb	6–12	13–16	14–20	2	50
Admiralty gunmetal	88	10	2	—	10	16–20	8–25	6	65
High-quality brass ..	75	—	25	—	20–25	16–18	40	40	45
General brass ..	60	—	37	2 Pb and up to 1 impurities	14	12–20	15–25	10	50
Manganese bronze ..	58–65	—	rem.	Up to 3 Al, 2 Mn, 2 Fe	15–20	30–40	20	20	100–150
Brass (die-cast) ..	60	—	40	—	25	25	45	30	85
Aluminium-bronze .. (die-cast)	88	—	—	9 Al, 3 Fe ..	10–15	38	40	30	130
Aluminium bronze ..	80	—	—	10 Al, up to 10 Fe, Mn and Ni	6–12	40–47	15–20	20	175–240

a contact blade; the two rings at the right-hand side, contact rings; the others are miscellaneous parts. In general, the " contact " castings carry current, while the others do not. Fig. 11 shows one pole of a contactor, the support for the fixed contact and the braid block being cast in electrical bronze.

Die-castings in either brass (60 per cent. Cu and 40 per cent. Zn) or aluminium bronze (88 per cent. Cu, 9 per cent. Al, and 3 per cent. Fe) may be employed if sufficient repetition parts are required to justify the initial tool outlay and provided the design lends itself to this method of production; typical uses are brush holders and switchgear parts, such as illustrated in Figs. 12 and 13. A matter which sometimes gives rise to criticism of both brass and aluminium-bronze die-castings is that of machining; lead additions to the die-casting alloys, particularly the brasses, cannot be permitted owing to cracking troubles during casting. In competition with castings, it might be mentioned that there are numerous parts which are made by parting-off from extruded brass sections, by hot-stamping, and by machining from free-cutting brass rod; a free-cutting type of copper is now about to enter the market and this may further compete with foundry products.

Apart from die-castings, relatively little use has been made of the aluminium-bronze alloys, although they have many advantages from the mechanical point of view. An application of a special type is the welding jaws for flash-welding machines, for which alloys of slightly greater aluminium content, and consequently greater hardness, than that given in Table III are used.



(Courtesy A. Reyrolle & Company, Limited.)

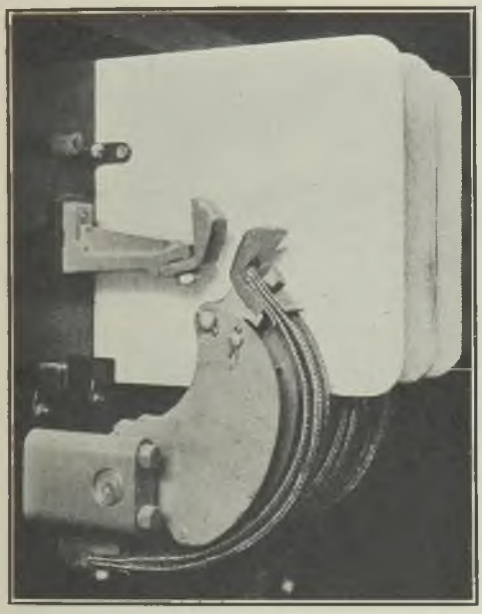
Fig. 10.—Group of 88/10/2 Gunmetal and 75/25 Brass Castings.

PART 4.—MODERN HIGH-CONDUCTIVITY HIGH-STRENGTH CASTING ALLOYS

The alloys considered in this section have been introduced within the past twenty years, and they owe their development to the elucidation of the basic principles underlying precipitation hardening. The application of these principles to both cast and wrought products is of as much significance from the electrical point of view as it is from the mechanical aspect, although up to the present most precipitation-hardening copper-base alloys have been used purely on account of

their mechanical properties. Many of the alloys are the subject of numerous patents, and the conflicting interests of the various patentees have perhaps tended to hinder the use of such heat-treated materials; in many cases the patent position is most confusing.

Kempf[22] has recently reviewed the application of precipitation hardening to foundry products, and only a brief outline of the principles will be attempted here. With alloys of suitable composition (determined by the nature of the equilibrium diagram) a condition of supersaturation is achieved by rapidly cooling from a high temperature, and in this state both the hardness and



(Courtesy Brookhirst Switchgear, Limited.)

Fig. 11.—Contactor with Braid Block and Fixed Contact Cast in Electrical Bronze.

electrical conductivity are at a minimum. On ageing at ordinary temperatures, or on reheating at some temperature intermediate between the initial quenching temperature and ordinary temperatures, there occurs a precipitation of the excess hardening constituent from solid solution, and in consequence of this depletion of the solid solution there is an increase in conductivity; at the same time an increase in hardness and strength also results, especially if the critical reheating conditions are adhered to. Over-ageing (by reheating at too high temperatures) results in coalescence of the precipitated particles with a consequent loss of strength and hardness, but with little further effect on conductivity, because this property depends on the composition of the solid solution rather than on the distribution of the precipitate.

With copper-base alloys, the rate at which ageing occurs at ordinary temperatures is extremely slow and can be disregarded altogether; precipitation-hardening of copper alloys is effected by heating at temperatures between about 250 and 600 deg. C.

The heat-treatable copper-base alloys which may be considered for castings include:—

(1) Copper-chromium alloys, often with additions of aluminium, cadmium, silicon, silver, zinc, zirconium or other elements.

(2) Copper-nickel-silicon alloys.

(3) Copper-cobalt alloys generally with additions of silicon or beryllium.

(4) Copper-beryllium alloys, sometimes with nickel, zirconium, or other elements added.

(5) Copper-titanium-silicon alloys.

Copper Containing Chromium Additions

Of the above list of heat-treatable copper-base alloys, most consideration has been given to the alloys based on the copper-chromium series because the electrical properties of these are outstandingly high. While Hunter and Sebast,[23] as early as 1917, noted that alloys containing 0.5 to 1 per cent. chromium possessed high conductivity, it was only realised in 1924, on Patent applications being made by Corson,[24] that the alloy series was amenable to heat-treatment. Details of Corson's investigations have since been published,[25] and amongst subsequent important contributions relating to copper alloys containing chromium are the Papers by Harrington,[26] Davis[27] and Brace.[28] Kinzel[29] and Corson[30] have recently made general reviews on the present stage of development of copper-chromium alloys, the former dealing particularly with castings for conductivity applications. In addition to these technical references, there is also a large patent literature, while data on proprietary alloys have also been made available.[31]

The commercial casting alloys all contain between about 0.4 and 0.8 per cent. chromium, a typical figure being 0.5 per cent. The additional elements, such as silver, beryllium or silicon, present in some of the proprietary alloys, can be regarded as optional, and they are of comparatively minor influence on properties, although this is only a generalised statement made from the point of view of cast products.

It is most convenient to consider the alloys in conjunction with the equilibrium diagram, and Fig. 14 reproduces the copper-rich end of the diagram, this incorporating the solid-solubility limits as recently determined by Alexander.[32] Castings made in the basic 0.5 per cent. chromium alloy, if of small dimensions and

rapidly cooled, exist in a state of solid solution and consequently the high-temperature solution treatment may be omitted, as advocated by Neave and Miller.[33 34] Alternatively, the castings are "solution-treated" at approximately 1,000 deg. C. and then rapidly quenched. In either of these conditions the products are, of course, soft and of inferior conductivity. Reheating at a temperature of 500 to 525 deg. C. for upwards of two hours results in precipitation of the hardening constituent, with changes in mechanical and electrical properties as reported in the first section of Table IV.

The ultimate products are seen to have high values for limit of proportionality and proof stress, and they may consequently be used in applications involving considerable stresses; with copper castings of about the same conductivity these properties are negligibly low, being, in fact, somewhat less than those of chromium-copper in the soft state. Some results by Harrington[26] on a copper-chromium-beryllium alloy are also given in this Table, and, although somewhat inferior due to the use of an insufficiently high quenching temperature, the results are in general seen to verify those obtained with the binary copper-chromium alloy.

Another important feature of heat-treated chromium copper is its retention of strength and hardness at elevated temperatures. Hence the alloys are of particular importance for such applications as parts of resistance-welding machines, examples of which are illustrated in Fig. 15, and for cylinder heads for special types of internal-combustion engines and mould parts required for casting purposes. A temperature of 350 to 400 deg. C. may be accepted as a safe maximum range at which heat-treated chromium-copper castings may be used for long periods without change of properties. Kinzel[29] has recorded that a load of 6.7 tons per sq. in. produced no appreciable creep in one month at 400 deg. C.

TABLE IV.—*Copper-Chromium Alloys.*

Alloy composition.	Condition.	Limit of proportionality. Tons per sq. in.	Yield or proof stress (0.15 per cent.). Tons per sq. in.	Tensile strength. Tons per sq. in.	Elong. Per cent. on 2 in.	Reduction of area. Per cent.	Brinell hardness.	Electrical conductivity. Per cent.
99.3 per cent. Cu, 0.5 per cent. Cr, 0.2 per cent. Zn	Cast	—	2	12	50	55	45	45
	Cast and heat-treated at 500–525 deg. C. for 2 hrs.	9	15	21	20	30	100	83
99.5 per cent. Cu, 0.4 per cent. Cr, 0.1 per cent. Be	Cast and heat-treated (solution treated at 900-925 deg. C. and reheated at 500 deg. C.)	7	—	13.4–15.6	10–15	—	—	72–75

Other Alloys

The properties of the remaining precipitation-hardening alloys can perhaps best be presented by means of a comprehensive Table, and some typical properties of castings made in the various alloys are summarised in Table V. It will be possible from these selected results to appreciate the combination of mechanical and electrical properties which can be obtained.

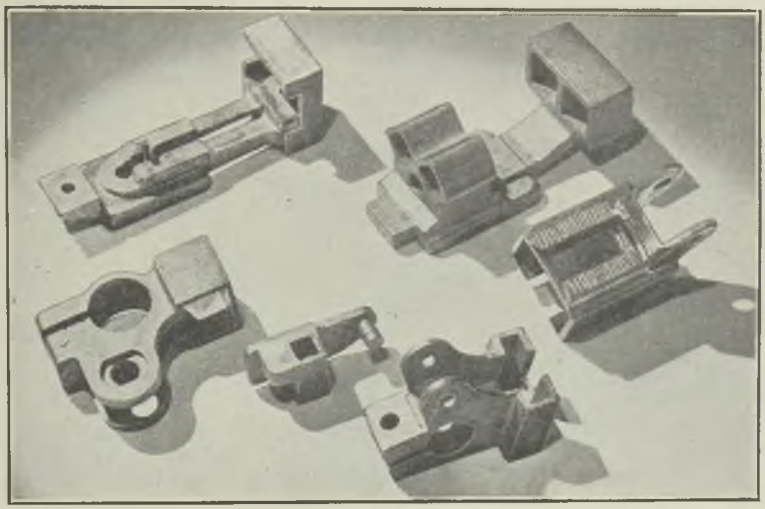
None of these alloys has yet been used to the same extent as the chromium copper, but they are of potential importance where greater strength and hardness are desirable, although there is inevitably a sacrifice of some of the conductivity. The copper-nickel-silicon alloys were originally introduced by Corson at the same time as other precipitation-hardening alloys containing copper and silicon, together with either iron, chromium or cobalt.[35] The maximum precipitation occurs, and consequently best mechanical and electrical properties are obtained, when the nickel and silicon are adjusted in the proportion of 4:1. With other ratios, excess quantities of either nickel or silicon remain in solid solution, and hence will be especially deleterious to conductivity. From statements in Gillett's Paper [36] it is evident that these alloys are not easy to handle in the foundry.

The fact that copper-cobalt alloys could be hardened by precipitation was another of Corson's discoveries, but neither the binary alloys nor those containing silicon have been used commercially, although the former have been sug-

gested in recent patents for internal-combustion cylinder-head castings owing to their intrinsically greater hardness. The copper-cobalt-beryllium alloys were introduced by Dahl,[37] and have been developed extensively by Harrington[26 38] and others, although applications in the form of castings have as yet been limited. The alloy containing 2.6 per cent. cobalt and 0.4 per cent. beryllium, however, possesses excellent casting properties and amongst possible applications are commutator slip-ring castings, trolley-wire frogs, clamps and splicers, circuit-breaker parts and sliding contacts, in addition to a wide range of resistance-welding-machine parts. The properties of these cobalt-beryllium alloys at elevated temperatures are superior to those of the chromium-copper alloys.

Copper-beryllium alloys have been in commercial production since about 1928, and alloys containing nominally 2.2 to 2.5 per cent. beryllium are unique in the response which they show to precipitation-hardening treatments. However, the cost of beryllium, even though it is now but a fraction of its price ten years ago, is such as to limit the uses of the 2.2 to 2.5 per cent. beryllium alloys. Apart from castings for non-sparking tools, industrial use of beryllium copper has been practically confined to spring applications, including contact springs for electrical purposes. It is, however, interesting to note that Laissus and Persoz,[39] at the Paris International Foundry Congress, pointed out the significance of the alloy group for foundry castings. Although it would seem that the hardness of castings made in beryllium copper would almost equal the hardness of wrought products, yet the tensile strength falls very much short, namely, about 50 tons per sq. in., as against upwards of 80 tons. The conductivity figure of 30 per cent. suggests that the electrical industries may be important users of cast beryllium-copper when highest mechanical properties are desired.

Comstock[40 41] has investigated the properties of copper alloyed with various combinations of elements including titanium and silicon, and beryllium with titanium, silicon or zirconium. While some of the alloys showed marked response to heat-treatment, the properties obtained did not appear to be sufficiently outstanding to suggest extensive application; the properties of one of the copper-titanium-silicon alloys are included in Table V.



(Courtesy Sagar-Richards, Limited.)

Fig. 12.—Aluminium-Bronze Die-cast Brush Holders.

PART 5.—FOUNDRY TECHNIQUE

This section is limited to a consideration of the procedure suitable for deoxidised copper and copper containing chromium additions, although the principles may also be taken as being applicable to the other alloys of copper content exceeding about 97 per cent. Foundry practice with the brasses and bronzes has been the subject of many reviews and will not be considered in this Paper.

The factors necessary for the satisfactory casting of copper into complex shapes may con-

veniently be considered under the following divisions:—(1) Melting procedure, and (2) moulds and mould materials.

Melting Procedure

Although the use of certain particular types of melting units is often claimed as being essential by practical foundrymen, it is not considered that the method of melting is of supreme importance and equally satisfactory results can be obtained with almost any melting equipment, providing that this conforms with the necessary standard of efficiency. The majority of deoxidised copper castings are made from metal which is melted in coke-fired crucible furnaces and for this reason general remarks will be concerned with this melting method.

It will have been clear from Parts 1 and 2 that absorption of gases, particularly hydrogen, by the molten metal is the principal cause of troubles in casting. Consequently it is desirable that the melting conditions should offer a minimum chance of gas solubility. The first requirements are rapid melting and avoidance of overheating of the metal, but there are many minor points, attention to which will greatly help.

The practice of preheating part of the charge in the waste gases, which still persists in some foundries, must be rigorously avoided, as this provides a maximum opportunity for absorption of gases and of sulphur. (On the other hand, with charges of cathode copper, there may be an advantage in resorting to a preliminary reast so as to remove some of the hydrogen which is occluded in the metal.) The procedure should be to charge the copper into the crucible, cover with charcoal, flux or other covering and then seal the crucible with a well-fitting lid. This latter should not be removed except for the purpose of making further additions to the crucible. The coke must be thoroughly dry as the water present in wet coke dissociates into hydrogen and oxygen at elevated temperatures. There seems little doubt that the moisture contained in fuels is the principal source of the hydrogen found in crucible furnace atmospheres, and the importance of controlling such atmospheres will be appreciated from the fact that crucibles show considerable permeability.

Although charcoal (preferably well dried) has been the conventional cover for copper, use has sometimes been made of fluxes such as glass, while fluoride-base fluxes have also been employed when making copper-chromium alloys. Flux covers of an oxidising nature, such as are at present being advocated for copper-tin alloys, offer some attractions, but it would seem that the attendant disadvantages of ineffective control of oxygen content and contamination from metallic elements derived from the flux covers are such as to debar their use.

With standardised raw materials and conditions, the addition of a predetermined amount of deoxidant immediately prior to withdrawal from the furnace should give consistently satisfactory results. It has already been explained that, while from the point of view of effects on conductivity a minimum amount of deoxidant

TABLE V.—*Properties of Precipitation-Hardening Casting Alloys.*

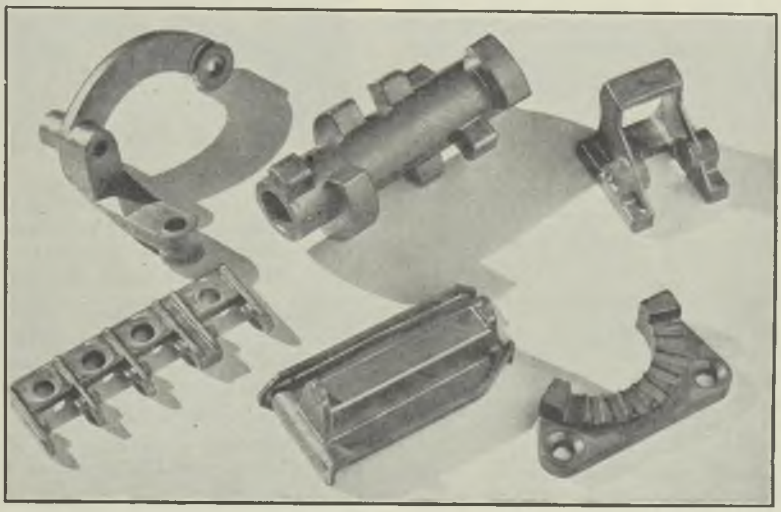
Alloy composition.	Condition.	Limit of proportionality. Tons per sq. in.	Yield or proof stress (0.15 per cent.). Tons per sq. in.	Tensile strength. Tons per sq. in.	Elong. Per cent. on 2 in.	Reduction of area. Per cent.	Brinell hardness.	Electrical conductivity. Per cent.
96.9 per cent. Cu, 2.5 per cent. Ni, and 0.6 per cent. Si	Sand-cast and heat-treated at 450 deg. C.	—	29	34	8	15	200	40
97 per cent. Cu, 2.6 per cent. Co, and 0.4 per cent. Be	Cast in graphite mould and heat-treated	20	—	40	10	20	220	45–50
97.8 per cent. Cu, 2.2 per cent. Be (other elements sometimes present to the extent of 0.25 per cent.)	Sand-cast and heat-treated at 350 deg. C.	—	40	50	1	0	400	30
98.9 per cent. Cu, 0.8 per cent. Ti, and 0.3 per cent. Si	Cast and heat-treated at 450 deg. C.	—	10	20	16	23	78	41

is desired, yet for casting there must be sufficient deoxidant present to counteract oxygen pick-up during pouring. For these reasons the practice of taking small sample ingots has been established in some foundries, and, according to the soundness of the fractures in the sample castings, increasing additions of deoxidant are made until freedom from porosity is obtained.

The procedure of adding further amounts of deoxidants after pouring the first part of the charge, while necessary with large quantities of metal, does not seem to be practised with the usual small quantities melted in foundries; the necessity with large quantities of metal, of course, arises from losses due to oxidation.

Moulds and Mould Materials

Two paramount features which must be taken into consideration are (*a*) the weakness of copper at temperatures just below the freezing point and (*b*) the pronounced shrinkage. The weakness of cast copper at temperatures just below freezing point has a bearing on design and on the choice of mould materials. Considerable care is necessary to avoid the development of cracks in cast products; any "hanging" of the castings is fatal, while abrupt changes in section also often give rise to troubles. With the object of avoiding cracking it is the practice in some foundries to remove castings from the moulds as early as possible, although



(Courtesy Sagar-Richards, Limited.)

FIG. 13.—ALUMINIUM-BRONZE DIE-CAST SWITCHGEAR PARTS.

With chromium-copper alloys, the chromium additions should be made after the deoxidation, allowing about five or ten minutes for complete solution of the master alloy. The chromium itself is a strong deoxidant and will prevent pick-up of oxygen during the period in the furnace and during pouring; the losses appear to vary between 10 and 30 per cent. of the amount of chromium charged.

An important point with copper required for conductivity purposes is that stirring and skimming of the metal be carried out with graphite tools; the ordinary iron tools give rise to iron contamination. Pouring temperatures are generally close to 1,200 deg. C., which temperature should not as a rule be exceeded at any time during melting.

it is not known to what extent this effects an improvement; from recent researches it would seem that the brittle range occurs at temperatures extremely close to the melting point, and hence it is thought that removal of castings from the moulds could not be effected sufficiently rapidly to avoid the occurrence of cracks if these were prone to develop. The main precaution which is usually adopted is to employ fragile moulds and cores, with the aid of which a high degree of success may be attained. Beyond stating that a permeable type of sand is desired, practical founders do not appear to have given definitions on the grade of sand employed. For small castings green-sand practice is adopted, but for larger castings dry-sand moulds are used. It is evident that an important accompaniment

of the high permeability aimed at by founders is low strength of moulds and cores at high temperatures. From the recent observations of Dietert and Woodliff[42] on the hot strength and collapsibility of foundry sands, low strength at high temperatures is achieved by using coarse-grained sands, low moisture contents and minimum amount of bond.

Certain special castings, such as hollow-shaped "mother-moulds" required in the copper-refining industry, are cast in 1 : 10 cement-sand moulds. On account of the cracking susceptibilities, die-casting of copper is not possible.

Chiefly owing to the absence of a solidification range, shrinkage is a source of much trouble with copper, and it is necessary to provide feeding heads and risers of generous proportions; in this connection the practice to be adopted is closely similar to that necessary with steel,

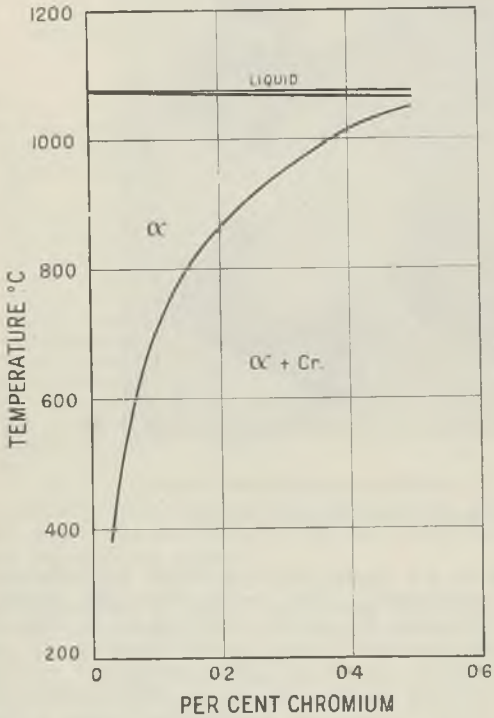
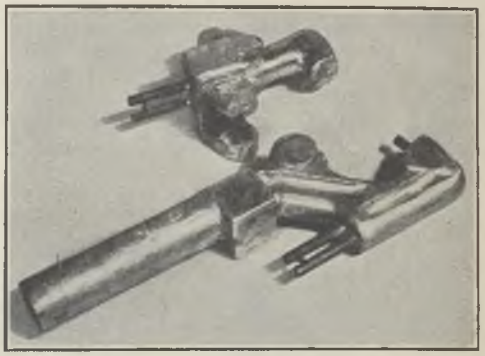


FIG. 14.—COPPER-CHROMIUM EQUILIBRIUM DIAGRAM.

aluminium bronze, manganese bronzes, and other materials which do not possess a wide solidification range. It might be noted that, contrary to general belief, the freezing shrinkage and subsequent solid shrinkage of deoxidised copper are no greater than those of any copper alloys[43]; it is the absence of a freezing range which causes the difficulties so frequently reported. Avoidance of large shrinkage cavities in the castings themselves is attained by the usual procedure of maintaining the metal in the feeding heads and risers in the molten condition until solidification of the casting itself is complete. It is thought that little purpose would be served by enlarging



(Courtesy High Duty Bronze, Limited, and Mallory Metallurgical Products, Limited.)

FIG. 15.—ELECTRODE HOLDERS, FOR RESISTANCE-WELDING MACHINE, CAST IN CHROMIUM-COPPER ALLOY.

on this aspect since every casting necessitates individual treatment. Several examples have been detailed by Dwyer,[44] while Phillips[20] has provided photographs of many castings showing the gating methods adopted.

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DISCUSSION

Mr. Miller first apologised for the omnibus nature of the Paper. He had been compelled to deal with a wide range of alloys, and this point alone might be taken as signifying difficulty in meeting the requirements of electrical engineers and others. However, he had been impressed by the considerable range of brasses and bronzes used, and thought that there was little justification for the use of such a range of alloys. Hence, efforts which would result in standardisation were to be highly commended; tribute must be paid to the work of the Non-Ferrous Technical Sub-Committee of the Institute of British Foundrymen, which had issued valuable reports on leaded bronzes and gunmetal. As against this use of a multitude of cast bronzes and brasses, the electrical and mechanical properties of which were not widely different, he had been impressed by the development of other alloys permitting the attainment of special combinations of conductivity and strength. Thus, while on the one hand it might be said that the number of the older alloys could be reduced, yet it must be recognised that some of these newer materials were advantageous. These alloys as yet were in the early stages of development, but he believed that their future use in the electrical industry would be very wide.

Electrode Holders

Mr. T. Krogvig (Norway), after a tribute to the author, said that the usual commercial alloys which were mentioned did not include the one alloy which was used in Norway for large electrode holders for electric furnaces; it was an alloy containing about 15 to 17 per cent. zinc, the remainder being copper. He asked whether the author was of the opinion that that was a better alloy than those containing 25 per cent. zinc. It was not so easy to cast as were those containing 25 per cent. zinc, so that if it did not give better service than the latter, there was no reason for using it.

Mr. Miller was interested in the fact that in Norway they had been able to standardise on an alloy containing 83 to 85 per cent. copper and 15 to 17 per cent. zinc. He had intended to give the impression in his Paper that the brasses used in Great Britain ranged in copper content between approximate limits of 55 and 80 per cent. Almost every manufacturer or specifying engineer selected a different composition to which founders had to comply. He had mentioned in particular the 75 per cent. copper, 25 per cent. zinc alloy and the 60 per cent. copper, 2 per cent. lead, 38 per cent. zinc alloy because he had thought that these were typical and very logical compositions.

There would not be a great difference in the properties of the binary copper-zinc alloys in which the zinc content varied from 15 per cent. to 25 per cent. Naturally, alloys having the lower zinc content would be slightly weaker and softer, while, in respect of electrical conductivity, he suggested that the difference would be between about 25 per cent. and a little over 30 per cent.

Degasification of Copper

Professor Portevin, dealing with the author's statement concerning the *rôle* played by gas in the reactions, particularly on the elimination of hydrogen and oxygen, and the point made that hydrogen could be eliminated by a process described in an American Patent, said he was not well acquainted with the Patent as distinct from other technical literature, because it was sometimes rather difficult to interpret; he was aware of only one process for removing the hydrogen from alloys of the kind discussed, and that process depended on the use of oxygen to remove the hydrogen. He asked for further information on the matter.

With regard to the suggestion that aluminium was a good deoxidiser, he expressed the opinion that it was difficult to deoxidise satisfactorily by the use of aluminium. From experiments actually carried out by Dr. Bastien, who was present, it was found that when aluminium was added to highly oxidised copper, the little drops of melted aluminium surrounded themselves with an oxide film which precluded deoxidation; it was necessary to stir the melted metal vigorously, preferably with a flux dissolving the oxide on formation.

Mr. Miller's Reply

Mr. Miller replied that the Patents to which he had referred were taken out by the American Metal Company or their subsidiaries, and there

was no doubt that with the aid of those Patents the company had been able to produce and market oxygen-free copper which in the cast condition was extremely sound, free from oxygen, and was of high conductivity. According to descriptions given in the Patents and by E. F. Cone,* production involved the melting of cathode copper in a reverberatory furnace, the molten metal then being led into a subsidiary furnace sealed from the ordinary atmosphere. In this, charcoal, which functioned as a cover and a filter, reduced the oxide; in addition there was provided an atmosphere of carbon dioxide and nitrogen from which there was careful removal of water vapour. The metal was led by closed launders into the moulds, which were also filled with carbon monoxide and nitrogen, so that solidification occurred out of contact with air. It was presumed that the hydrogen was removed by a purging action of the non-reactive gases.

As to the use of aluminium as a deoxidant, he said he had not had actual experience of its use in very small quantities. Such Papers as he had read rather deprecated its use for this purpose, since it formed aluminium oxide films, which became entrapped in the metal and gave rise to defects of a very serious nature. On introducing aluminium into copper he could quite visualise the immediate formation of a film which would prevent the remainder of the aluminium from functioning satisfactorily.

* "Metals and Alloys," 1937, 8, 3.

Paper No. 681

Organisation and Development of Steel Foundry Research

By WILFRED JOHN DAWSON, Assoc. Met., Sheffield

Introduction

The comprehensive character of this subject is such that a fully adequate treatment would require a contribution of much greater length than the present Paper. The subject has, therefore, been treated briefly in a number of sections, commencing with a somewhat historical treatment and concluding with a discussion of the outstanding problems. Prominence has been directed to the activities with which the author has been more particularly concerned, notably the work of the Steel Castings Research Committee of the Iron and Steel Institute.

There is probably no steel product which presents such difficulties in manufacture as a perfectly sound steel casting. It is true, also, to say that in few processes does successful production depend so much on the individual skill of the operative. Whilst the art of the moulder, accordingly, must always be an important factor in steel founding, the application of scientific control in the foundry plays an increasingly important rôle. In every branch of human activity this replacement of the art of the individual craftsmen by methods based on co-ordination of effort, and the systematised study of many experiences, is the natural course of progress.

When consideration is given to the accomplishments of the steel founders in the seventies of last century, it is impossible not to admire the excellent results obtained in the absence of all those methods of scientific control that are freely available to-day. Nevertheless, due to the absence of systematic knowledge, progress had doubtless to be paid for dearly in terms of wasters before a particular type of casting could be perfected. The history probably will never be written of those early struggles in the development of a technique which formed the basis of present practice.

EARLY DEVELOPMENTS

It was in the early fifties of the last century that success was first attained in making steel castings. Jakob Mayer, of Bochum, had overcome the disability arising from the burning-on of ordinary moulding sand to the casting by the use of calcined fireclay, or old crucibles ground to powder. The process was patented in England by E. Reipe, and first operated in this country by Vickers in 1855. The earlier castings made were bells, cog wheels, railway crossings and rings for rolling into railway tyres.[1]

The Terre Noire Works in France were supplying railway carriage wheels, crossings and rolls in 1870, and the author's own company, then known as the Hadfield Steel Foundry Company, exhibited at the Paris Exhibition of 1878, double spur wheels, railway crossings, wheels, pulleys and hydraulic cylinders.

It was only four years after this time that Mr. Hadfield, now Sir Robert Hadfield, Bt., F.R.S., invented manganese steel, and the subsequent application of this material in the production of manganese steel castings provided a signal instance of the value of research in the foundry. Concerning the origin of the first manganese steel castings, it may be of interest to recall that Hadfield, at that time a young man of 22, recorded in his experimental notebook under the date September 7, 1882, the following:—

> "I was led to make the following experiments with a view to the production of a very hard steel for tramway wheels, and grinding wheels or discs to be used in the place of emery wheels. The experiments have led to some curious, perhaps most momentous results that may to some extent *entirely revolutionise metallurgical opinions as regards alloys of iron and steel.*"

How true were the words italicised was amply proved by subsequent metallurgical history.

The perfecting of this first austenitic alloy steel as applied to castings involved the solution of new problems in every branch of manufacture: in modification of the material used in the ladle lining and of the refractories used in the moulding; new problems of feeding were involved and, owing to the hardness of the steel, new methods of cleaning, fettling and finishing had to be found; moreover, to develop the

unique physical properties which characterised the new steel, the method of heat-treatment as used for ordinary steel castings had to be revolutionised.

Initiation of Sand Research

The application of scientific control in the metallurgy of steelmaking has been operative for many years; on the other hand, it is only within comparatively recent times that really serious attention has been devoted to scientific method in moulding and casting technique. Control of moulding sands is at the very foundation of steel-foundry technique. In this field, great credit must be given to Professor P. G. H. Boswell, amongst others, for his pioneer work, for it can be truly said that it was he who, in Great Britain, laid the foundation of the scientific testing of foundry sands.

Boswell himself in 1921[3] had noted that, although the extensive endowment of scientific research in the United States had become proverbial, it was remarkable that research upon foundry problems had there received so little attention. The Bureau of Standards alone had conducted investigations on moulding sands. Boswell had quoted the opinion of an authoritative American writer familiar with foundry technique that at that time, in Great Britain, he had found a more advanced state of affairs relating to the treatment and investigation of moulding sands. Boswell's conclusions resulting from his early inquiries were that in no branch of refractories were the results of research and tests under standard conditions more necessary.

In 1919 the Hadfield Company decided to intensify the study of foundry materials, and embarked upon a programme of investigation in consultation and co-operation with Professor Boswell. Organised work of this nature was still in its infancy, but a comprehensive scheme was worked out which had the following features:—The development of methods of testing for grading by elutriation, mechanical properties (crushing and transverse strength), permeability, as well as the accepted methods of chemical analysis; their application to the study of the materials in use and the alternative mixtures utilising artificial colloidal and other organic bonds; the correlation of the relationships determined with the behaviour of the sand in the mould, and with the character of the resultant casting.

The methods of testing were developed independently, but they had many points of resemblance to those ultimately agreed to by the American and British organisations studying the subject. Differences naturally occurred, and in these circumstances standardisation has ultimately been applied on the basis of the more widely practised methods, even though the earlier methods had some advantages in detail over their successors.

Since the inception of this scheme, the scientific control of moulding materials has been enlarged in scope and become more fruitful in its application. The development of metallurgical practice has introduced a new technique in melting and a multiplication of the types of steel to be encountered in casting. Machine-moulding has increased. All these changing conditions have introduced special moulding conditions involving specific foundry problems. Correlation of the results of laboratory tests with foundry experience has indicated the characteristics of major importance, so that it has become possible to forecast with reasonable certainty the behaviour of any sand mixture before being sent into the foundry. The value of such testing in the routine control of moulding sand needs no advocacy here. Many specific problems requiring new methods of investigation have been solved from time to time. A few examples out of many will serve as an illustration. Thus, in order to determine the conditions under which cores could be made to give in the baked condition the same size as the original core box, an investigation of the expansion characteristics was necessary, and ultimately the solution was found in the selection of a specific type of grading of the sand.

The use of old crucible pots and waste firebricks had certain disadvantages. They were growing scarce, or were variable in moulding compositions and uncertain in character. Investigations to find substitutes showed that there could be used a fired grog of a specific refractoriness, hardness and toughness, and that, with care in drying, a reducing atmosphere in burning and the presence of carbon being advantageous, the proper combination of different classes of clay could in the case of a manufactured grog give a material of the required character, if the economic factors were satisfactory.

The development of new paints, the establishment of the optimum conditions for tarring or coating moulds, the search for improved bonding by the use of deflocculating agents and organic binders and the determination of the bearing of the type of mill and its influence on the character of the product, are but a few of the many problems which have been investigated.

Pioneer American Investigations

Organised research on the properties of moulding sands, sponsored by the American Foundrymen's Association, began in 1921, at a time when little attention in that country had been

given to sand control. Dr. Richard Moldenke, then secretary of the Association, had published the results of tests on a wide variety of sands carried out under his supervision. Moldenke's work had been in its earliest application concerned with the iron foundry, but his work showed a pioneer spirit and ultimately embraced all branches of the founder's art. His name, therefore, must be prominently associated with the early developments of scientific research in the foundry industry in America.

The American Foundrymen's Association, with the co-operation of the Division of Engineering, National Research Council, organised the Joint Committee on Moulding Sands Research to conduct "research on natural and synthetic moulding sands, as well as on the employment of greater proportions of used sands in moulding operations."

The primary need was considered to be the provision of practical and accurate methods for testing the physical properties of foundry sands, and the properties decided to be of greatest importance were moisture content, permeability, strength, fineness, refractoriness and durability.

Tentative standards for the determination of these physical properties and methods for chemical analysis were published in 1924 by the Committee on Standard Tests. These were revised and elaborated, and a grading classification added, in 1928. Reference to this important work would not be complete without mention of the name of Dietert, whose pioneer work in connection with the development of sand testing appliances is well known.

The extensive nature of the American activities is indicated by the fact that, in the Steel Division of the American Foundrymen's Association, there are 32 Committees and Sub-Committees, of which no fewer than 13 are dealing specially with foundry sand research.

EDUCATIONAL FACILITIES

In the initiation and application of research a factor of cardinal importance is the provision of adequate educational facilities for training purposes. Not only does this apply to those who will ultimately serve as managers and foremen, but in some measure also to operatives. In order that the results of research shall be usefully applied in practice, it is of supreme importance that foundry personnel shall be so equipped in a scientific sense that they may be able to understand, translate and apply in practice the findings of the scientific workers.

That any doubt should ever arise that such a requirement is an essential feature of a progressive state of affairs in the industry is not to be expected. Nevertheless, the matter was raised in the United States in 1930, when the question was being considered of the modernisation of the existing shop for foundry work used in connection with the training of engineers at the Pennsylvania State College. Doubt was expressed as to whether the building and equipping of a new foundry was justified, since there was occurring at that time a tendency towards gradual displacement of castings in engineering practice by forgings and fabricated structures.[4] In answer to this challenge strong refutation of the doubt was expressed by the leaders of the foundry industry in that country, for obvious reasons, but it was also urged that the relative position of the various types of steel manufacture was subject to variation, that the pendulum had swung too far in favour of the competitive products, and that it would inevitably swing back and that the state of education and research in relation to the industry must be an index of that development.

At about the same time as the very existence of special foundry education was being challenged in the United States, Ingall,[5] on behalf of the Constantine Technical College of Middlesbrough, which now has a department for instruction in foundry work, had made an inquiry into the facilities for training foundry personnel in this country. The replies revealed that in many centres suitable courses were available, but there was a general lament that the number of students coming forward and (what is more important) the number completing the course were disappointing, and that the standard of education of the entrants was in many cases low.

During recent years the improvement of the education of foundry personnel has received considerable impetus both here and abroad. In France, the Ecole Supérieure de Fonderie, Paris, has been in existence for about 15 years and is claimed to be the first educational establishment of its kind. It specialises in higher education for foundry work. Courses in foundry instruction are also given at the Conservatoire des Arts et Métiers and at the Ecole Centrale des Arts et Manufactures. In addition there are available courses for apprentices at provincial centres, and those which form part of a works' organisation for the training of their own men.

The Technical High School, comprising also a Foundry Institute, at Aachen, is well known for the educational facilities provided for those in the foundry. A foundry course is included in the curriculum of the Clausthal Bergakademie, and foundry work is covered, although to a less extent, by the Freiberg Bergakademie. There are educational establishments dealing with foundry practice in Warsaw and Krakow.

Some dozen establishments of advanced rank in the United States carry out training and research in foundry practice. In a number of these, foundry conferences are held.

British Conditions

Dealing now with the United Kingdom, the industry is fortunate in having at Sheffield University, due largely to the enthusiastic pioneer work of Prof. J. H. Andrew, Dean of the Faculty of Metallurgy, what is probably the most complete equipment for the teaching and practice of foundry science available anywhere. The facilities include all the plant necessary for the production of steel castings on a practical scale from start to finish. A degree course in Foundry Science is provided in the Faculty of Metallurgy. In addition, the University provides exceptional facilities for the educating of foundry operatives in the form of trade lectures on foundry subjects.

This course, extending over three evening sessions, comprises training in metallurgy and the principles of foundry practice. Instruction is also provided for patternmakers and moulders. The influence of such a centre in inculcating a scientific spirit into the industry will be apparent.

Educational facilities in foundry work are provided by the British Foundry School, the foundation of which is largely due to the efforts of Mr. J. G. Pearce, the energetic and capable director of the British Cast Iron Research Association, and it is conducted in Birmingham under the ægis of that body.

Apart from the teaching institutions, the important influence exerted by the technical press ought not to be overlooked. The industry owes a debt of gratitude both to the foreign and British foundry Press; for example, the "Foundry Trade Journal," amongst others, renders excellent service, not only in publishing work done in this country, but by reviewing the major researches published abroad.

RESEARCH ACTIVITIES

Proceeding now to current activities of research organisations abroad and in this country, according to Mr. J. Léonard, Belgium is more individualistic with respect to technical and scientific investigations than other countries, and has no research association comparable with the British. The steel foundries in that country strive, each according to its means, to keep abreast of the requirements of the present time, the greatest advancement being made in the sphere of special alloys.

The Association Technique de Fonderie de Belgique has been active in the prosecution of research into sands and other foundry subjects, and Prof. A. Portevin has paid a high tribute to the activities of this body.[6] The Fonds National de Recherches Belge has also carried out researches on castability and on heat- and corrosion-resisting steel castings.

In France there is a special organisation concerned with the problems of steel casting, the Steel Casting Committee of the Association Technique de Fonderie, presided over by Mr. R. Lemoine. Problems are investigated by the research departments of the large French steelworks (Ugine, Imphy, Le Creusot, Firminy, St. Chamond, etc.), but it is understood that such research is not generally reported.

So far as Germany is concerned, Dr. Geilenkirchen, of the Technische Hauptausschuss für Giessereiwesen, has informed the author that the investigation of steel castings is not so highly organised in Germany as it is in England. On the other hand, private firms, especially the large companies, carry out extensive investigations in this field. The smaller companies also possess well-equipped laboratories and research departments. The Kaiser-Wilhelm Institute in Düsseldorf investigates technical foundry matters, but not to any special degree.

The Verein Deutscher Giessereifachleute, in which all branches of the foundry industry are represented, has formed a special steel castings committee, which co-ordinates the work of the separate private companies.

The Technical High School at Aachen is noted for its special research activities in connection with foundry problems, investigations being undertaken under the direction of Prof. Dr.-Ing. E. Piwowarski.

Research in foundry work is also carried out at Breslau Technical High School, at Berlin, at the Bergakademie Clausthal, and at Freiberg Bergakademie, where the work is concerned only with casting.

In Poland, steel foundry research occupies the attention of some half a dozen steelworks. A Polish Society of Foundrymen was founded in 1936.

In the United States of America, as in other countries, a large amount of research is carried out by individual firms, and the American Foundrymen's Association, as part of the programme of their general Foundry Sand Research Committee, is conducting at Cornell University some research on the effects of high temperature on steel foundry sands. In these respects probably the Battelle Memorial Institute is most prominent, and this famous metallurgical centre is excellently equipped to carry on research in steel foundry problems.

Steel-foundry research, in common with other research at Battelle, is concerned largely with work sponsored by industry. In some cases the sponsors are individual companies and in other cases associations. In either case, the problems are, in general, prescribed by the sponsor. The work is done on an actual cost basis, Battelle Institute being a non-profit organisation.

Other work is carried out on endowed funds of the Institute. Such investigations incline toward fundamental data of general application. Recent examples of these are a study of hydrogen in cast steel, the development of a simple and practicable test for the castability of steel, and a valuable research[7] on the effect of additions of aluminium used as a deoxidiser to steel on resultant ductility of the casting.

Thus, it will be seen that foundry training and research are being pursued in many countries. No doubt a certain amount of overlapping of work takes place, although this should not necessarily be considered a disadvantage; however, it would seem desirable that the research bodies should systematically inform their fellow workers in other countries of the nature of the work being instituted; such knowledge would undoubtedly be advantageous to those concerned in the planning of research programmes.

RESEARCH ORGANISATION IN GREAT BRITAIN

Steel Castings Research Committee

Whilst, as in other countries, most foundries conduct research relating to their individual and special problems, co-operative research has in recent years been actively pursued in Great Britain by a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation. It works under the supervision of the Research Council of the Federation.

Financial assistance is provided by grant from the General Steel Castings Association, a national body embracing the steel foundry industry of Great Britain, and also by the Research Council of the Federation. Besides the money thus provided, considerable contributions are rendered in kind by research work conducted in individual foundries by the members of the Committee and others.

The Research Committee is so constituted as to avoid overlapping with other bodies interested in foundry work, maintaining an effective liaison with the General Steel Castings Association, the Institute of British Foundrymen and the British Cast Iron Research Association by the inclusion of delegate members nominated by those bodies.

The First Report of that Committee[8] dealt principally with the examination of castings, many of them of intricate form. It served as a stimulus to the development of a scientific outlook in regard to foundry practice. In the continued work of that Committee it was determined that attention could be most usefully directed to an individual and intensive study of the basic factors which enter into the production of steel castings, and at the outset to the properties of steel which affect the quality of steel castings. The pouring character of molten steel was regarded as being amongst the cardinal problems to be solved, and a series of investigations was undertaken with a view to determining a suitable test of fluidity for workshop use. The progress made in this direction has been promising.[9]

As shown in the later Reports, a relationship has been traced between the fluidity and the freezing characteristics of an alloy system as defined by the solidus and liquidus curves in the equilibrium diagram of the system. The results fall into agreement with relationships found by Portevin and Bastien in regard to non-ferrous metals.[10] [11]

In the Second Report considerable further attention was devoted to the question of the strength and ductility of cast steel during cooling from the liquid state in sand moulds.[12] Briggs and Gezelius,[13] [14] working in America, had provided a very complete discussion of the effect of directional solidification on the soundness of steel castings. It was apparent that the effect of casting temperature and the rate of pouring on the actual contraction occurring during cooling was required to be ascertained.

A general review of the properties of steel which affect the quality of steel castings, communicated by Dr. R. H. Greaves, formed a basis for the first reports on fluidity of molten steel[15] and the investigations[12] of Mr. H. F. Hall, in the Research Department, Woolwich, on a series of cast test-bars, which were subjected to mechanical tests at successive intervals of time whilst cooling in the mould.

Other matters which had engaged the attention of the Committee in the Second Report had been the position of radiological examination of steel castings, pyrometric measurements and a bibliography on the fluidity and viscosity of metals.

The radiological examination of steel castings is a subject to which increasing attention is being directed, particularly as an aid to the production of sound castings with a minimum expenditure of steel in the form of feeder heads. The difficulty of assessing correctly a practicable standard of soundness in relation to the application of a casting to its purpose is a real one, which presents a problem that calls for an answer. In the United States, considerable attention is being given to this question.

As to the value of X-ray examination as a means of setting up suitable manufacturing procedure, there can be no question; on the other hand, there is a natural fear on the part of many foundries that, when it is used as a reception test in an arbitrary manner, perfectly good castings may be rejected, although of an order of soundness equal to those already func

tioning quite satisfactorily under service conditions.

In the Third Report[16] the subject of fluidity of steel, studied both from the fundamental and practical standpoints, has been carried forward to the point of arriving at a fluidity test, which served the imperative need of an indication of the fluidity of the metal before it was poured into the mould. Further progress was reported of the investigations into the susceptibility of steel to hot tearing.[17] The advantages which copper offered as an alloying addition in steel castings have been determined.[18]

Two Sub-Committees have commenced activity, one concerned with moulding materials and the other with foundry practice. Their programmes of investigations are as follow:—

The Sub-Committee on Moulding Materials is continuing investigations relating to methods of testing moulding sands, the search for new native sources of material, the various laboratory investigations being defined as follows:—

(*a*) Examination of the properties of different sands suitable for foundry use.

(*b*) The preparation of "standard" moulding sand.

(*c*) Various methods of testing sands, including sieve testing, and methods of dry-sand testing.

(*d*) An investigation of synthetic sands.

(*e*) The determinations of diagrams of oxide systems affecting the work of the Sub-Committee.

(*f*) An investigation of different bonding materials.

The Sub-Committee on Foundry Practice is continuing work previously undertaken by the main Committee in regard to the conditions affecting the production of tears in castings. Other researches to be undertaken are:—

(1) The investigation of the effect of heading and running methods on the solidification cavities formed when casting simple shapes in steel. The object of the investigation is to enunciate rules to be followed in order to obtain:—(*a*) The absence of any cavities or segregated areas in a casting, and (*b*) the best ratio of the size and weight of the feeder head to the casting and the best position of the feeder head.

(2) The application of the results from (1) in the study of selected castings.

(3) The investigation of the influence of brackets and chills (both external and internal) in avoiding defects or overcoming manufacturing difficulties.

(4) An investigation into the methods of running and gating castings.

NATURE OF OUTSTANDING PROBLEM

Some answer to the question "Why has foundry development lagged behind metallurgical progress?" is to be found in the complexity of foundry practice. The variables involved in the production of a steel casting include questions of design, the nature of the mould, the quality of the steel and the pouring conditions. Each of these factors includes numerous others, an infinite variation in proportion for the casting; thus, for example, in the moulding materials all the variables of the mixture, grading and preparation; in the steel, the effect of process, composition, fluidity, hot strength and air-hardening quality; and as regards casting, running, gating and temperature.

The successful production of steel castings depends upon the control of factors which, for convenience, may be classified under three headings, and on this basis consideration may be given to possible subjects for investigation.

(*a*) Design

It is not difficult to understand why, having in mind the many possible combinations among the above-mentioned variables, it frequently happens that different foundries adopt different methods of dealing with a casting of given form.

By comparison, the casting of sound ingots is a very simple task, yet even here there are many difficulties to be surmounted, notwithstanding the advantages arising from the greater flexibility of design of the ingot and the possibility of feeding by differential chilling.

Consideration of these facts leads to the conclusion that the most effective way of research into such a complicated problem is to proceed from the simple, involving the least possible number of variables, and stage by stage to develop into the more complex.

In this respect the needs of engineering practice are so diversified and from the point of view of the production of a really sound casting the design is frequently so irrational that the founder is driven to a more or less satisfactory compromise.

The subject has often been discussed, and a necessity demonstrated for co-operative action between the user and the steel foundry. It is one that might well be investigated by a joint body representing foundrymen, technical and engineering users.

(*b*) Nature of the Mould

In this case the essential elements of success depend upon the properties of the moulding materials, and accordingly the extensive work which is being carried out all over the world in an effort to evaluate the critical characteris-

tics of moulding materials should provide ultimately a sound basis for unerring practice. The extensive reports of the American Foundrymen's Association and a recent First Report to the Moulding Materials Sub-Committee are full of references to problems which await solution.

(c) The Quality of the Steel and (d) The Pouring Conditions

These are complementary factors, the former depending upon the melting conditions and the latter the ladle practice. In both of these, advances are being made in all the principal steelmaking countries in the application of those fundamental methods of investigation which are generally referred to as the study of the physical chemistry of steelmaking.

Further, the steel as it freezes in the mould passes through three stages, each having an entirely different set of physical characters, namely, the fluid state; the plastic state between the liquidus and solidus range, and that occurring just below the freezing point in the range of temperature in which the stresses arising during cooling down can cause disruption (tears and pulls), or warping; and the rigid state where again the influence of stresses and the cooling conditions are capable of producing a multitude of different effects on the structure and the properties of the cooled metal.

The Heterogeneity Committee of the Iron and Steel Institute has now been at work some fifteen years attempting to elucidate the rationale of the formation of the structure of steel cast in metal chill moulds. The same problem remains to be solved in regard to steel cast in both green and dry sand. It has been found that the heterogeneity of a chill-cast ingot is influenced largely by the character of the liquid steel which is poured into the mould, by its essential composition, *i.e.*, degree of freedom from sulphides, phosphides, oxides, and by its casting temperature. Accordingly, therefore, the trend of recent work has been directed towards a study of the factors governing the characters of the liquid steel during its melting and refining. When, however, a sand casting is considered, additional complications arise from the change in the character of the mould, the greatly increased complexity of dimensions and the influence of gases from the mould. Different conditions of running and feeding arise, and it does not necessarily follow that a set of conditions which may be ideal for a simple geometrical shape, such as an ingot, will apply to complicated designs.

The nature of the difficulty was ably expounded by the late J. H. Dickenson, in the discussion of the First Report of the Steel Castings Research Committee.[10]

At present the design of feeder heads, their location, method of gating and running may be regarded more or less as an art, and therefore success is dependent upon the skill and experience of the individual. It is, however, believed that intensive and co-operative study of this branch of foundry practice will lead to the formation of generalisations which will go far to lay a scientific foundation upon which can be built a rationale of practice for any particular class of product.

A wide field for investigation is offered in the correlation of the physical properties of the casting as a whole with its variation of structure, as governed by casting design and the mode of heat abstraction applied in the cooling, as distinct from the results obtainable on cast coupons.

The further work being undertaken by the Steel Castings Research Committee on the properties of steel during cooling at temperatures just below the setting point should throw considerable light on a number of these problems. The bearing of the design and construction of the mould is a more elusive problem, but of equal importance in its effects.

The question of soundness and cleanliness of the steel is fortunately a problem which can be studied apart from the complicating effects of mould design.

The bearing of deoxidation and the influence on fluidity of refractories and fluxes corresponding to the variations in the steel melting process, present another unsolved problem.

Temperature control has been recognised as an essential factor governing casting conditions, and considerable work is now being done on this question with a view to overcoming some of the disabilities of the optical pyrometer, when applied to foundry practice.

As regards the accurate correlation of the properties of the sand in the mould with the resultant effects on the casting, it has been recognised that at the very foundation of the problem lies the need for the availability of thoroughly standardised and accurate methods of assessing the moulding properties of foundry material. For this reason the Moulding Materials Sub-Committee of the Iron and Steel Institute is giving particular attention to the examination of the present methods. The efforts of a national Sub-Committee which is engaged on the specification of standard methods for testing are also to be welcomed. The co-operating bodies are the Moulding Materials Sub-Committee of the Iron and Steel Institute, the Institute of British Foundrymen, the British Cast Iron Research Association, and the British Non-Ferrous Metals Research Association.

The field covered by the foregoing remarks is so wide that omissions are inevitable. Nothing has

been said in the Paper concerning individual and independent research, which after all is and always will be the backbone of technical achievement. On the other hand, attention has been directed to that class of investigation which can be more profitably attacked by team work. In the organisation of such work it must often be necessary to allocate certain sections of the investigation to an individual scientific worker, whose task may be to work out a fundamental principle bearing on the general problem. The association thus brought about between the scientific worker and those closely in touch with the practical problem is of mutual benefit. With regard to the problem of co-operative research, it is hoped that the discussion will be directed to the possibilities of a wider exchange of ideas on these matters.

Acknowledgments

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DISCUSSION

The author, Mr. W. J. Dawson, presenting the Paper, said that, in connection with that section outlining foreign research activities, he had subsequently received a communication from Dr. Vanzetti, who had stated that in Italy there was an institute specially engaged in steel foundry research, and that the National Council in Rome was engaged on the same subject. Whilst at present there was no centre of organisation for research on foundry matters there, it was proposed to inaugurate one very shortly. Education in foundry science, commented Mr. Dawson, appeared to be very adequately dealt with in Italy. He added that he wished to apologise for not having mentioned the useful work carried out by the Technical Committee of the Institute of British Foundrymen, more particularly the Sands Sub-Committee and the Steel Castings Sub-Committee. He wished to ventilate, he said, the desirability of closer and more intimate association of ideas than had been effected in the past between the co-operative bodies engaged in research work.

The Steel Castings Reports

The President (Mr. W. B. Lake), commending the Paper, mentioned the hope expressed by Mr. Dawson that it would lead to an exchange of ideas on the findings put forward by the Steel Castings Research Committee. He hoped sincerely that that would be the case; but he was rather doubtful, because the conclusions had been arrived at after such careful study that he did not think many people would venture to criticise them.

Mr. C. D. Pollard (Derby), after paying tribute to Mr. Dawson and his colleagues for their valuable work as set out in the Report, said that he and those who were engaged on production in the works were doing their utmost to put into practice the investigations enumerated in the Report. At the same time, however, the scientists were doing their best to help the works executives to understand the more abstruse matters without the aid of such research work as that which Mr. Dawson and his committees were carrying out.

Mr. F. N. Lloyd (Wednesbury), referring to the work of the Foundry Practice Sub-Committee mentioned in the Paper, said that it was formed with the very idea of correlating foundry practice in various works. The Sub-Committee had been in existence only about six months, but during that time it had found that results were not going to be obtained quickly. The members of the Sub-Committee had pooled their ideas, and then by experiments conducted in their various firms they tried to prove or disprove

their ideas and to reach agreement upon those fundamental theories upon which all their ideas must be built. They had progressed a certain distance, and had been working on the production of steel castings under various heads and under closely controlled conditions of casting, and they hoped to be able to report on that matter within a short time. He mentioned the matter to show how they were tackling the very awkward problem submitted to them, and to show that the work was being done by people actively engaged in the foundry industry.

Paper No. 682

Radiography in Iron and Steel Founding

By F. W. ROWE, B.Sc. (Associate Member)

Modern industrial radiology embraces two main fields: (*a*) The examination of the crystal structure of materials in the form of X-ray diffraction, and (*b*) the examination of internal soundness by radiography with both X- and gamma-rays. The subject to be dealt with concerns the latter category.

Historical

Probably the first hint of the existence of properties which are now utilised so universally was given when Francis Hauksbee reported to the Royal Society in 1705 on the production of flashes of purple light by mechanically rubbing together amber and woollen cloth under a bell-jar connected to a vacuum pump.

Abbé Nollet continued Hauksbee's work in Paris in 1753, and William Morgan delivered a Paper before the Royal Society in 1785 on the electrical properties of a very high vacuum. Morgan very probably produced X-rays, although, of course, undetected by him.

Pluecker, in 1859, and Hittorf, in 1869, published work on fluorescence, remarking that objects placed between the cathode and the wall of a high-vacuum tube threw a distant shadow. Crookes, in 1879, began to establish the physical principles underlying these phenomena. Later, in 1895, Roentgen, in an experiment to discover the emission of ultra-violet light from these high vacuum discharges, found that a fluorescent screen of barium platino-cyanide lying some 10 ft. from the tube glowed whenever he switched on. He immediately began an intense study of this unknown or "X" radiation, and found that it is emitted from anything, especially the positive electrode, hit by the stream of electrons from the negative electrode. He found that these "X-rays" have a remarkable ability for passing through material opaque to visual light, and that their penetrative power increases with voltage, although the higher the atomic weight of the material the less will the rays penetrate through it. He also found that the radiation produces a photographic image and, as far back as 1897, Roentgen obtained satisfactory radiographs of many metal objects.

Until 1912, however, efforts to apply X-rays industrially were seriously hampered because the tubes then in use could not stand the high voltages required, nor would the generating equipment deliver sufficient current, which, in conjunction with the slow glass photographic plates, necessitated very long exposures. But, in 1912, Friedrich, Knipping, and Laue published a Paper on "X-Ray Diffraction Phenomena," which aroused keen interest in X-ray research. In the same year Coolidge introduced a new type of tube, which could be operated continuously at higher voltages, using greater currents, thus increasing both the penetrative power and the intensity of the rays. The advent of the Coolidge tube marks the beginning of the effective use of radiography in industry.

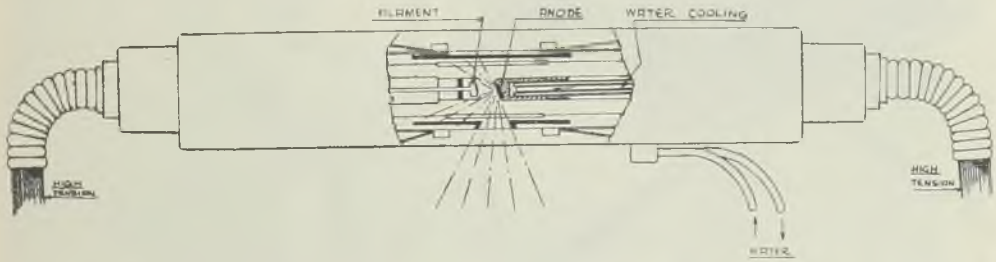

Fig. 1.—Diagram of X-Ray Tube, showing Relative Positions of the Various Parts.

During and after the Great War radiography continued to improve steadily with the introduction of better power plants, higher quality fluorescent screens, and photographic film coated on both faces with special X-ray sensitive

emulsion. In 1922 the U.S. Government Arsenal at Watertown, Massachusetts, installed a 200,000-volt equipment passing 5 milliamps, raising the possible thickness of steel able to be radiographed from 1½ in. with the then maximum of 125,000 volts to 3 in. with the new tube.

About 1925 engineers began to demand X-ray inspection of important castings in high-pressure steam plants, and from then on this method of inspection was increasingly applied to castings in light alloys. In 1925, too, Pilon and Laborde claimed the honour of first using gamma-rays for the inspection of metal. However, Mehl, in the United States, in 1929, seems to have been the first worker to do any systematic research on the use of radio-active materials for industrial inspection and, in conjunction with Barret and Doan, established the basic principles of the method.

The year 1930 saw the introduction of the first portable X-ray sets, and the successful shock-proofing of smaller tubes has lent great impetus to this type of apparatus. The possibility of X-ray equipments decreases with the use of higher voltages, for, while remarkably flexible set-ups are available at 200,000 volts, the apparatus required for field inspection at 300,000 volts is by no means so manœuvrable.

In 1932 a 300,000-volt Coolidge tube became available, increasing the thickness of steel that can be radiographed from 3 in. to 4½ in. Although not strictly within the scope of this Paper, a glance at recent advances in other fields discloses the successful installation of a 750,000-volt tube for deep therapy in St. Bartholomew's Hospital, London, and million-volt tubes are now being used experimentally. The introduction of the rotating anode, where the energy of the cathode stream is spread over a ring instead of on a small, fixed area, permits a very much greater input, with corresponding increase in X-ray intensity, without any loss of definition. A 2-amp., 25,000-volt, 50-kw. tube with a rotating anode has been perfected by Muller and Clay in the Royal Institution for crystal structure analysis, X-rays of longer wavelength, generated at lower voltages, being more convenient for this type of work. Professor Lawrence, too, has evolved the "Cyclotron," which generates artificial radio-activity

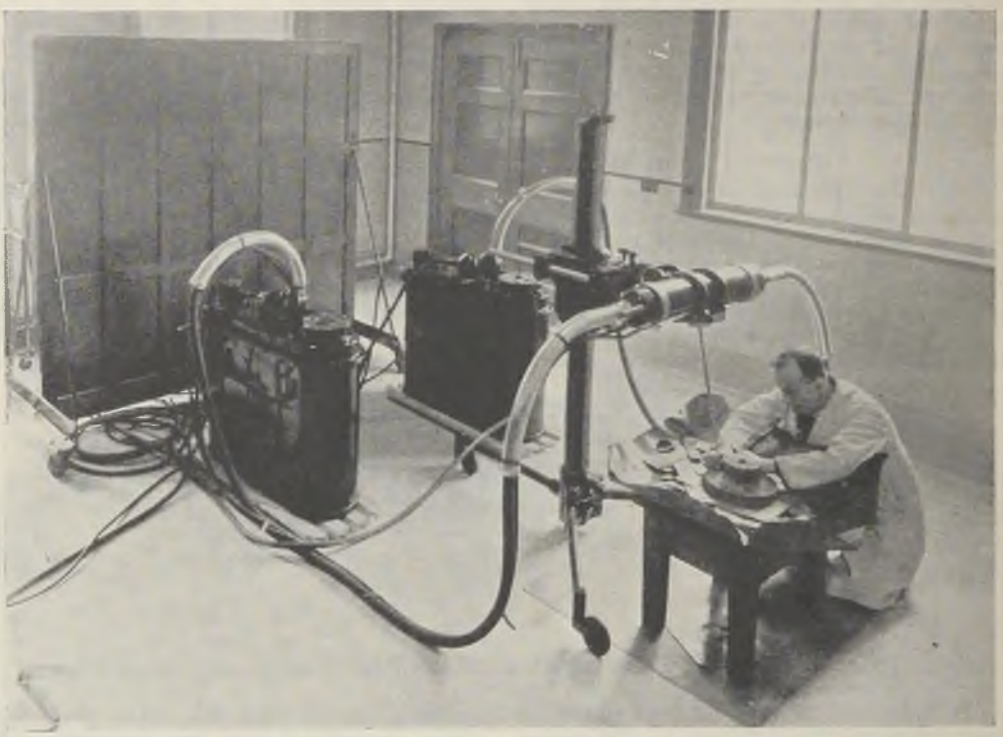

Fig. 2.—General View of the 300-kw. Plant in David Brown & Sons' Penistone Works.

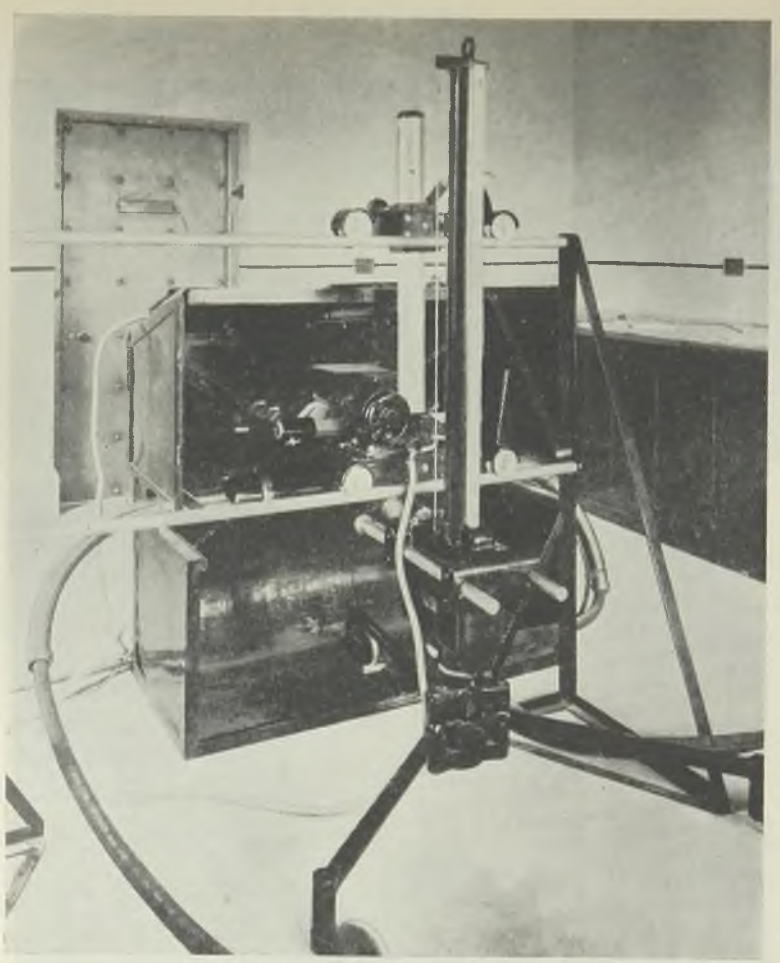

Fig. 3.—Set-up for Visual Inspection at the Penistone Works of David Brown & Sons.

Fig. 4.—Casting on the Work Table of the Set-up Ready for Visual Inspection.

Fig. 5.—Visual Set-up as in Use, showing Operation of the Rocking Control.

Fig. 6.—Set-up for Radiography using Film. The Operator is Measuring the Distance from Target to Casting.

by the bombardment of certain elements with high-speed photons or deutrons.

So far only developments in apparatus have been mentioned. The Ilford and Agfa-Ansco concerns have, however, recently introduced new X-ray film stock which is a definite advance on the older materials in definition, contrast and speed. No intensifying screens are required. The Ilford and Kodak companies have also introduced new developers enabling a 40 per cent. reduction in exposure on that required a short time ago. It is possible, too, by means of other developers introduced by these two firms to develop, rinse and fix within 1 to 3 min.

Generation of X-Rays

Fig. 1 is a line drawing of an X-ray tube, indicating diagrammatically the relative positions of the various parts. The anode and fila-

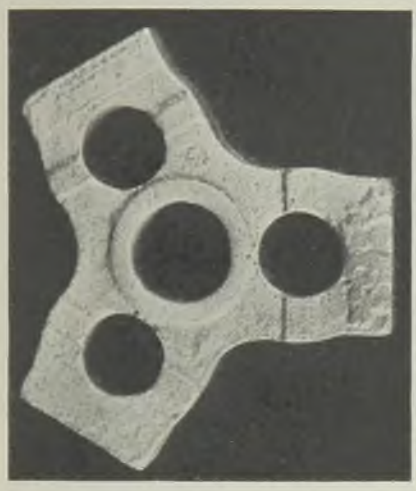

Fig. 7.—Manganese Steel Hammer.

ment are enclosed in a glass envelope, around which is a metal shield to absorb the X-rays. The anode is water-cooled. The two high-tension leads and the filament cable are brought out at either end in flexible earthed metal tubes.

An X-ray tube consists of a sealed glass envelope, encased in various ray-proof layers of metal, evacuated to a very high degree, containing an anode, usually of copper with a tungsten target inset, and a filament coated with electron-emitting material. A high d.c. voltage is applied to the tube, the positive to the anode, and the negative to the filament or cathode. The cathode, when heated, supplies electrons to bridge the gap between it and the anode. The very high voltages used cause the electrons to accelerate towards the target, and to bombard the atoms on its surface. This impact of a rapidly moving particle into an atom causes disturbances in the inner electrons of the atom, which, as they subside, give out X-radiations of a wavelength depending upon the force of the impact. The higher the applied voltage the greater the impact and the shorter the wavelength, with consequent increase in penetrative power. Thus, the higher the voltage applied to a tube, the greater will be the penetration of the rays emanating from it. The wavelength of the emanation is also somewhat dependent upon the material of which the target is made.

The quantity of X-rays produced depends upon the number of impacts occurring in a given time, of which the tube current is a measure. Thus, for any one tube, the applied voltage determines the wavelength of the radiation, and the tube current determines its intensity.

After X-rays leave the target, they obey the normal inverse square law, *i.e.*, the quantity of X-rays passing 1 sq. in. at 1 in. from the target is spread over 4 sq. in. at 2 in. and 9 sq. in. at 3 in., and so on. Thus, on any given area the intensity of X-rays decreases as the square of the distance from the target.

Further, although X-rays, by reason of their extremely short wavelength, are able to penetrate materials opaque to visible light, they are absorbed as they travel through the material. In any one material the absorption depends on the thickness, while in different materials the absorption varies as the atomic weight, lead, for instance, absorbing far more rays than an equal thickness of aluminium.

Thus, the intensity of X-rays reaching a point at a distance from the tube depends upon:—

(*a*) The material forming the target of the tube.

(*b*) Voltage applied to the tube.

(*c*) Current passing through the tube.

(*d*) Distance of the point in question from the target.

(*e*) Thickness of the interposed material.

(*f*) Atomic weight of the material.

The usual method of driving modern X-ray tubes is by static apparatus as opposed to the older rotating machinery. Alternating current at normal domestic voltages is transformed up to the voltage required for the tube and rectified by the use of rectifying valves, both the transformer and the valves being oil-immersed. By this means a pulsating d.-c. voltage is impressed on the tube. The filament of the tube is heated from a separate low-voltage winding on the transformer.

Both voltage and filament current are controllable from a separate control table which is arranged so that mishandling of the apparatus

is almost impossible. By the inclusion of various locking and protective devices, the maximum tube life is secured, and adequate safety provided for the personnel. The question of safety is of great importance, both in relation to the danger possible from the high voltages used, and from the rays themselves, since over-exposure can give rise to permanent changes in the tissues and to severe burns.

All modern tubes, except perhaps those in experimental laboratories, are effectively shock-proof and ray-proof. The floor, walls and ceiling of X-ray rooms are lined with sufficient absorptive material to take up any scattered radiation which may be reflected or diffracted from parts being radiographed. Where a set is being used in a location not specifically laid out for X-ray work, adequate precautions must be taken to prevent scatter by enclosing the radiographed area in sheet lead.

Fig. 8.—Radiographs of the Casting shown in Fig. 7.

Technique

Many people are already familiar with some of the more elementary though fundamental points of radiography, but the following *résumé* describes briefly the principles.

In the early days of photography, it used to be quite a vogue to take silhouette portraits of one's friends, whereby the shadow of the sitter was recorded on the plate. A similar principle is employed in radiography, except that, instead of using radiations in the visible part of the spectrum of wavelength 7,500 to 3,800 Ångstroms (10^{-8} cm.), actual penetration of the object is achieved by the use of X- and gamma-radiations. This penetration is obtained because X-rays have a wavelength of 500 to 0.4 Å., and gamma-rays are even shorter, at 1.4 to 0.01 Å. The shorter the wavelength the greater the penetration.

In passing through the material—say, a steel casting, the radiation is absorbed by it in amounts dependent upon the thickness. Thus, the radiograph of a truly homogeneous piece of material would show blackening of the negative under thin parts (casting a light shadow), while the thicker parts, absorbing more radiation, would throw heavier shadows, with consequently less blackening on the negative. Added to this, cavities in the material do not absorb so much of the radiation as the bulk, and so cast lighter shadows, which show on the negative as dark spots. The same applies to inclusions, such as sand or slag, so that radiography provides a means of probing the interior of a casting for defects without having to section the article and so destroy it.

As mentioned previously, X-rays can be generated electrically, while gamma-rays emanate from radio-active material. It is conceivable that gamma-rays may eventually be generated electrically, since, in the light of present experience, a tube working at a voltage in the neighbourhood of 1½ million volts should generate X-rays having a wavelength equal to that of gamma-rays. Unfortunately, the human eye cannot detect X-rays, so that some recording device is required to register these shadowgraphs. Two principal methods are available, namely, fluoroscopy and photography.

Fluoroscopy

Roentgen's barium platino-cyanide, mentioned earlier, has the property of fluorescing or converting X-radiations into visible light, the point

to point brightness of the glow depending upon the amount of radiation reaching the screen. Barium platino-cyanide, though very efficient, has now been replaced by screens of calcium tungstate and zinc silicate. Screens built up of thin deposits of these salts on glass serve to make visible to the naked eye the radiograph of any object placed between them and the X-ray tube.

Such visual inspection has the considerable advantage of being instantaneous, but, like most good things, there is a catch in it. An image with good detail may be registered on a photographic film by allowing the rays to take an accumulative effect during a long exposure, but no such accumulation occurs during fluorescence, so that the image is very much weaker. This fact limits the thickness of metal which may be visually inspected, for, while a 200,000-volt tube might yield a good photographic image of 3 in. of steel, the same tube could only give a satisfactory image on the fluorescent screen of half an inch of steel.

Fluoroscopic inspection is thus only applicable to the detection of large cavities and inclusions in limited thicknesses of metal, or to the routine inspection of articles which are not very absorbent, such as foodstuffs. The chocolate manufacturer, for instance, can check up on the contents of his more expensive chocolates, and the fruit packer can tell by the image on the screen whether he is packing good or bad oranges.

Fig. 2 shows a general view of the 300-kv. plant at David Brown's Penistone Works, showing the tube and the tube generator housings, containing the necessary transformers and rectifying valves.

Fig. 3 illustrates a set-up for visual inspection. The work table is supported on rollers on the two horizontal cross-bars, while the tube can be seen beneath the table. A motor is used to rock the table slowly on a central pivot, and is switched on and off by a portable switch resting on top of the viewing shield. This obviates the necessity for the operator to manipulate the casting with his hands in the X-ray beam. Above the table may be seen the fluorescent screen, while, surrounding the whole, is a lead-lined shield which protects the operator. In the background the lead-lined door may be seen, with an inside lock, the rectangular plate being at the back of an illuminated danger sign. The walls, too, have been plastered with barium sulphate so that as little stray radiation as possible reaches the rest of the laboratory personnel. X-ray films are stocked on the floor above in a lead-lined chest to prevent fogging.

Fig. 4 shows a casting on the work table ready for visual inspection. When ready, the whole table may be run along sideways under the viewing screen, and can be moved when the beam is on by the rubber-handled bar above the shield. The switch for the rocking motor can be seen resting on top of the shield.

Fig. 5 illustrates the visual set-up as in use; it shows the operation of the rocking control, and the tube control table in the background. The room is normally darkened for visual work.

Radiography with X-Rays

The more usual method of X-ray investigation of iron and steel castings is by photography. Special double-coated, X-ray sensitive film of two standard sizes, namely 15 in. by 12 in. and 15 in. by 6 in., is placed between two fluorescent intensifying screens and packing in light-tight

Fig. 9.—Ni-Cr-Mo Cast-Steel Elbow.

aluminium cassettes. The screens emit light of high actinic value during exposure to X-rays, and thus serve to supplement or intensify the action on the film of the rays themselves. The cassette is placed under the object or otherwise arranged in such a position that the resulting exograph will show likely defects.

Fig. 6 shows the set-up for radiography using film. The tube is clearly shown with the negative conduit on the right-hand side and the positive or anode lead on the left. Also on the left may be seen the two flexible water pipes connected through the tube casing to the anode. The table stands on a lead mat to absorb stray radiation, thus preventing reflection up from the floor. On the table is a further lead screen on which is placed the film cassette with the casting resting directly on it. Strips of lead are arranged round the casting as a mask, so that the film outside the shadow of the casting will not be

exposed. This gives less scatter and better definition. The operator is in the act of measuring the distance from the target to the casting by means of a telescopic gauge specially designed for the job. He bases his time of exposure partially on this distance, and arranges the tube as near as he can to a standard working distance, say 20 in.

The gauge is removed before the casting is radiographed, the whole of the chromium-plated fitting unscrewing from the tube aperture. During the actual exposure the operator controls the plant by means of the control table shown in Fig. 2, and shelters behind a leaded screen, seen in the background.

Experience is prerequisite for the radiographer if a casting is to be adequately inspected, for he must be able to forecast where cracks, cavities, porosity or inclusions are likely to occur, and to expose his film accordingly. On certain jobs visual inspection may be used as a preliminary. Since radiography is expensive, the number of radiographs made per casting must be kept to a minimum. Experience is also necessary in interpreting the exograph when developed.

Using modern plant, the manipulation is very simple and foolproof. Exposures in the region of 20 to 30 mins. are usual when radiographing 4 to $4\frac{1}{2}$ in. of steel. After exposure, the film is developed, fixed and dried, and usually inspected in the negative. By using negatives, rather than making positive prints, the maximum definition of the method is obtained, since the negative may be viewed by transmitted light and small local changes in density seen.

Using film packed in cassettes as described earlier, the sensitivity of the method is, in general, such that a change in thickness of 2 per cent. is detectable by eye on the film, that is, a cavity 0.08 in. deep in a 4-in. thickness of steel could be seen.

Radiography with Gamma-Rays

The principle of radiography with gamma-rays is precisely the same as with X-rays, except that the electrical source of X-rays is now replaced by a small quantity of radio-active substance. The substance chiefly used is radium sulphate, which has a longer life and is more permanent in nature than the alternative Radon, a gas otherwise known as radium emanation. Although it is possible to approach nearer to the ideal point source using Radon, difficulties are encountered, because the emanation has a half-life of only 3.85 days, which necessitates complicated adjustments to allow for the decreasing intensity during exposure. Radium salt, however, although more bulky, is to be preferred, since, even during the longest exposures, it is unnecessary to allow for any changes in the quantity of radiation.

The method is very much simpler than that involved in the use of X-rays. The film is placed behind the object and the radium placed in position at a definite distance from the film, and left there for the appropriate exposure time. Unlike X-rays, one is hardly troubled at all by scattering when using gamma-rays, as the scattered gamma-rays are almost entirely absorbed by the material of the casting. Thus, gammagraphs are particularly suitable for

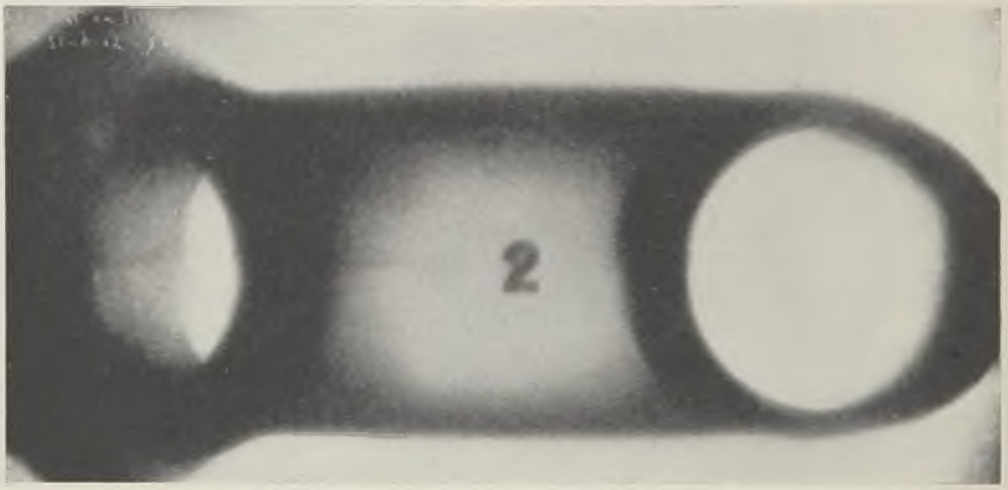

Fig. 10.—Radiograph of Steel Elbow shown in Fig. 9.

objects of irregular shape which, in exographs, would show extensive blurring and over-exposure under the thinner parts. Also, while the limit on X-rays at present appears to be about 4½ in. of steel, gamma-rays have been used for thicknesses as great as 10 or 11 in. of steel.

The slight absorption which is responsible for the great penetration of gamma-rays becomes a disadvantage when the rays reach the film, for the absorption and consequent reaction in the film itself become correspondingly less. In order to offset this effect, lead-foil intensifying screens are placed in contact with either side of the film, and these, when struck by gamma-rays, emit secondary electrons which have a greater effect on the film than the rays themselves. It is also common practice to use two films together, arranged lead-film-lead-film-lead. A double record is then obtained and faint marks the more easily interpreted. Pullen ("Engineering Radiography") gives a comparison between gamma- and X-ray exposures. The Research Department, Woolwich, at the time of his comparison, was using a source of 242 mg. of radium. Gamma-rays from this source and X-rays at 240,000 volts, both 18 in. from the film, required an equal exposure of 1½ hrs. at 4.6 in. of steel. At 6 in. of steel, however, the exposure for gamma-rays is 6 hrs., while that for X-rays is about 5 days.

Mochel ("A.S.T.M. Symposium on Radiography and X-ray Diffraction") compares the two methods as follows. Cost of film, developing, film holders, etc., does not differ greatly. Gamma-ray practice offers marked advantages in the way of operating expense, as the operator may go about other work during exposure periods.

As to cost of plant, one may consider the matter from many standpoints. Probably over 200 mg. of radium could be purchased for the price of a 300-kv. X-ray unit. Both will do excellent work in their respective fields of application. If "life" be the desideratum, radium will reach its half-life in about 1,600 years. Radium requires no maintenance and occupies very little space, while X-ray units of large size are not usually portable. Radium can be quickly set up and used, requiring no power from without; nor is it affected by line failures. It requires no switches, wiring, ventilation or water. It can be worked continuously, day and night, over week-ends, with no personnel required to operate it. Also one radium source can be arranged to yield gammagraphs of a number of objects at once, placed around it, under it and over it.

Although such comparison seems very cut and dried, the laurels rest with neither method, for they are both supreme in their own field. Industry has need for both, and the exploitation of gamma-rays should be encouraged equally alongside X-rays.

Examples

The following illustrations show a few examples of work encountered during the use of radiography at Penistone. They have been chosen as illustrations of the various types of jobs for

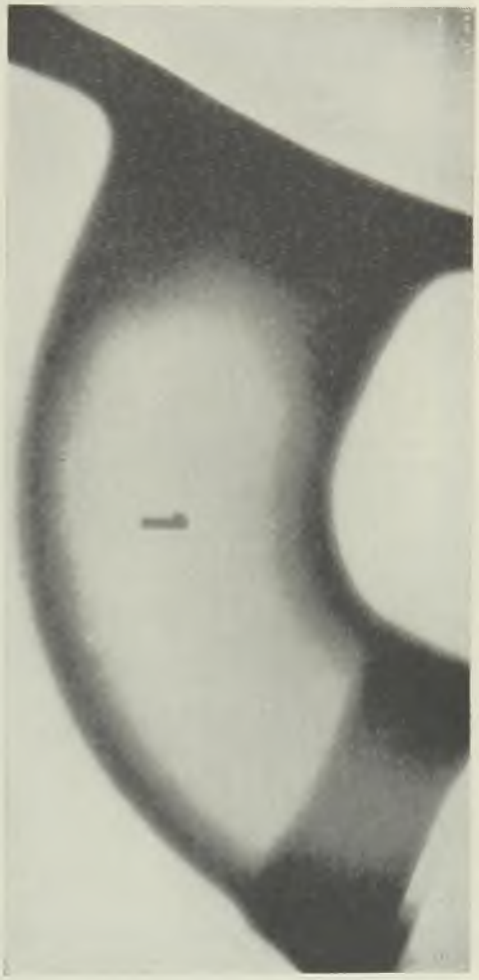

Fig. 11.—Radiograph of Elbow on Side.

which radiography is suited. The radiographs have suffered somewhat in the process of being converted into blocks, but they are still quite good enough for the purpose. Thus Fig. 7 shows an austenitic 14 per cent. manganese cast-steel hammer, weighing 6 lb. Fig. 8 is a radiograph of the hammer shown in Fig. 7, wherein the dis-

tance of target to casting was 22 in., exposure 20 secs., and voltage 160 kv. It reveals cracks or hot tears, drawing in the central portions, and drawing near the riser.

An elbow in nickel-chromium-molybdenum cast steel is shown in Fig. 9. This is the pilot casting made before production started, and was radiographed both as shown and lying on its side as a check on the technique of casting. Fig. 10 is a radiograph of the elbow taken as in the previous illustration. The distance was 20 in., the voltage 235 kv., and filters 1.5 mm. lead and 0.76 mm. copper.

Fig. 11 is a radiograph of the same elbow, but with the casting lying on its side. After inspection of the casting and of the two radiographs, the slight marking shown distributed over the pictures was found to be due to surface blemishes, and the casting pronounced sound. A casting which is to be radiographed must be finished very well on the surface, for surface irregularities show up on the exograph in a way which is quite out of proportion with internal defects.

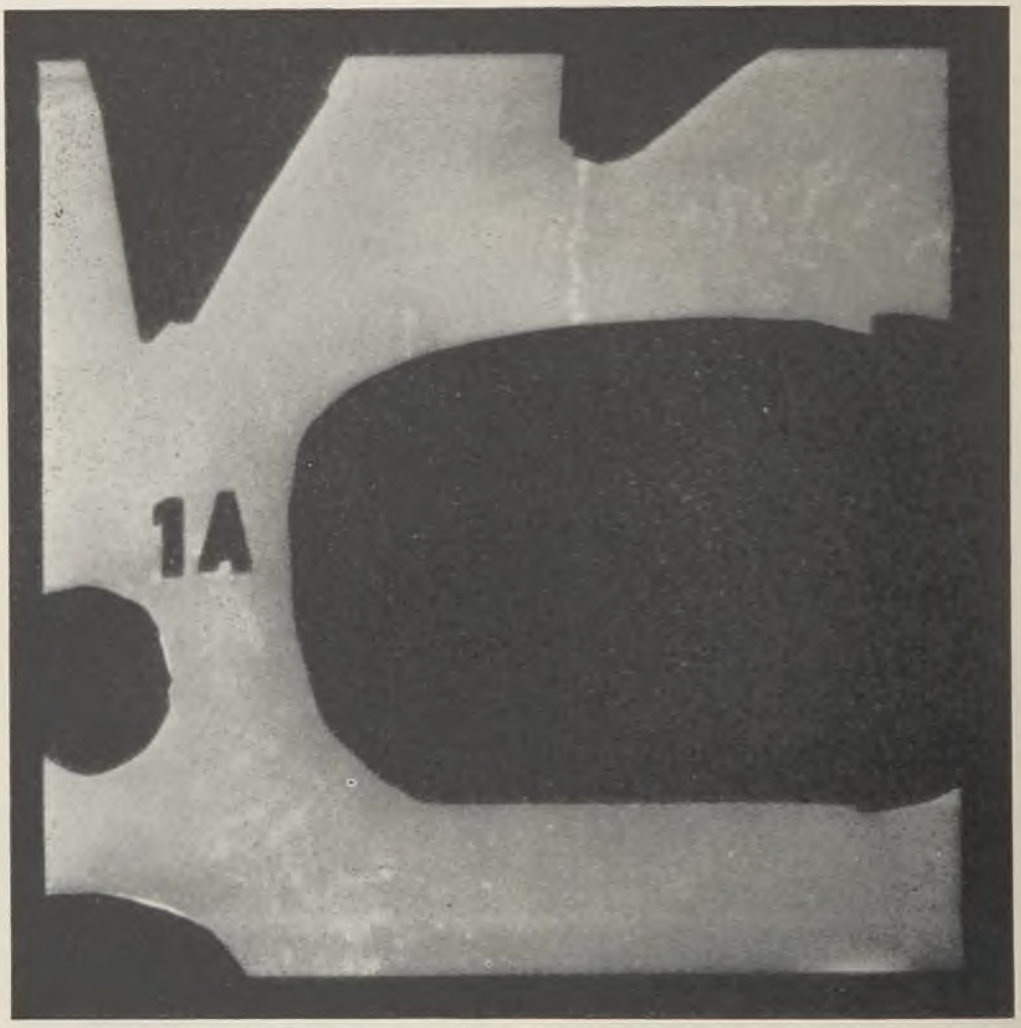

Fig. 12.—Radiograph of Manganese Cast-Steel Cutter Blade.

A radiograph of an austenitic 14 per cent. manganese cast steel cutter blade is shown in Fig. 12. The exposure was 35 seconds and the voltage 115 kv. The illustration shows a generally bad casting, porosity, and a crack on the top arm. The porosity was cured by redisposi-

tion of the runner, and the crack, which arose from severe quenching, was remedied by changing the mix slightly, thus enabling the heat-treatment to be modified so that less drastic quenching was required.

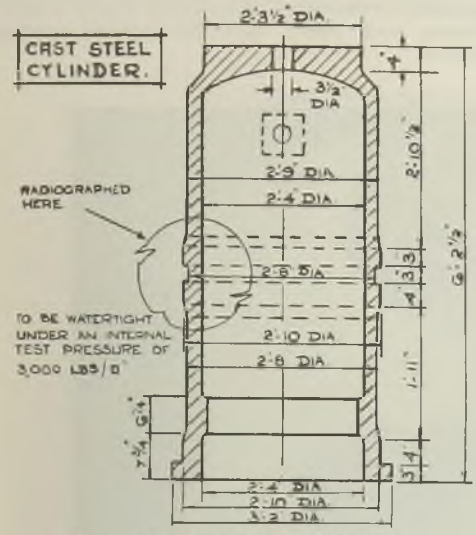

Fig. 13.—Cast-Steel Cylinder.

The various figures given of exposure time, distance, and voltage are interesting in that they bring out the flexibility of the apparatus. The same set-up may be used for thin and thick sections alike. In making a radiograph there are four main variables, namely the tube current, the tube voltage, the distance between the tube and the film, and the time of exposure. The tube current is usually maintained at a constant figure for all radiographs, and, as far as possible, the tube-to-film distance is standardised. This leaves the tube voltage and time of exposure as variables. In general, the lower the voltage the greater the contrast, but a certain minimum voltage is necessary for complete penetration. Experience tells what voltage to use for any thickness, and the exposure is varied to meet it. Too low a voltage or too short an exposure gives a very thin negative, while too high a voltage or too long an exposure gives a very black negative. The mean, using as low a voltage as possible commensurate with reasonable exposure time, yields radiographs of good contrast and density, wherein the internal structure of a casting is adequately revealed.

Fig. 15.—Manganese Steel Cutter.

Fig. 14.—Radiograph of Central Portion of Cylinder shown in Fig. 13.

Fig. 13 shows a sketch of a cast steel cylinder. The cylinder was found to be leaking in service. The casting was returned to the makers and X-rayed in the leaking portions to determine location and nature of the defects.

A radiograph of the central portion of this cylinder, shown in Fig. 14, was obtained under the following conditions: Thickness, about 2 in.; distance, 20 in.; voltage, 265 kv., and exposure, 8 mins.

The outer portions of the casting were too thick to give any appreciable record at the voltage used, so that only the central, grooved portion has shown on the radiograph. This portion shows shrinkage cavities due to unsuitable casting and feeding methods.

A photograph of an austenitic 1¼ per cent. manganese cast steel cutter is reproduced in Fig. 15, and Fig. 16 is a radiograph of it procured under the following conditions: Metal thickness, ½ in.; distance, 22 in.; voltage, 130 kv., and exposure, 20 secs.

The dark spots show porosity, and the lighter spots show surface irregularities. The trouble in this cutter was remedied by redistribution of the runners and risers and in general casting practice.

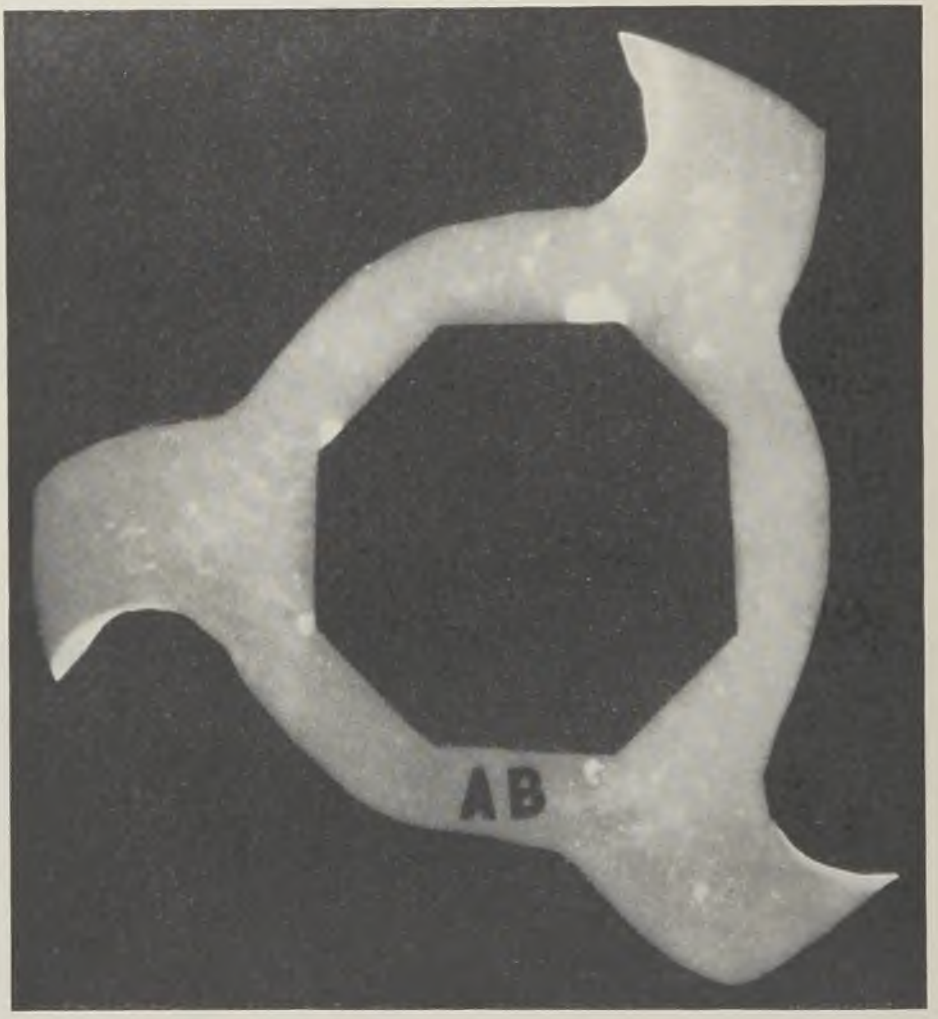

Fig. 16.—Radiograph of Cutter shown in Fig. 15.

Fig. 17 shows a radiograph of a crosshead casting. The voltage was 265 kv. and the exposure 5 mins., a filter being used. The radiograph shows defects in the bore, in spite of which the casting is giving good service, which brings out the point that some experience is required

before castings should be condemned entirely on the evidence of radiographs.

Fig. 18 is a radiograph of a box-shaped steel casting, 14 mm. thick, showing a hot tear. The trouble was cured by changing the runner positions to allow free contraction, and by casting at a lower temperature.

Thickness, ½ in.; voltage, 265 kv., and exposure, 5 mins.

Shrinkage cavities by the bosses being indicated, the casting was made sound by chilling the bosses and changing the position of the runner.

Fig. 21 shows a radiograph of a small valve body taken under the following conditions:—

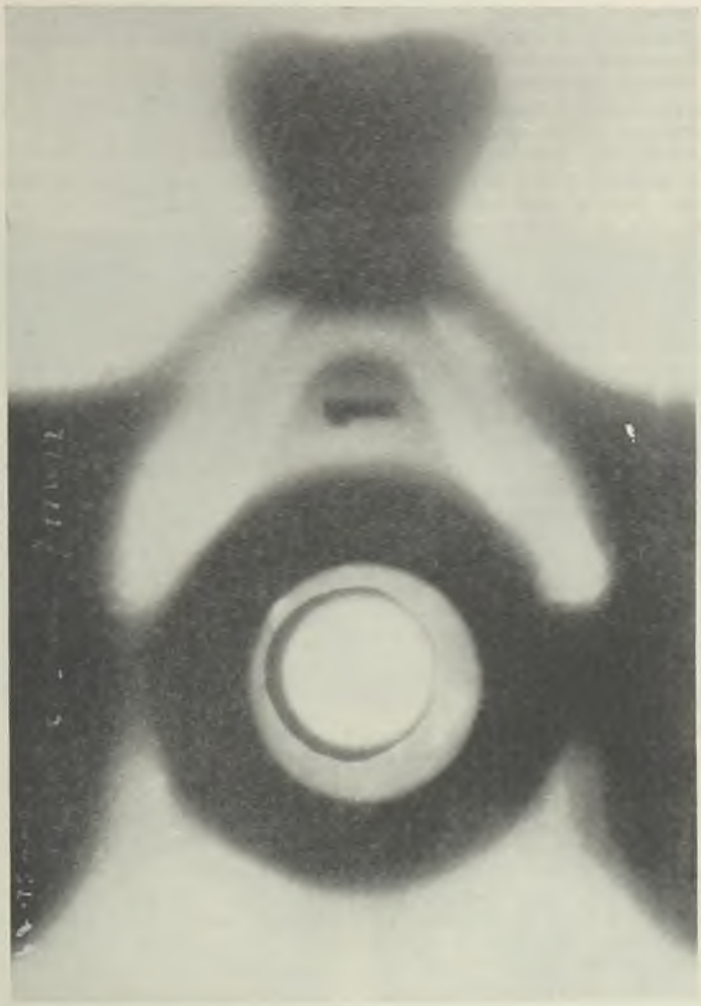

Fig. 17.—Radiograph of a Crosshead Casting.

Fig. 19 in a similar way delineates a valve body showing a good casting, procured under the following conditions:—Voltage, 235 kv. and exposure, 5 mins., filters being used.

A radiograph of a rear spring bracket is shown in Fig. 20 The details in this case are:—

Distance, 14 in.; voltage, 175 kv.; exposure, 30 secs.; copper filter used.

Radiographs of a nozzle box found to be leaking in service, showing an unmelted densener, are reproduced in Fig. 22. In this case the larger size of cassette was used and

half the plate covered with lead sheet while the other half was exposed.

Conclusion

It is often possible and practicable to apply this non-destructive method of testing as an aid to routine inspection or to the post-mortem investigation of failures. It is, however, a short-sighted policy to confine radiography to the field of inspection. Uncertainty as to the soundness of the interior of a casting has been a very big factor in making designers search for substitutes for cast metals in welding, forging or stamping. There is a quite justified mistrust of castings.

The foundryman can only win back his position by developing methods which tend to produce sound castings. Radiography may be used to this end as an aid in developing foundry techniques, as not only is it non-destructive, but it is usually cheaper and quicker than cutting up a casting.

The idea of foundry research seems to be gathering a greater following every day, and shop experiments of a general, fundamental nature, not necessarily connected with any particular production job, are becoming a necessity. Radiography may be used as a supplementary method of investigation on this work.

Another field which will assuredly repay inquiry is the use of model castings as pilots. Successful attempts have already been made whereby the running and risering of a casting have been studied on model castings, much smaller than the actual job. The same principle is used in the study of aerodynamics, the design of ships' hulls, and numerous other fields where the behaviour of the full-scale process may be judged and often accurately calculated from work on a small-scale model.

The examination of deep cracks and flaws by tomography and planigraphy is now being developed in the Research Department, Woolwich. By the use of this method it is possible to obtain the shadowgraph of one thin layer of a casting on the film, while the remainder is blurred or completely absent. The tube and the film are connected together by a link mechanism, so that, during the exposure, the tube is moved from left to right above the casting, while the film is moved from right to left under the casting. Both tube and film move on an imaginary pivot located in the casting at the point chosen for investigation. Since the relation of the pivot to both the target and the film is constant, the shadowgraph of the point will show up clearly on the film, while points above and below will be blurred.

In conclusion, the author would like to give his thanks to the directors of David Brown & Sons (Huddersfield), Limited, for their permission to publish this Paper, and to H. Walton, M.Sc., of the Research and Development Department of the Penistone Works, who assembled all the data for the Paper, and E. Firth, head of the laboratories at Penistone Works, who is responsible for the various radiographs.

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DISCUSSION

Interpretation of Results

The President (Mr. W. B. Lake) commented that the use of radiography was approached by steel foundries with some misgiving. Steel founders would welcome it in their shops when they could be sure they would be able to put a proper interpretation upon the results shown by the photographs or the visual examination, as the case might be; but they were a little doubtful as to how those results would be interpreted by some inspectors.

Dr. Guido Vanzetti (President, International Committee of Foundry Technical Associations) emphasised that he would not like his words to be wrongly or in any way interpreted as contrary to the new discoveries of science and progress. Dealing particularly with the use of X-rays in the foundry, he said he noticed a certain apprehension among foundrymen lest this system be made compulsory by the buying authorities, who often had a tendency to adopt any new inspection system even before thoroughly knowing how to use it or how to interpret the results.

Care in Industrial Application

Mr. J. H. Cooper (Darlington) congratulated Mr. Rowe on his Paper, and said that since Mr. Rowe had had his X-ray plant he had made wonderful strides, indeed, he had been progressive in many things other than the application of X-rays.

Mr. Cooper recalled that a year or so ago he had spent some weeks in Germany, where he had seen steel and other castings inspected by X-rays, and he had become very keenly alive to the possibilities of the use of X-ray apparatus in the hands of people who could use it, as well as to the possibilities of its use in the other direction by inspectors who could not use it. Just as the difficulty had arisen at the time of the introduction of the sand-blast, that people who came to see it could not appreciate the defects, so it was with X-rays. It was important when using X-rays to ensure that the distance from the piece must be correct, and that the piece must be examined in several positions. The apparatus, used at low amperage and high voltage, could not be put into the hands of any inspector who had not the advantage of intensive training. It was of great importance to avoid under- or over-exposure; a variation of distance of 10 or 20 mm. would result in entirely different readings. The problem of interpretation was a matter calling for the greatest care. By radioscopic methods one could examine small castings on a fluorescent screen with very great rapidity, so that if troubles occurred, as, for instance, where there was a defect at the bottom of the runner, causing tears, etc., one was able to put the matter right before a large number of castings were produced.

The maximum penetration of X-rays into steel was about 5 in., and by reason of that limitation one must take careful note of the differences of cross-section in the casting to be examined. If one were inspecting a casting at an angle in a corner, for example, it must be borne in mind that the maximum depth of penetration was only some 2 or 2½ in., in a direct line at right angles to the edge of the casting.

Ionisation Chamber Method

Mr. Bensimon (Paris) pointed out the importance to be attached to the methods based on the determination of the intensity of X-rays using ionisation chambers. He had seen, for instance, in the laboratories of the Philips' concern, a very simple arrangement comprising two small ionisation chambers in a differential circuit, of which the currents, suitably amplified, light up an incandescent lamp each time when, because of the presence of a defect, the X-rays impinging on the two chambers differ in intensity above a critical minimum.

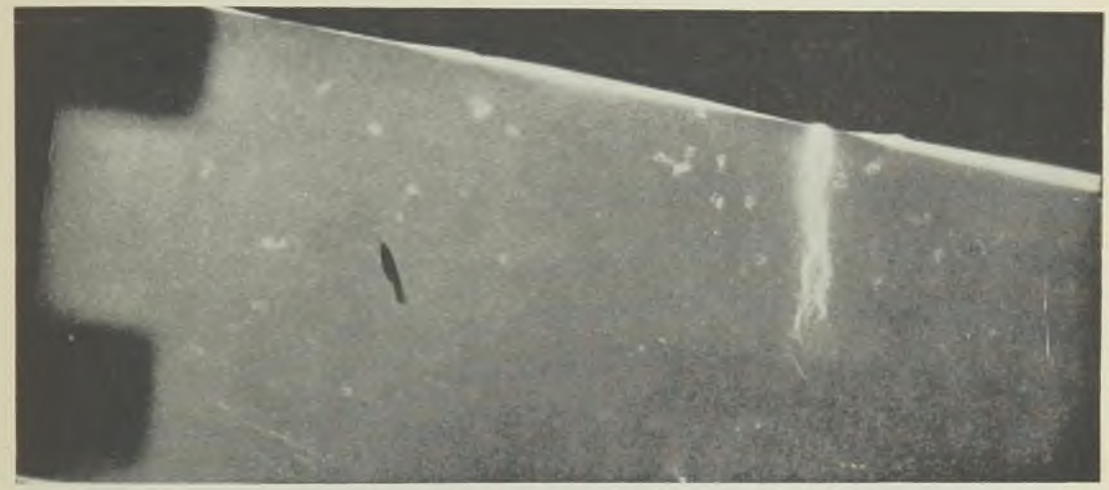

Fig. 18.—Radiograph of Box-shaped Steel Casting showing a Hot Tear.

Mr. C. H. Kain (Braintree) said that the use of X-rays was something which all steel founders would have to face sooner or later. Perhaps they had been rather afraid of it in the past, and he congratulated Mr. Rowe and his company on their initiative. He asked what degree of experience was necessary in order to interpret correctly either X-ray photographs or visual examinations. Finally, he mentioned jocularly that he rather deplored the sentence in the conclusion of the Paper that there was a quite justified mistrust of castings. It was surprising that the members of the Institute of British Foundrymen had taken that as calmly as they appeared to have done.

Limitation of X-ray Inspection

Mr. T. Henry Turner, M.Sc. (chief chemist and metallurgist, L.N.E. Railway), replying to

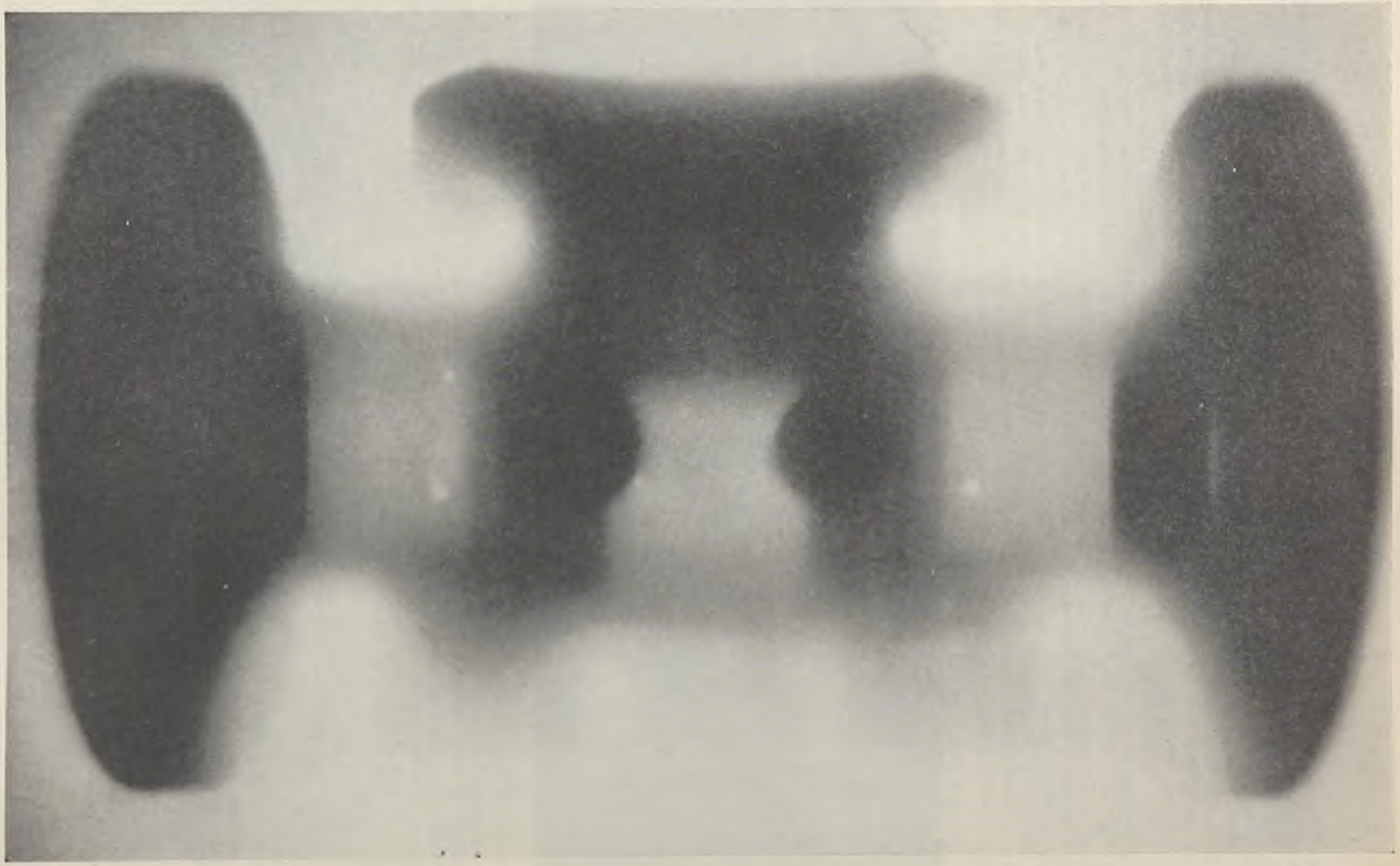

Fig. 19.—Radiograph of a Valve Body which is shown to be a Good Casting.

Dr. Vanzetti, said it seemed that there would be very little chance of inspectors using X-rays on railway castings. In the first place, the bulk of the foundries were not equipped with the apparatus, and, secondly, the sort of defect it would show most readily, such as bad porosity in a wheel centre for a locomotive, was not really of the greatest importance. A surface crack might be more serious, and there were other methods of inspection which would show up such cracks better than X-rays. Considering the field of steel castings, he said it seemed to him that engineers should be generally much more afraid of cracks than of blowholes. Unfortunately, the X-ray method of testing was particularly weak in regard to small cracks, for the reason that cracks did not penetrate straight into the metal as would a knife blade in a soft material, but persisted in following wriggly paths around grains. Obviously, if one looked along such a path through the straight eye of the X-rays, one's vision was crossing that infinitely small crack many times, and the crack could hardly be expected to show up.

X-rays were useful, however, for the examination of light alloys and welding; in the light alloys there was greater penetration, and in welds there were nearly always thin sections. If, however, one tried to look through perhaps 10 in. of a large steel boss, X-rays could hardly help. So that the answer to Dr. Vanzetti seemed to be that the railways were not contemplating standardising the use of X-rays as an acceptance test. X-ray inspection was expensive per test, which was inevitable for the present. But if the purchaser's inspector did not ask for the use of X-rays, he hoped X-rays would be regarded as a means of investigation which others should use.

He admired greatly Mr. Rowe's courage in installing the apparatus and using it, because, from the foundryman's point of view, it could show more than could be learned from the cutting of a great many sections.

An Aid to Production

Mr. G. Lutoslawski (Warsaw) emphasised the value of constant inspection by means of X-rays in the course of the production of a series of important castings, because the producer could examine the pictures in the early stages of production, could cut out pieces from places in the castings where defects were indicated by the pictures, and determine a certain parallel between the pictures and the pieces themselves. After that, a skilled inspector could determine whether a casting was good or bad by examining the X-ray picture. Of course, that could not be applied to very big castings; but the very big castings were rarely produced in series. Smaller castings produced in series could be inspected in that way, and in Poland they were so inspected with success. In respect of the larger castings, he suggested that the X-ray test could be of use in the hands of the inspectors to help in cases of doubt as to whether a casting was or was not a good one. He knew of specifications which gave inspectors the power

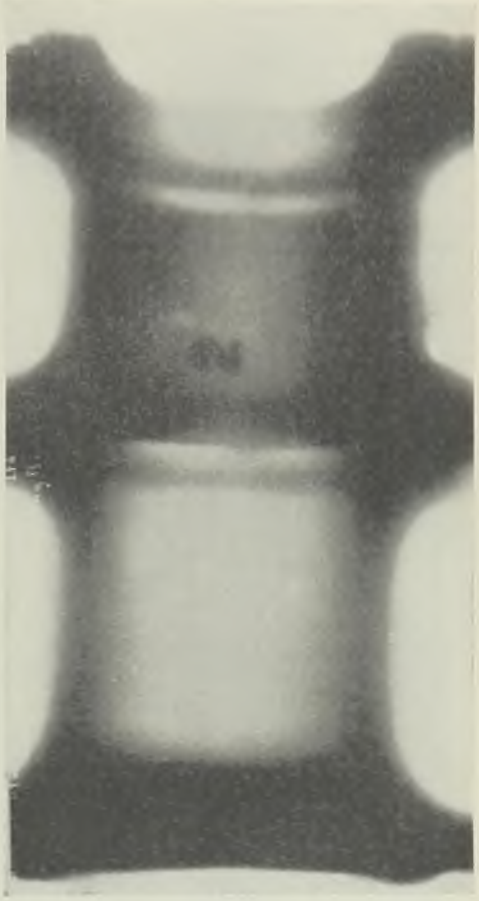

Fig. 20.—Radiograph of a Rear Spring Bracket.

to demand an X-ray picture if they thought it necessary. Of course, such work must be only in the hands of the higher inspection staff, and not in the hands of the inspecting operator.

Mr. C. D. Pollard (Derby) paid Mr. Rowe the compliment of being the first steelfounder to install X-ray apparatus for use as an aid to the production of good castings, but wondered whether he was taking steps to educate in-

specting authorities in its use. It was not only a question of whether a particular casting had a defect, but the extent of such a defect, and unless the inspector could interpret the X-ray pictures correctly, their use might be a disadvantage from this point of view.

Those who were connected with the steel industry knew that it was almost impossible to

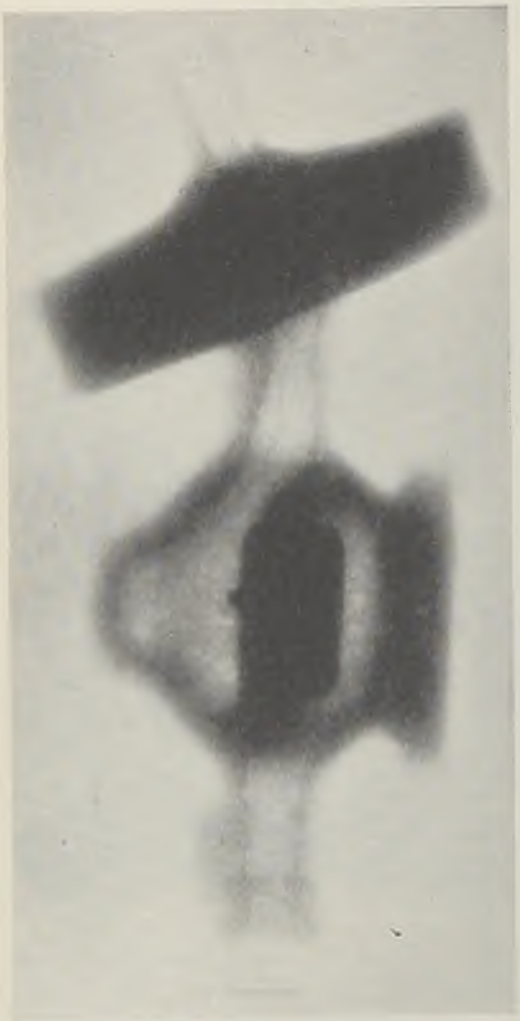

Fig. 21.—Radiograph of Valve Body.

produce a sound ingot, yet at times foundrymen were expected to make perfect steel castings, however intricate their design. He was afraid that unless inspecting engineers regarded its use as an aid to judge whether castings were serviceable and not as a further excuse for scrapping castings, the installation of X-ray apparatus was a danger.

The President (Mr. Lake) suggested that before X-rays could be applied to any extent we needed to know more about it. As Mr. Pollard had correctly observed, one could not get every steel casting solid in every part, and more knowledge was needed as to which defects really affected the casting adversely, and which defects were only of minor importance, if of any importance at all. Such knowledge could be attained only by a large amount of hard work, involving the X-ray examination of a whole series of castings which had given good service, together with a series which had failed. By comparison of the two sets of results we should arrive at some solid ground upon which to work.

AUTHOR'S REPLY

Mr. F. W. Rowe, B.Sc., replying to the discussion, said that Dr. Vanzetti, in common with a great many other steel founders both in this country and abroad, had some fear that the installation of an X-ray plant might lead to more arduous testing conditions and more rigorous inspection than had been demanded hitherto—on the principle, one supposed, that what the eye had not seen the heart had not grieved about. Whilst his own firm and his own staff were as yet only children in the use of X-rays, such fears as they had had before they had installed their apparatus had since proved to be groundless. He would almost go so far as to say that they had had more castings accepted, due to putting forward X-ray photographs, than they had had rejected.

Very often the inspectors for purchasers of castings saw a defect on the surface which might or might not penetrate a long way; and it was sometimes impossible, due to the nature of a casting, to disclose the full extent of such a defect without spoiling the casting entirely. During their short experience there had been an agreeable number of instances where defects had appeared which had seemed to the founders as likely to be of a minor character, and which the inspector had feared might prove to be major defects, but where the differing opinions had been settled by an X-ray photograph; that had led to acceptance more often than it had led to rejection.

As to the relative merits of gamma-rays and X-rays, he said they were somewhat similar methods for examining the interiors of castings, but he did not think anyone could say that one method was better than the other or that one method was likely to go further than the other in foundry use. Each had advantages which the other did not possess, and each had disadvantages which the other did not possess. Thus they

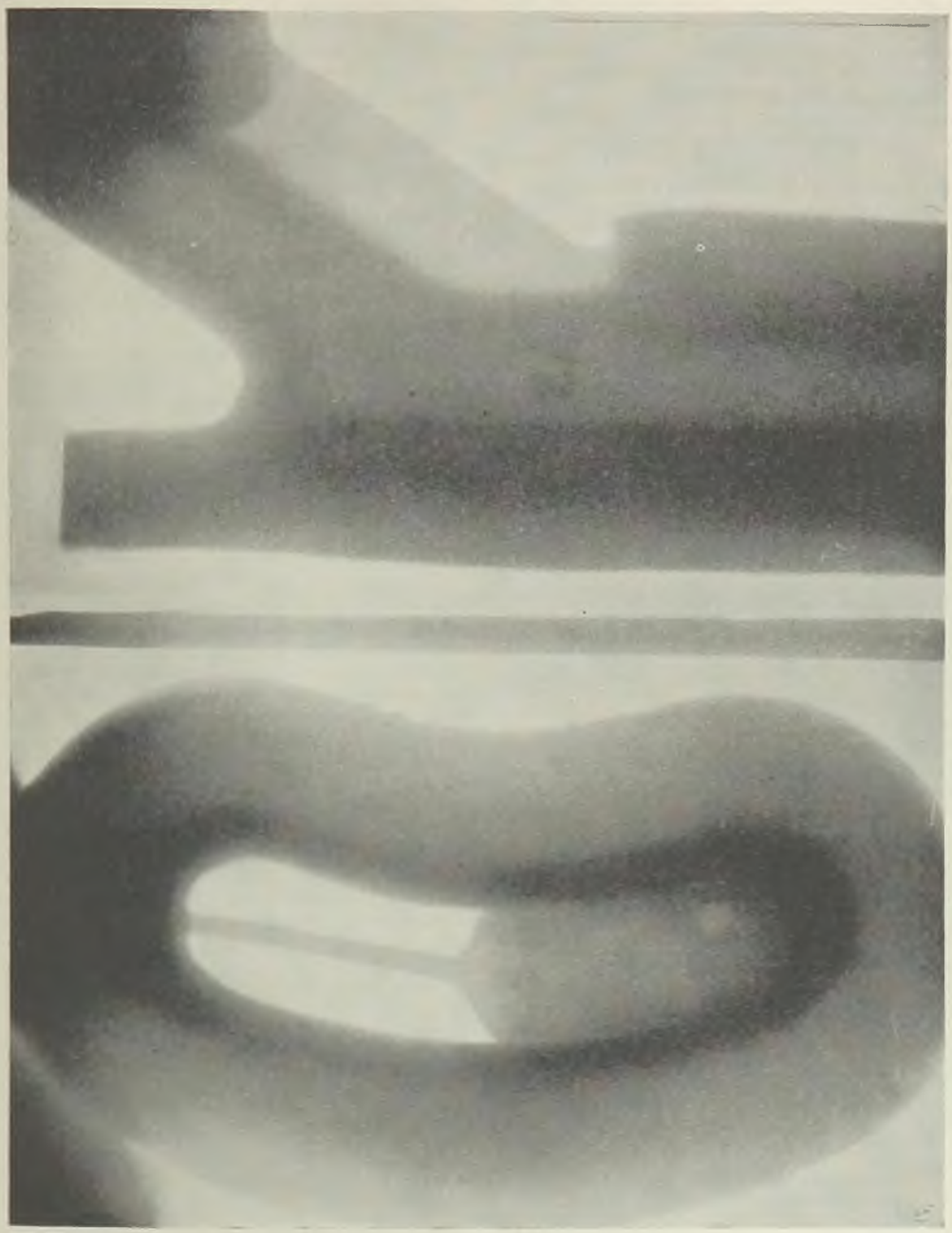

Fig. 22.—Radiographs of Nozzle Box, showing Cause of Leakage to be an Unmelted Densener.

were both excellent. His very limited experience of the use of gamma-rays would not lead him at the present stage to be more dogmatic than he had been in the Paper, in which he had tried to give a fair and reasonable summary of the relative merits of each method.

Having spent a good deal of time, particularly on the Continent, in studying the application of X-rays to steel and iron foundry practice, Mr. Cooper would appreciate how largely X-ray examination was entering into the production of some really excellent steel castings in Germany, and he was quite right in sounding the warning that mere examination by X-rays was not a cure for all foundry troubles, and that the interpretation of radiographs needed considerable experience and was attended by a fair amount of difficulty.

In reply to Mr. Bensimon and Mr. Kain, he said it was very difficult to put into words how much experience was needed before really dogmatic opinions could be expressed as the result of the examination of a radiograph. One needed almost a lifetime's experience before one could be really dogmatic about radiographs. An experienced man could obtain more or less direct quantitative measurements of the size or location of defects by taking two or three photographs at different angles. Mr. Rowe added that his knowledge of the apparatus mentioned by Mr. Bensimon as having been installed by the Philips' concern was certainly not sufficient to enable him to pass an opinion upon it.

An intelligent man with three months' experience of an X-ray plant could be of considerable assistance in dealing with the simpler kinds of castings, in which variations of section were not very considerable.

Increased Acceptance

Experience with various inspecting bodies had been that in cases of doubt the higher inspecting bodies were likely nowadays to ask that the matter should be settled by expert radiographic examination. For some time it had been obligatory to use X-rays for examining certain aircraft castings in light alloys, and a great many of the light alloy castings now going into service in this country were subjected to 100 per cent. X-ray inspection.

Agreeing with Mr. Turner that X-ray examination was not so valuable as other methods for the examination of surface cracks, he said that presumably Mr. Turner was referring to magnetic tests. The importance or otherwise of purely surface cracks was best evaluated by magnetic tests.

Then Mr. Turner had raised another bogie which Mr. Rowe's experience had not shown to be borne out, in regard to the alleged expense of X-ray testing. The experience of his company was that X-ray testing was very considerably cheaper than cutting up castings. He was afraid that the hacksaw, the milling machine and the cold saw were common tools in the foundries, and that the expense involved in using such tools in connection with the examination of castings was not always realised. It was very seldom that the cutting up of a casting in two or three directions would cost less than 30s. or £2; quite a number of X-ray photographs could be taken much more quickly, and with less disturbance to the shop than was caused by the traditional methods of examining castings.

He was indebted to Mr. Lutoslawski for having put his own thoughts into such concise English, and he endorsed whole-heartedly all that Mr. Lutoslawski had said.

The education of the inspecting authorities, mentioned by Mr. Pollard, was largely in the hands of the steel founders. One felt that if any attempt were made to resist progress, or to damn with faint praise any new method of inspecting castings for soundness, the inspection authorities were likely to insist upon its use; they would assume that there must be something in it, otherwise the producers would not protest against it.

The point raised by the President was one which he had tried to emphasise in the Paper, that a considerable amount of really hard work, perhaps covering 5 or 10 years, was necessary before the X-ray plant would be as readily accepted a tool for metallurgical examination as, say, the microscope, and he urged that, however late the iron and steel founding industry in the United Kingdom might have been in adopting X-ray examination, they ought to do more than they were doing to contribute their full quota to the progress of research on steel and iron castings, particularly having regard to the importance of this country in founding and engineering.

Paper No. 683

Notes on Dry-Sand Practice for Steel Castings

By C. J. DADSWELL, Ph.D., B.Sc., Ing.E.S.F., and T. R. WALKER, M.A. (Members)

Steel castings are poured into moulds made of a variety of materials, such as green sand, skin-dried sand, dried sand, dried "compo," and baked core mixtures. The choice of material is governed by such factors as the size and section of the castings to be made, the numbers required, the design of the castings, the facilities at hand in a particular foundry, and the economics of available raw materials.

During recent years, the manufacture of steel in green-sand moulds has increased considerably in Great Britain. Different types of sand mixtures have been investigated, and very large numbers of castings up to several hundredweights are now cast green, mostly in mixtures consisting of silica sand and some type of clay, often with the addition of a small amount of an organic binder, such as dextrin. More than half the tonnage of steel castings manufactured, however, is still cast into dried moulds. Dried moulds are stronger than green moulds, so that they will stand more handling, and also can be used for larger and heavier castings than can green sand. They have a hard surface and evolve little gas or water vapour during casting.

The materials used in this country for dry-sand work are familiar to British foundrymen, but, the present Congress being an international one, some particulars will be given of the materials used both here and in other countries.

United Kingdom Practice

In Great Britain, dried moulds are used for castings from the largest down to castings smaller than are made by this method in other countries. This is mainly because the natural sands available in this country are not, without special treatment, particularly suitable for green or skin-dried work, and small or medium-weight castings are therefore made in dry sand as a measure of precaution.

A good deal of Belgian moulding sand is still used in Great Britain, either alone or diluted with silica sand, which may be British or Belgian, the latter being usually preferable. These Belgian sands are apt to vary in properties in different consignments, but if care is taken in making up foundry mixtures, they give very satisfactory results. Owing to the fall in sterling, their price has risen during recent years, and this has led to a diminution in the amount used. Belgian sand is not, so far as the authors are aware, used for the heaviest types of steel castings.

Prepared synthetic sands can be purchased in different grades, suitable for use either as received, or after milling with silica sand or with reclaimed sand. They consist of heavily-bonded natural sands milled with a suitable proportion of silica sand of a similar grain size. Equivalent mixtures can also be prepared in the foundry from the same raw materials.

Another type of synthetic sand is produced in individual foundries by milling a selected silica sand with a suitable clay, sometimes with the addition of an organic binder. This type of sand has not been extensively used until recently, although one company, well known for the good finish of its castings, has used a similar mixture, but containing core compound, for many years. Ordinary oil-sand core mixtures are also used in some foundries, either for moulds in boxes or moulds made as outside cores.

For light castings, similar mixtures are also sometimes used when skin drying, the moulds being left exposed to the atmosphere to allow the core compound to harden. It is possible, however, to use for this purpose cheaper synthetic sands.

The natural resources of Great Britain in refractory sands were surveyed by Boswell, the results being published in 1918.[1] During recent years, the technical examination and control of moulding mixtures have made rapid progress, and this, together with other factors, has led to a renewed search for other British moulding materials suitable for steel foundries.

The results of foundry trials of a new moulding sand from Erith, and another one from the millstone grit beds near Chesterfield, are given in the "First Report of the Moulding Materials Sub-Committee" of the Iron and Steel Institute, which has recently been published.[2]

The report also includes results of laboratory tests of sands prepared from other gritstones near

Sheffield, and another from the Wrexham area.[3] Further investigations are being made of other materials, including both silica sands and clays.

Overseas Practices

The European continental practice in dry sand was reviewed in a Paper given last year by P. C. Fassotte,[4] in which he pointed out that Belgian natural sands are used extensively in Belgium and Northern France, where the foundries are very close to the sand deposits. This sand was formerly exported to many other parts of the world, including America and Australia, but owing to difficulties in obtaining supplies during the last war, and for other reasons, these countries have now developed their own resources of foundry sands. In Belgium, the natural sand is used for making castings of 50 tons or more in weight, but in Great Britain such castings are made in compo. Other foundries in France use either Belgian or French naturally-bonded sands to a considerable extent.

Another moulding material, first developed in France, consists of silica sand bonded with cement. This method of moulding has been adopted by at least one steel foundry in Great Britain, and its use in that foundry was described in a Paper given at last year's Conference of this Institute.[5] It is also in regular use in several foundries in the United States, and the results of laboratory and foundry tests on different sands and cements were given in a Paper published in the transactions of the American Foundrymen's Association in 1937.[6]

In America, synthetic sands are in almost universal use. They consist of fairly coarse-grained silica sands with a low clay content, milled with some type of refractory clay, an organic binder being sometimes added. To those accustomed to seeing in this country medium-weight castings being made in dry sand and the heaviest castings in compo, it is a surprise to find in America very large castings made in sand moulds. Some of these American sands were compared with English sands in a Paper given by one of the present authors at last year's Conference of this Institute.[7]

Sheffield Compo

Reference has already been made to the use of "compo." This moulder's composition, often known as "Sheffield compo," is probably the oldest synthetic moulding mixture used in this country. Its use may have been originally suggested by the fact that a similar material was employed in the hot tops placed on steel ingots, so that the ingredients were at hand for utilisation in the steel foundry. This mixture, which may seem somewhat strange to those visiting this country, consisted for many years of old crucible clay pots, old firebricks and Sheffield ganister, all milled up together with fireclay, some carbonaceous material such as coke or graphite being often added. Old crucible pots and old firebricks were plentiful and cheap; Sheffield ganister, a hard rock of high silica content, was already in use in the crushed or ground form as a refractory base for steelworks materials, so that the use of steel-foundry compo spread rapidly, and it has been used ever since almost exclusively for the manufacture of large and very large steel castings.

Old crucible clay pots are now becoming scarce, as the crucible furnaces are replaced by high-frequency electric furnaces, and it has become necessary to find other materials to replace the old pots. Old retort bricks from gas works have been, and are still being, used, but suitable ones for making up compo are becoming less easily obtained, since the newer gas works use different refractories. The material which has lately been adopted in place of the clay pots is a calcined bauxitic clay to which the name of "chamotte," from a similar material used on the Continent, is becoming attached, this clay in most cases being obtained from Ayrshire. The foundry with which the authors are connected was one of the first foundries in Great Britain to use this clay with no addition of old pots, and has made regular use of this type of mixture for five years with success, for castings up to 120 tons in weight, which are the heaviest made in this country.

Chamotte

In Germany, Czecho-Slovakia and other parts of Europe, there are few naturally-bonded sands available for the steel foundry, and a material somewhat similar to English compo is used for dried work. The base is a calcined lean refractory clay-grog called "chamotte," which is ground and milled with raw clay to form a moulding mixture whose working properties resemble those of English compo. A similar mixture has also been lately adopted by a few American foundries.

At Skoda, very large steel castings are made by an unusual process. Chamotte of a coarse grading, mixed with about 10 per cent. of clay, is rammed up behind the pattern. After the pattern is withdrawn, the green mould is very weak and has a very open face, which is closed up by successive applications of finer and finer chamotte paints. After drying at about 700 deg. C., the mould is extremely strong, and castings made in such moulds strip both easily and cleanly. This process has been successfully used in the foundry with which the authors are connected. Its disadvantages are, first, the high cost in England of the moulding material, and, secondly, the necessity of training moulders in an entirely new technique. The use of calcined

clay-grog of the chamotte type has also been lately adopted by a few American foundries.

Properties of Moulding Sands

The significance of many of the properties of moulding mixtures which influence their behaviour in the foundry is now well known. They include, in the case of dry sands, the size, shape and nature of the surface of the grains, permeability, green and dry strength, and water content after drying. The dry

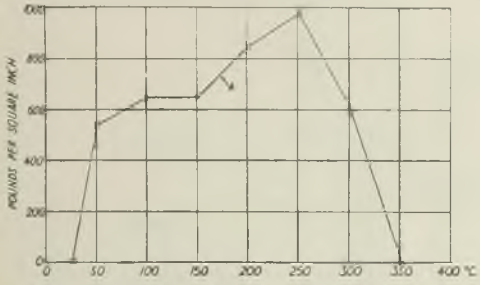

Fig. 1.—Cold Compressive Strength after Heating to Temperatures Shown.

strength is, however, by no means a simple property. If it is defined as the strength of the sand after being heated and allowed to cool, its value depends on the maximum temperature to which it has been heated. The strength of the sand may also be measured whilst it is at the high temperature, this strength depending not only on the nature of the sand mixture and the temperature at which the strength is measured, but also on the rate of application of the load.

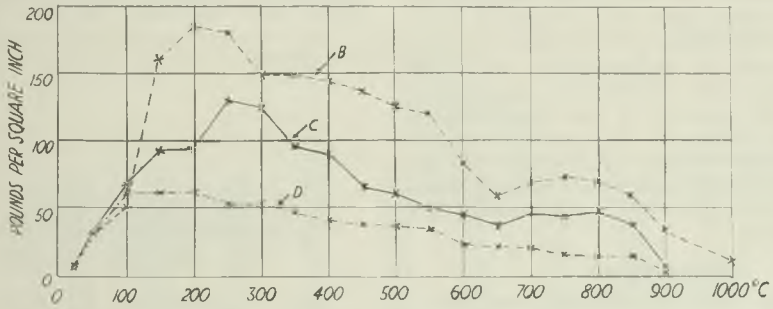

Fig. 2.—Cold Compressive Strength after Heating to Temperatures Shown.

In both cases the strength properties of the sand have important effects in the foundry.

The strength of the sand whilst it is at a high temperature is important during the casting process, when the layers of sand next to the casting are heated to a high temperature. The strength after cooling from these high temperatures becomes important during subsequent fettling operations, especially if the surface layer of the sand burns on to the casting.

Strength of Core Mixtures

In the case of core mixtures made from silica sand and organic binders, the binders burn out at a comparatively low temperature, so that parts made of such mixtures which happen to be near the steel during casting lose their strength and are easily removed afterwards on cooling. Sands bonded with clays vary considerably in this respect. The behaviour of a core mixture and of typical moulding materials is illustrated in Figs. 1, 2 and 3. In each case cylinders 2.256 in. long by 1.128 in. diameter were prepared by double compression, kept at a selected high temperature for an hour, allowed to cool on the laboratory bench, and then crushed.

Core mixture A (Fig. 1) consisted of Chelford silica sand mixed with 3.3 per cent. of a proprietary core-oil compound. After heating to 350 deg. C., it lost practically all its strength. Somewhat similar behaviour is shown by sands B, C and D (Fig. 2). Sand B consisted of 75 per cent. Belgian yellow moulding sand and 25 per cent. of Chelford silica sand, the cylinders being rammed to a relative density of 1.8. Mixture C contained four parts of Leighton Buzzard silica sand and one part of King's Lynn red silica sand, milled with 4 per cent. of refractory clay and 2 per cent. bentonite. The relative density of the cylinders was 1.8. Both these mixtures are used for dry-sand work. Sand D is a facing sand for green work, which has been included for comparison purposes. It consisted of King's Lynn red silica sand milled with bentonite and a small amount of dextrin, the cylinders being rammed to a relative density of 1.6. Such graphs may be used to fix the drying temperature of moulds made with the sands. In the present instance, they illustrate the fact that each of these sands loses its strength almost completely after being heated to 900 or 1,000 deg. C.

The behaviour of moulding materials E, F and G is somewhat different, as shown in Fig. 3. Sand E was Belgian yellow sand, milled but not diluted with silica sand, at a relative density of 1.8. Sample F was of foundry compo, made from $3\frac{1}{2}$ parts old firebricks, 2 parts calcined clay, $1\frac{1}{2}$ parts calcined ganister, $1\frac{1}{4}$ parts fireclay, and 1 per cent. of black lead. This was tested at a relative density of 1.9. Sand G was prepared from the millstone-grit sand from Chesterfield, referred to earlier in the Paper, milled and tested at a relative density of 1.8. All these materials retain an appreciable strength after being heated to 1,000 deg. C., though in the case of the Belgian sand the proportion of the maximum strength retained is not high.

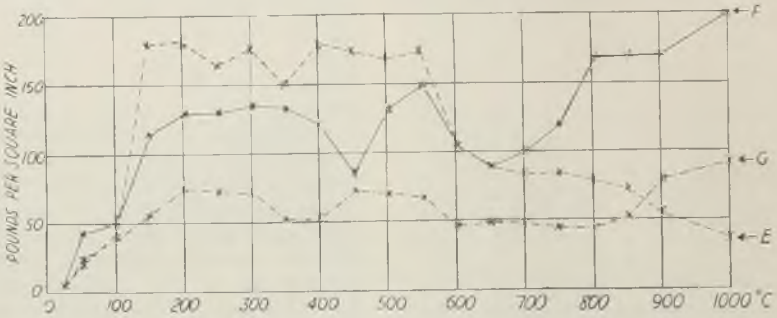

Fig. 3.—Cold Compressive Strength after Heating to Temperature Shown.

The compo and millstone-grit sand, however, are stronger after being heated to 1,000 deg. C. than after heating to any lower temperature. If, therefore, there were any burning on to the casting of surface layers of this compo or sand, the casting would be correspondingly more difficult to fettle. The burning-on of compo is usually guarded against by the application of paints to the surface of the mould, a matter which is referred to later. A foundry trial was made of the millstone-grit sand, without painting, and the castings made in it were particularly difficult to fettle.

Surface Effects

Whether the moulding mixture used has a natural or a synthetic base, it is possible, after it has been properly rammed and moulded, to obtain poor results in the surface of the castings, by incorrect treatment of the mould face after withdrawing the pattern and finishing the mould, and also by improper treatment either in the drying stove or subsequently. Drying is of prime importance, since both under-drying and over-drying often lead to trouble: under-drying because water is present in the mould during casting, and over-drying because, in the case of some sands, it weakens the surface of the mould, which is then more easily washed away by the steel.

Importance of Proper Drying

The importance of proper drying is generally realised, and many new drying plants have recently been installed in steel foundries. New plant does not, however, of itself guarantee success, and if any signs are observed of variations of moulds dried in different parts of a stove, exploratory tests should be carried out.

The temperature of a mould drying stove is usually controlled by observing the readings of an indicator or recorder connected to either a thermometer or a low-temperature thermocouple, placed in a fixed position in the stove. Sometimes two such instruments are used in an attempt to obtain better control, one being placed near the entry for the hot gases, the other near their exit. Usually the thermometric parts are robustly constructed and heavily protected against rough shop usage, which means that their readings lag considerably behind any alterations in temperature to which they are exposed. It also minimises any such variations. One or two such instruments cannot be expected to give any reliable indication of the temperature distribution throughout the stove space, but

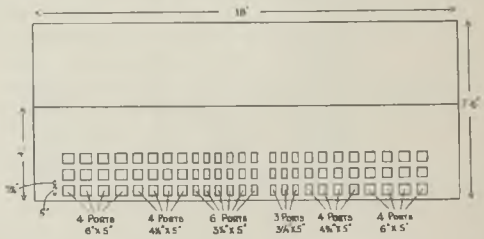

Fig. 4.—Elevation of Fire Side of Drying Stove, showing Ports.

this distribution is, nevertheless, extremely important in determining the efficiency of the drying process. New stoves have been recently installed in the foundry with which the authors are connected, and from observation it was considered necessary to carry out experiments to determine the temperature distribution in a selected stove.

This is of the type fitted with doors at both

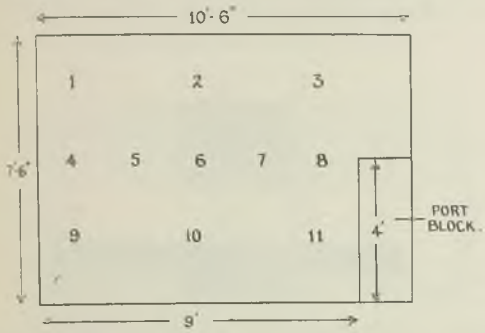

Fig. 5.—End Elevation of Stove showing Position of Thermocouples.

ends, and the moulds were charged into it by means of bogies.

The chamber is rectangular in section, being 18 ft. long by 9 ft. wide at the bottom by 7 ft. 6 in. high. The firebox is at one side, the gases being led into a mixing chamber from which they enter the stove through ports arranged in three horizontal rows. These ports consist of holes in a brick structure which projects 18 in. into the stove, so that the upper part of the stove is 10 ft. 6 in. wide. The arrangement of the ports is shown in Fig. 4, there being twenty-five in each row, the ports near the doors being larger than those towards the middle of the stove. The stove was already fitted with two recorders of the dial type connected to heavily-sheathed couples, one near the firebox side, the other near the exit side. Heating is by means of coke burned in the firebox, and secondary heated air is blown into the stove by means of a fan, along with the products of combustion. The exits in the floor of the stove are connected to an exhaust stack with natural draft.

Eleven additional thermocouples were put in the stove, their positions being as shown in Fig. 5, which is an end elevation of the stove

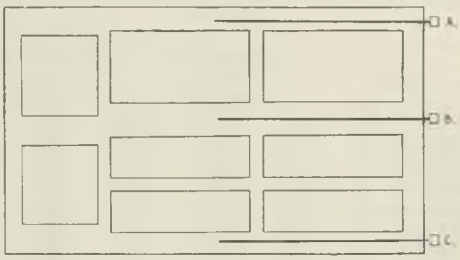

Fig. 6.—Plan of Stove, showing Moulds in Position. (A, B, C = Thermocouples.)

at its medial section. Fig. 6 is a plan of the stove showing the arrangement of the moulds during one of the experiments described below, the other arrangements being extremely similar. In the first run, a number of moulds were dried according to the usual practice, all the ports being left open, and readings of all the couples were taken at intervals during the later portion of the drying period. The results are set out in Table I.

Table I.—*Temperature Readings in deg. C. taken on a Mould Drying Stove. First Test. Heating Started at 4.40 a.m.*

Time.	Couple number.										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
10.30 a.m.	440	405	405	455	365	270	245	365	480	280	270
11.00 a.m.	425	424	424	460	330	280	250	380	485	295	285
11.30 a.m.	462	435	424	464	382	290	280	385	502	305	295
12.00 noon	470	445	442	470	394	300	268	395	508	315	302
12.30 p.m.	474	445	440	470	394	300	268	395	508	315	302
2.00 p.m.	460	436	434	470	405	310	280	394	494	325	310
2.30 p.m.	460	430	432	460	405	420	290	394	484	325	315
3.00 p.m.	465	440	438	464	408	425	292	398	495	330	318
3.30 p.m.	470	446	444	468	417	330	300	404	504	338	323
4.00 p.m.	478	448	445	470	420	338	306	406	502	345	328
4.30 p.m.	475	450	448	472	424	342	312	410	504	345	330

At the same time the readings (Table II) of the recorders permanently installed on the stove were taken.

It is evident that throughout the period the temperature distribution across the stove was very far from uniform. It will also be seen that the gradual rise in temperature of all parts of

the stove section is not shown by recorder A, and only in part by recorder B. This behaviour was repeated in the later experiments described below. It was decided to close some of the ports and so alter the course of the gases through the stove in an attempt to obtain a more uniform temperature distribution, all ports being left open in the above test, as illustrated diagrammatically in Fig. 7 (1).

TABLE II.—*Readings in deg. C. from Permanently Installed Recorders.*

Time.	Recorder at firebox side (A).	Recorder at port side (B).
10.30 a.m. ..	538	332
11.00 a.m. ..	540	343
11.30 a.m. ..	543	349
12.00 noon ..	543	354
12.30 p.m. ..	543	360
2.00 p.m. ..	538	360
2.30 p.m. ..	532	366
3.00 p.m. ..	532	360
3.30 p.m. ..	532	366
4.00 p.m. ..	532	368
4.30 p.m. ..	532	372

Second Test (Table III)

For this, eight ports in the middle of all three rows were closed, as shown in Fig. 7 (2).

Third Test (Table IV)

For this, all twenty-five ports in the top row, and the central eight in the middle row, were closed as shown in Fig. 7 (3).

Fourth Test (Table V)

For this, the central seventeen ports in the top row and the central eight in the middle row were closed, as shown in Fig. 7 (4).

in each case the final observed temperatures, the difference at the one side between top and bottom (couples 3 and 11) has decreased from 108 to 67 deg.; from side to side of the middle (couples 4 and 8), decreased from 62 to 41 deg.; from corner to corner (couples 3 and 9), de-

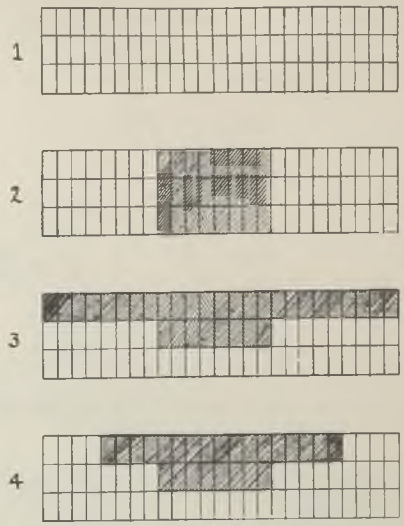

FIG. 7.—DIAGRAM SHOWING ALTERATIONS MADE TO PORTS OF DRYING STOVE.

creased from 56 to 7 deg. To obtain absolute uniformity of temperature distribution is, of course, impracticable. Even if it were obtained for a particular loading of moulds, it would be upset for the next batch to be dried, unless the arrangement of moulds was exactly the same.

TABLE III.—*Temperature Readings in deg. C. after Modifications. Second Test. Heating Started at* 3.45 *a.m.*

Time.	Couple numbers.										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
10.45 a.m.	350	335	325	367	308	338	288	292	318	225	208
11.00 a.m.	350	337	328	370	310	312	290	298	300	228	212
11.30 a.m.	362	348	335	381	318	323	300	304	288	237	219
12.00 noon	377	364	349	402	327	334	310	318	292	244	225
12.30 p.m.	405	394	372	445	343	352	325	335	305	358	235
1.00 p.m.	445	430	408	525	366	376	350	362	342	282	254
2.30 p.m.	483	463	440	570	417	419	393	398	380	341	290
3.00 p.m.	518	478	463	571	445	440	410	413	395	353	302
3.30 p.m.	481	463	443	518	438	432	402	406	391	353	302
4.00 p.m.	445	425	408	454	410	400	375	370	364	320	270

Considering the distribution of temperature across the stove, the second and third tests gave results better in parts, but mostly worse than the first test. The fourth test, however, shows an all-round improvement. For example, taking

It is nevertheless important, for adequate drying of moulds with even moderate fuel economy, to avoid cold areas in the drying stoves, since these either prolong the drying operation unduly, or give incompletely dried moulds.

Moisture Absorption after Stoving

Plastic clays are hygroscopic after drying, and absorb water vapour from the air with great readiness. This absorption takes place at the surface of the dried mould, and leads to a rapid decrease in the strength of the face, so that, on casting, the steel is more easily able to wash away the surface or to penetrate into the mould through the surface layer. The fall in strength of dried sand specimens was described in a Paper given by one of the present authors at the French Foundry Congress last year,[8] and the results of further experiments are set out in the Iron and Steel Institute Report already referred to.[9] If the drying process has been incomplete, so that water is still present inside the mould material, then this water will move outwards towards the surface after the mould has cooled down. This movement or "striking back" is likely to occur more particularly in pit-moulding, where the mould cannot be heated as a whole, and all the drying takes place from the face inwards.

It is thus important not to allow moulds which have been dried to stand in the casting bay for a longer time than is definitely necessary, before casting. If a dried mould does stand for a long time in the foundry, putting it back into the drying stove and reheating it to drive off the absorbed water does not restore the original strength of the dried surface, but leaves it permanently weaker than after the original drying.

TABLE IV.—*Temperature Readings in deg. C. after Second Modification. Third Test. Heating Started at* 8.00 *p.m.*

Time.	Couple numbers.										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
12.00 noon	425	396	390	426	331	272	316	362	404	269	257
12.30 p.m.	446	404	388	437	334	281	312	365	407	278	265
1.00 p.m.	440	410	407	439	349	294	340	381	429	282	271
2.00 p.m.	441	416	402	450	362	314	351	385	441	295	285
2.30 p.m.	442	420	411	449	369	319	359	389	440	298	287
3.00 p.m.	469	439	422	472	376	325	361	399	443	299	289
3.30 p.m.	458	435	425	468	386	334	370	404	452	313	300
4.00 p.m.	472	443	429	482	393	348	378	411	456	321	308

Mould Paints

In modern dry-sand practice, most moulds are given a coating of some kind of paint, and the results obtained in the stripping of the castings depend largely, other things being equal, on the nature and manner of application of the paint. It is the surface layer of the mould which comes into contact with the steel during casting, and is consequently raised to the highest temperature. The properties of this layer, therefore, determine the behaviour of the mould during stripping. A paint may be applied to increase the refractoriness of the surface of the mould. It is found, however, that too refractory a coating, though it may leave the steel readily after cooling, is apt to give a rough surface to the casting. Most paints contain mixtures of oxides such as silica and alumina, whilst any oxidation of the steel in contact with the mould gives ferrous oxide, with small amounts of other oxides such as manganese oxide. All these oxides can react together to give a highly viscous slag, which should adhere to the facing sand behind it, and not be fusible enough or of such a composition as to fuse to the surface of the steel in front of it.

Modern dry-sand mixtures are usually coarser in grain and more permeable than those formerly used, and one function of the mould paint is therefore to seal the surface of the mould and to prevent penetration of the steel. If penetration does occur, the steel flows for a surprising distance between the sand grains and a mixture of sand and steel results, which is very diffi-

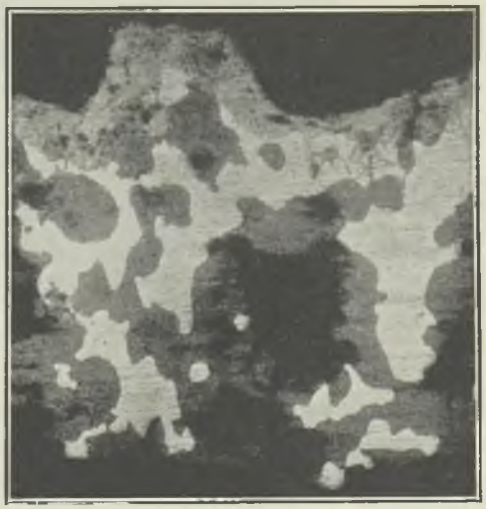

FIG. 8.—SAND-STEEL MASS PRODUCED BY PENETRATION OF STEEL THROUGH MOULD SURFACE. × 5.

cult to deal with in the fettling shop. Fig. 8 is a photomicrograph at a low magnification of a sand-steel mass produced in this way, the black areas being holes, the grey areas steel, and the white areas sand. In this mixture there was 47 per cent. of steel, which had penetrated two inches from the surface into the interior.

Paints for dry-sand moulds may be made in the foundry from a variety of materials, a very popular base being silica flour. This is suspended in water and may be applied either by brushing or by spraying. A coating of silica flour by itself, however, is powdery and easily rubbed away after drying. The liquid is therefore stiffened by the addition of bentonite, which increases the dry strength of the coating, and a small amount of core compound, which hardens the surface.

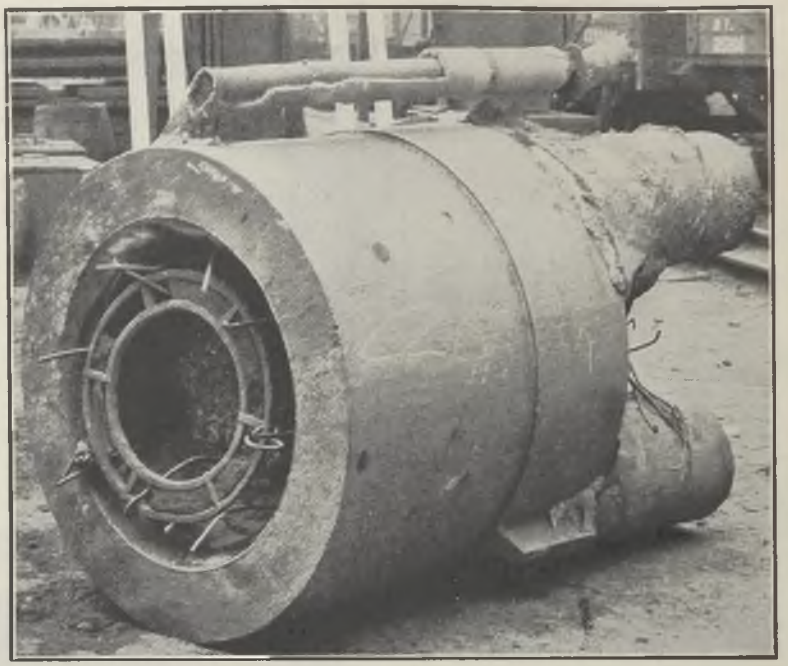

Fig. 9.—3-ton Casting made in Dried Synthetic Silica Sand and Clay Mixture, painted with White Silica Paint.

A typical composition of such a paint is as follows:—

Silica flour	20 lbs.
Bentonite	½ lb.
Core cream	1½ lbs.
Water	2 gallons.

This is suitable for spraying. If a brushing paint be required, the amount of water is reduced until the desired consistency is obtained.

Table V.—*Temperature Readings in deg. C. after Third Modification. Fourth Test. Heating Started at 3.00 a.m.*

Time.	Couple numbers.										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
11.15 a.m.	397	382	372	431	381	286	328	364	365	296	318
11.30 a.m.	408	393	383	440	389	296	333	375	372	304	324
12.00 noon	472	429	425	455	419	323	348	403	394	320	339
12.30 p.m.	492	442	451	465	444	341	364	425	421	337	356
1.00 p.m.	513	470	473	470	452	355	380	444	448	352	370
2.30 p.m.	442	424	418	430	434	366	380	404	443	343	360
3.00 p.m.	448	433	424	448	443	367	383	414	442	355	367
3.30 p.m.	458	451	437	457	450	375	390	424	448	362	374
3.50 p.m.	483	458	448	473	461	383	398	432	455	370	381

A casting weighing 3 tons made in a dried synthetic silica sand and clay mixture, painted with white silica paint, is illustrated in Figs. 9 and 10, in the stripped state. Fig. 9 is a view on the side opposite the runner and shows an excellent finish. Fig. 10 shows the part of the casting in front of the runner, where there is a small amount of burning-on, due to penetration of the paint, which has not sufficiently resisted the wash of the steel. Fig. 11 is a photograph of a similar casting, the mould being made with the same materials treated in exactly the same way, except that it was left standing a longer time before casting. The surface of the mould has been weakened and there is more penetration of the steel through the surface, though the face is not much burnt on to the casting.

These photographs of castings cast in moulds of a synthetic sand consisting of silica sand and clay may be compared with Fig. 12, which shows a smaller casting weighing 8 cwts. cast in a mould made from a proprietary facing sand, diluted with an equal amount of King's Lynn red silica sand. In this case, the sand has fallen away from the casting very well, but there is some burning-on in the re-entrant angle, where the sand has been heated most strongly.

Apart from the composition of a mould paint, the way in which it is applied to the mould surface is very important. It should be sufficiently thin to penetrate into the surface, and thus key itself well to the mould material. This means that it is often necessary to apply more than one coat, to give an adequate thickness of paint. If the paint is applied as a single thick layer, it frequently rests very loosely on top of the mould material without penetrating between the grains, and is easily dislodged in patches, especially during casting.

The finishing and painting of moulds is particularly important where compo is being used. Different methods of using compo are in operation in different foundries, and in the foundry with which the authors were concerned, good results have been obtained by using a coarse-grained compo for the moulding material, the face of the mould being afterwards finished by working into it a paint made from either crushed high-alumina clay which is the basis of the compo, or from crushed clay pots, with an addition of raw clay to provide sufficient bond. This paint may with advantage be made in two grades, one a coarser paint which is applied first, and keys very well into the coarse compo, the other a finer one which in turn

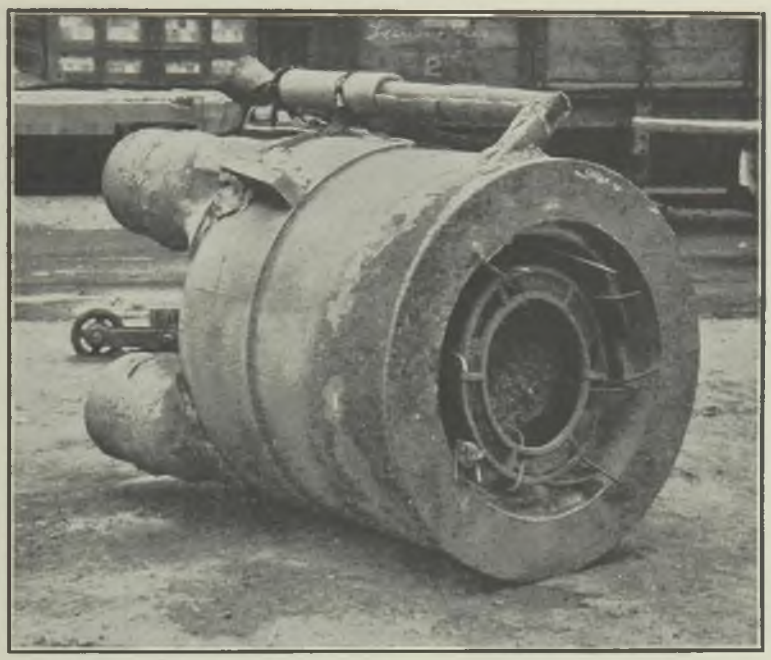

Fig. 10.—The Same Casting as in Fig. 9, showing Small Amount of Burning-on in Front of Runner.

keys itself into the rather rough surface left by the coarse paint, and provides a smooth finish to the mould.

Experiments with Compo

Compo has been used continuously in this country as a moulding material for many years. There were many local variations in its make-up due to the incorporation of materials plentiful in a particular locality, but no major alteration took place until the increasing scarcity of old clay pots necessitated the utilisation of alternative materials. The influence of size and shape of particle, and the importance of the distribution of particle size, which have been investigated during recent years in sands and other refractory materials such as bricks, appear to have received little attention in the case of compo.

This omission is now being remedied. Other investigations, some of which are described in the Iron and Steel Institute Report already referred to,[10] are towards the utilisation of a straight mixture of a single refractory material with raw clay.

The variation in particle size distribution and other properties of compos at present in use is illustrated in Table VI, which gives the results of examination of three compos manufactured and sold in considerable quantities to foundries by three well-known companies. It is naturally to be expected that the foundry behaviour of these three materials will be different if they are treated in the same way.

One fundamental difference between dry sand with a silica base and compo with a clay base is in their volume change after being strongly heated, silica expanding whilst clay contracts. This is illustrated by results (see column 2) of an experiment in which some of the materials already referred to in connection with Figs. 2 and 3 were formed into cylinders 2.256 in. long by 1.128 in. dia., which were heated to 1,460 to 1,470 deg. C. for 1 hr., and their lengths measured again after cooling.

The actual figures obtained naturally vary with the previous history of the materials. For example, a clay base which has already been calcined will have already contracted permanently, whilst the raw clay used for binding will contract on heating. Similarly, if any reclaimed silica grains are included which have previously been

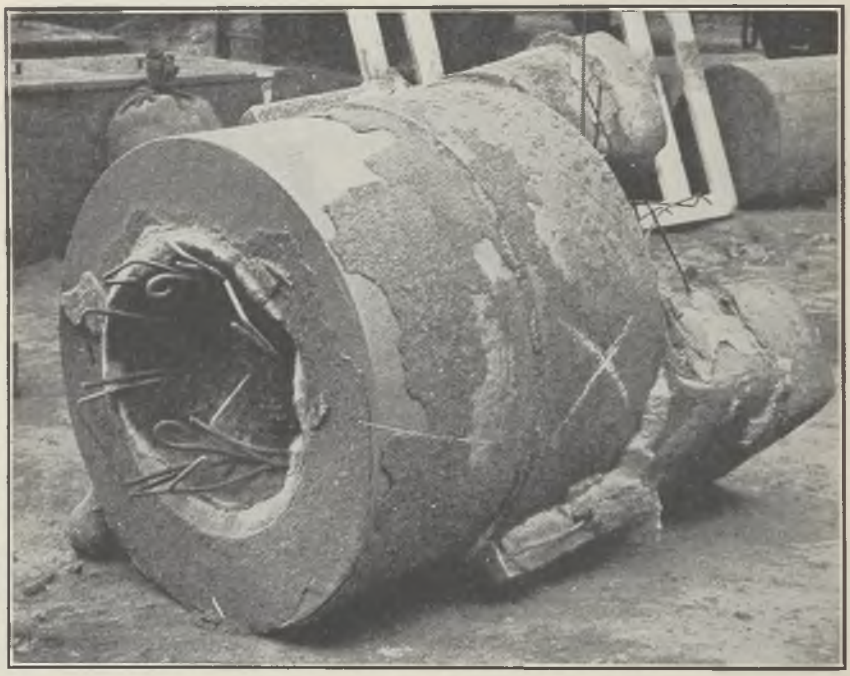

Fig. 11.—Casting made in Mould which had been allowed to Stand for a Longer Time.

heated to a sufficiently high temperature, the after-expansion of the sand mixture will be reduced.

Mixture.	Green relative density.	Change in length. Per cent.
B	1.8	+ 2.08
C	1.8	+ 4.07
F	1.9	− 1.39
G	1.9	+ 3.47

Making Medium-Weight Castings

For moulding medium-weight castings, compo and dry sand are competitive materials. Either can be used satisfactorily, and the choice, for a given casting, often depends on the relative quantities of the two materials available at the time, or on the amount of work passing through different sections of the shop. The possibilities of dry sand are being investigated, and it is being used for progressively heavier work. It may in time replace compo entirely, in this country. From an economic point of view, dry sand is a cheaper material than compo, since it

TABLE VI.—*Properties of Three Compos.*

Per cent. remaining on B.S.I. sieve No.	Compo 1	Compo 2	Compo 3
8	0.3	3.1	1.9
10	5.8	4.7	3.2
16	7.8	11.6	8.6
22	5.9	7.5	4.1
30	4.3	4.0	3.9
44	6.3	7.5	4.1
60	9.0	7.6	4.8
100	11.1	8.6	11.5
150	3.1	2.7	16.7
Silt grade	26.2	24.1	20.0
Clay grade	20.2	18.6	19.4
Permeability No.	19	33	30
Green strength. Lbs. per sq. in.	8.6	6.7	8.8
Water content. Per cent.	8.6	8.2	7.7
Dried at 200 deg. C. for 1 hr. Lbs. per sq. in.	116	218	140
Heated to 900 deg. C. for 1 hr. and crushed cold. Lbs. per sq. in.	190	470	150

uses a cheaper base, some old sand may be reclaimed for subsequent use, and the cost of painting moulds is less than in the case of compo. On the other hand, compo has an established position in making the heaviest steel castings, and also there seems no reason why larger amounts of compo should not be reclaimed than in current practice. In the authors' opinion, both materials will be used in this country for some years to come, their foundry properties being steadily improved as investigations progress.

The authors express their grateful thanks to the directors and management of English Steel Corporation, Limited, for permission to publish this Paper, the experimental work for which was carried out in the foundries and laboratories of that company.

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DISCUSSION

The discussion was opened by MR. V. C. FAULKNER (Past-President, Institute of British Foundrymen), who asked whether the steel-foundry industry had carried out any experiments in connection with the metal spraying of cores or mould surfaces with aluminium. It had been done successfully but to a very limited extent in ironfoundry practice, but he had not heard of experiments in connection with steel founding. He wondered whether it was of value, or whether the authors would regard it as merely a waste of time.

Influence of Elevated Temperatures on Sands

DR. J. G. A. SKERL, having commented on the great practical importance of the Paper to the steelfounder, said that graphs in Figs. 2 and 3 confirmed some work he had carried out for the British Cast Iron Research Association some years ago. In that work the cold compressive strengths of a range of sands after heating to certain temperatures were determined. It was found, for example, that the red sands of the Midlands of this country, which were somewhat comparable to the red sands of Belgium as regards part of their chemical composition, showed, after heating to about 250 deg. C., a progressive decline in strength at higher temperatures, whereas the Scottish rock type of moulding sand, which was similar to the Millstone Grit series from the Sheffield area, showed a gradual increase of strength as the temperature of drying became greater. The Erith sands and Pickering sands gave intermediate results.

The two graphs referred to raised the question as to what was required in a moulding sand. One could have two types of sand, one of which had decreasing strength with increase of

temperature, and the other increasing or retaining its strength. For some jobs, such as the production of a plain cylinder, a sand which retained its strength at high temperature must be of great value, especially as regards running. But for castings with ribs and flanges, etc., such a sand would be disadvantageous, because between the ribs or flanges a pressure would be developed in the sand due to the expansion, which would go against the contraction of the metal and so increase the liability to burn on. Therefore, it was necessary to choose sands to suit the particular job in hand.

With regard to mould paints, he asked whether they were applied before or after the drying of the moulds. In the iron founding industry it was found that when certain sands were used one could coat the moulds in the green condition, whereas that could not be done with other sands, and he asked whether that was the case also in the steel founding industry.

Moisture Removal from Stoves

Mr. M. Brown (Hadfields, Limited) said that the drying of moulds and cores was essentially a low-temperature furnace process. In the heat-

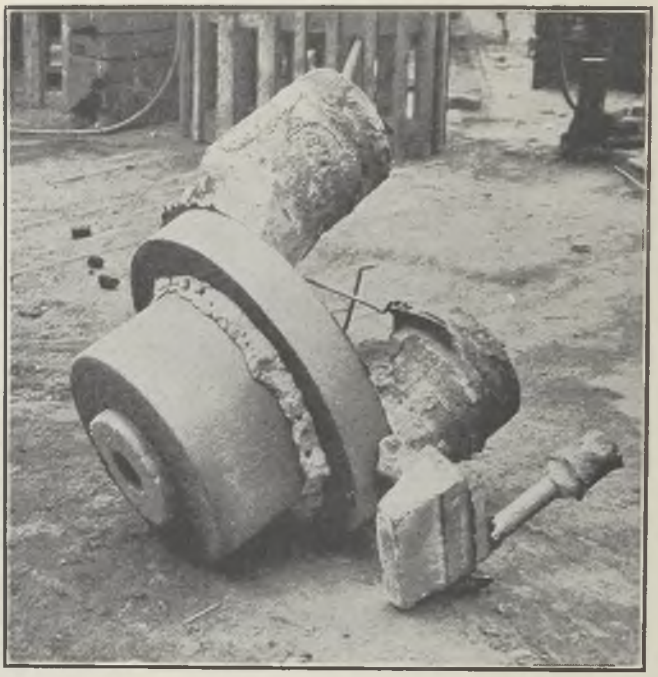

Fig. 12.—8-cwt. Casting made in a Different Sand.

For the general purposes of the steel foundry, the Belgian type of sand was preferable, because it lost strength at high temperature; and it was only for heavy castings that materials such as compo had to be used, which retained or increased strength at high temperatures.

He was very definitely of the opinion that the stoves which were referred to in the Paper as core stoves were not core stoves at all, but were merely annealing stoves. The difference of temperature throughout the stoves was enormous, and one must feel that if some moulds were sufficiently dried, some must be under-dried and some must be definitely burned.

treatment of alloy steel, such as tempering, uniformity of results was only attainable by circulating the atmosphere in the furnace to avoid the stratification caused by natural convection when the atmosphere was not disturbed. He felt that this principle could be applied with advantage to mould drying.

Another problem which did not arise in the heat-treatment of alloy steels, but was very important in mould drying, was the removal of moisture, and if one could get an instrument which would record automatically the degree of saturation of the exhaust gases the industry would be in a better position to control the dry-

ing process and could possibly speed it up. He wondered whether the authors of the Paper had considered these two aspects of the problem.

He also asked whether the sand used for the cores was the same as that used for the moulds. Fig. 11 gave a very good illustration of the phenomena met with in steel casting practice, that is, the difference in "burning-on" between a concave and a convex surface.

Ayrshire Chamotte

Mr. J. E. O. Little (Glenfield & Kennedy), referring to chamotte, asked exactly what was meant by the "calcined" bauxitic clay which was obtained in Ayrshire, for his foundry was in the district. In Ayrshire there was a quantity of surface clay of extremely low refractoriness; it was used to a certain extent in foundries in that district as a bonding clay for some of the wet loam for iron castings, and he wondered whether the bauxitic clay would be useful. Having made inquiries of various refractory suppliers, he had obtained very varying replies or widely differing definitions of "chamotte." Apparently most of them referred to it as being the crushed-up rejects or scraps of bricks which were put back into the mixture as a grog when making a fresh brick. He asked whether the chamotte had about 40 per cent. alumina content, because most of the materials in the district contained about 40 per cent. alumina, and whether it was supplied by just one particular supplier.

Mr. J. Deschamps (Kryn & Lahy, Limited) also asked for further information as to the theory concerning the use of chamotte, which was said to be a calcined bauxitic or siliceous clay. He asked what happened in the calcination. Was it aimed to effect a modification in the allotropic state of the silica?

Commenting upon a reference in the Paper to the drying of chamotte at a temperature of about 700 deg. C., he said that that seemed to be a very much higher temperature than one dare employ in making sand moulds, and he wondered whether the figure was a mistake. If it were not a mistake, he asked what reaction occurred at that temperature.

Mr. A. P. Riley (Sheffield) asked whether the authors had found that the type of milling and the milling time employed for their sands made any appreciable difference to the results. Also, he asked whether the backing sand was varied according to the facing sand used. Commenting upon a remark by Mr. Walker that a mould should be closed and cast as soon as possible after drying, presumably while still warm, he asked whether that remark applied to oil-bonded sands.

AUTHORS' REPLIES

Dr. Dadswell, replying to Mr. Faulkner's question concerning the possibility of metal-spraying the cores or moulds in the steel foundry, said that they had not attempted it. They had thought of metal-spraying, but more particularly in connection with the protection of patterns, especially when used with the Sand-slinger. He did not think that metal-spraying would have an application in steel moulding, because none of the metals which could be sprayed had a melting point sufficiently high to be of any use. Even if the core or mould were sprayed to give a layer of steel, he did not think the thickness of that layer would be of any use in contact with the molten steel.

Drying Stove Details

Dealing with Dr. Skerl's remarks concerning the drying stoves, he said that the stoves themselves had been in use for some years with a poor form of firing. The period of drying was at that time too long and the quality of the drying was bad. They were therefore modernised by installing new fireboxes and air-mixing chambers. The view in elevation of the fire side of the drying stove shown in Fig. 4 was a little misleading, and probably would lead Dr. Skerl to think that they looked rather like annealing stoves. Actually, the ports did not enter into the firebox, but into a form of mixing chamber. The products of combustion passed from the firebox into the mixing chamber, where dilution air was added, *i.e.*, a third supply of air, so that all the secondary air was not necessarily added in the firebox. The third supply of air was added in the mixing chamber to reduce the temperature of the products of combustion to the temperature of drying. The investigation was undertaken to find the best distribution of the ports. Having tried the stove for a while, it had been possible to improve the distribution by blocking up some of the ports and forcing the gas to take a certain course round the stove. The results were included in the Paper in order to show the necessity for studying the behaviour of stoves. It was a fairly easy investigation, for all they had done was to make a number of holes through the stove doors and to insert pyrometers.

The results of the tests on the dry strength of sands after different standing periods showed in quite a gratifying manner how laboratory experiment could definitely prove something which one had learned by practice and which one had not been able to show by scientific means. It did not always happen that way, but in that particular case it did, and that was why he regarded the results obtained as being so very interesting.

Paint Application

Paints were applied to green moulds before drying; but they were only applied to oil-sand cores when the cores were warm and dry. Certain compo moulds and cores received a further coat of paint when coming out of the stove, *i.e.*, whilst still hot; but the general practice was to paint moulds, sand cores and compo cores when they were green.

The remarks of Mr. Brown concerning the similarity between heat-treatment furnaces having re-circulation and a good drying stove were interesting. He believed the success of the continuous core-drying stove was partly due to the fact that one obtained good circulation, as the cores came out very much more uniformly dried than they often did from the ordinary batch type of stove.

For producing the casting shown in Figs. 9 and 10 the core material used was different from the mould material. In both cases synthetic sands were used, but the core contained a certain amount of core binder. The casting in Fig. 11 was slightly thicker than that in Figs. 9 and 10.

Use of Chamotte

The chamotte from Ayrshire was received from one supplier. He believed that a calcined clay such as that, of from 40 to 45 per cent. alumina, could be sufficiently refractory from the point of view of making a synthetic mixture, but in its raw state, used as a bonding material, it might not be sufficiently refractory. He had not used the Ayrshire clay as a bonding medium, but had used one of the Derbyshire fireclays. The high-alumina clay was used only as a grog, so that the explanation of the word "chamotte" that was given by Mr. Little was more or less correct. It really meant grog, and it was the coarse material which formed the basis of the refractory material. He and his colleagues had adopted the word "chamotte" because they had originally tried the method which might be described as the "Skoda method," using chamotte only, plus bonding clay. But that was rather expensive and the technique was rather different from the usual, so that it involved training the men; further, the cost of the material was rather high, for it had to be transported from Ayrshire to Sheffield, and in addition calcining was necessary. Therefore, they had used the chamotte clay as an ingredient in the ordinary compo in place of the old crucible pots formerly used. This used to be what might be called a witch's brew, consisting of a bit of everything, but it had since been simplified by using chamotte and old firebricks, etc.

Dealing with the reference by Mr. Riley to the type and time of milling, Dr. Dadswell said that both in the case of compo and of synthetic sand, those factors made a difference. In compo one was dealing with coarse materials and had to spread the clay around coarse grains, so that a heavier type of milling was necessary than for synthetic sands.

The type of backing sand was not varied in dry-sand practice over a certain weight. When using compo or synthetic facing for the larger castings, a common backing sand could be used. Oil-sand moulds should not be cast warm. The remarks in the Paper with regard to closing the mould as soon as possible after drying had related to clay-bonded sands. Indeed, the whole of the Paper really referred to clay-bonded sands, except for a brief reference to oil-bonded cores.

Aluminium-Sprayed Moulds

Mr. Walker, replying to Mr. Faulkner, said he knew of one steel foundry which had tried spraying cores with aluminium, the purpose being to supply a little extra aluminium to the steel and ensure that the steel in the mould was killed. The process had subsequently been abandoned.

Regarding Dr. Skerl's remarks, he agreed that the curves in Figs. 2 and 3, showing the cold compressive strength of sands after being heated to certain temperatures, confirmed the results obtained by Dr. Skerl in his work for the British Cast Iron Research Association. Some of the experiments carried out by Dr. Dadswell and himself, however, had been made on British materials not hitherto used for steel-foundry work, as they were investigating the possibility of finding new British materials for this purpose. So far they had not found any new materials with exceptionally good properties, and, generally speaking, the results were similar to those obtained by Dr. Skerl some years ago.

Replying to Mr. Brown, he said that they had made a large number of experiments in which they had analysed the gases issuing from the drying stoves to determine the moisture content, but so far they had not obtained a recorder for that purpose. He was not sure whether a recorder was on the market which would be entirely suitable for that particular service.

Ayrshire Bauxitic Clays

Discussing Mr. Little's reference to bauxitic clays, Mr. Walker said that there was only one particular type of Ayrshire clay which was suitable for the purpose mentioned, and it could be obtained from more than one manufacturer of refractory materials. Apart from its chemical analysis, an important property of the material was the manner in which it broke up on crush-

ng after calcining. The particles so obtained should be angular and the size distribution was important if the material were to be successfully used in the steel foundry.

The Ayrshire bauxitic clay referred to was not quite the same as the original Skoda chamotte; it had not exactly the same properties, but it was the nearest approach to the Skoda chamotte that the authors had been able to find in the British Isles. Mr. Deschamps had queried the temperature of 700 deg. C. which was mentioned in the Paper as the temperature to which a mould of chamotte and clay was heated during drying. That temperature had been frequently used at Skoda, and the authors had also used it on more than one occasion in their own foundry. There was no doubt that that temperature, or something very near it, was very suitable for drying the moulds of the Skoda chamotte. For the British material the temperature need not be quite so high, but it should be much higher than was ordinarily found necessary for drying sand moulds. A suitable temperature was a little below 600 deg. C.

Replying to Mr. Riley, Mr. Walker considered it best to allow oil-sand moulds to go cold and then to leave them for 24 hours before filling them with metal. This was because the strength of such moulds increased on cooling right out and for about 24 hours afterwards, whereas in the case of dry-sand moulds the strength fell rapidly as soon as the moulds become cold.

Paper No. 684

The Renaissance of the Steel Casting and the Rôle of the Metallurgist

By FREDERICK A. MELMOTH (Member)

Over the period of the last two decades, it has been not uncommon in certain circles to hear dire prophesies of the pending extinction of the founding industries. Acute competition has developed in various directions, each of which is a logical and expected happening in a progressive industrial civilisation. It is becoming obvious, however, that, far from the steel casting becoming an extinct relic of the Dark Ages of engineering industry, such knowledge of its production, and control of its major characteristics, are now forthcoming that an increasing scope of application is resulting.

In the late 1920's, a period of probably the greatest industrial activity the United States of America has experienced, the production of steel castings averaged about one and a quarter millions of tons. Since this time, many developments of a competitive nature have appeared, and, where suited, technically and economically, have taken a certain toll of the production of the industry. In spite of this, however, the year 1937, not by any means a good year, but one truly described as only an improvement on the two immediately preceding it, saw the production of steel castings almost touch the one million ton mark.

Affected by general stagnation, and the accumulated influences of several highly and efficiently advertised competitive products, such a figure indicates beyond question that new applications of steel castings have at least stabilised the position of the industry, and gives reasonable grounds for the belief that a return to normal business conditions will see it attain new heights of production. One of the most powerful influences in this development is believed to be the fact that the industry as a whole is becoming technically strong.

Steel founding has frequently been described as a mixture of art and science. A definition of the two terms possesses no hard and fast dividing line, but assuming one logically could define art as dexterity or skill in performance, acquired by experience, and science as systematised knowledge, then it is believed that progress for the future is most surely based on the encouragement and more complete application of the latter.

The present Paper proposes to offer evidence that this desirable condition is being achieved, and that the results forthcoming are a primary factor in the constantly widening field of application of steel castings in the United States. The incidence of the efforts of the metallurgist on this changing thought in foundry production is remarkable, and a study of the literature of the last ten years or so impresses one with the conviction that the broader conception of responsibility evinced by the metallurgist is producing a large part of the more systematised methods of attack on fundamental foundry problems.

A New Division of Metallurgy

Within the wider definition of iron and steel metallurgy, there is being built up what might be called a foundry metallurgy, devoted to the essential problems of cast-to-shape, unworked materials. Any metallurgical investigation into the conditions governing the production of sound steel castings runs immediately into the closely related factors of mould and core effects, temperature gradients and their effect upon solidification, localised temperature differences due to design, and many other points which, while not to be defined strictly as metallurgical, exert so profound an influence upon the success or failure of the ultimate casting as to compel their being taken fully into account.

It was a logical outcome, then, that the metallurgist should extend his active interest beyond the confines of the metal itself, and from this has grown most of the systematic investigation of moulding materials and methods of pouring and feeding steel castings. By taking each major operation singly, and correlating the work done in the United States during the last few years, as evidenced by published literature, it will be possible to demonstrate these statements clearly

Steelmaking

The manufacture of suitable steel for castings, in many of the principal features, is quite separate and distinct from steelmaking as

* Presented on behalf of the American Foundrymen's Association.

practised by the makers of ingot steel. In the latter case, physical work of a structure-modifying nature reduces the significance of certain conditions, which in the case of the sand casting may mean the difference between success and failure.

It is also of vital significance that the producer of steels destined to be mechanically worked, as by rolling or forging, exerts a complete and unquestioned control over the shape and general design of the ingot form in which his cast metal undergoes solidification. He is able, therefore, to assist sound and progressive solidification to whatever extent he may see fit.

The case of the steel foundryman is vastly different. Faced by a legion of differing shapes, and a multiplicity of sectional thicknesses in the same casting, and a very varying degree of response to his calls for design consideration, his molten steel has perforce to solidify many times in such fashion that no advantage can be taken of orderly and progressive conditions of transformation. In such circumstances, steel must possess, initially, every possible steelmaking inherent quality of soundness, cleanliness and regularity of temperature and composition.

In the last decade the recognition of such severe quality requirements has led to concentrated effort to regularise steel production for castings, and to attempt, at least, to elucidate such steel production problems as could be believed logically to have a bearing on casting behaviour. Prominent among American foundry metallurgists, who have advanced the knowledge of this subject, one finds such names as Sims, Lillieqvist, Batty, J. Howe Hall, to mention only a few.

The importance of slag constitution and deoxidising procedure has been investigated in the case of both electric and open-hearth practice. The significance of inclusions, their degree of occurrence and shape, had been considered not only from the viewpoint of their effect on ultimate properties, but also because of the possibly better behaviour of clean steel in the mould. In this connection, it is a widely held opinion that basic open-hearth steel is superior to that produced on acid linings in resisting hot-tear formation in castings of intricate and varied designs. There appears no basis for the opinion held at one time that sulphur and phosphorus content explained this diversified behaviour, as material control in acid practice, resulting in equally low percentages of both, did not eliminate the disparity.

There would appear to be no question that in cases where steelmaking practice, and particularly methods of deoxidation, were of a type disregarding the degree of occurrence and type of inclusions, there occurred a greater hot-tearing hazard. Discussion invariably brings out the fact that clean steel, foundry conditions being otherwise equal, suffers much less from this particularly dangerous tendency.

It is from the viewpoint of obtainable physical properties, however, that steelmaking methods have been most rigorously overhauled. In the absence of mechanical work of a structure-affecting type, a steel casting must respond perfectly to heat-treatment if the demands of modern specifications are to be met. Non-metallic inclusions, unaffected by any type of heat-treatment, are without doubt the most effective single factor in limiting the physical properties of steel castings.

The work of C. Herty, jun., on the conditions governing the formation, size and type of such non-metallics has been of great value to steel foundrymen. The realisation, also, that the major harmful effect of aluminium additions to steel for castings was an outcome of the action of aluminium on non-metallic inclusions, their shape being changed from a comparatively innocuous globule to a more or less membranous form occurring in the crystal junctions, paved the way for additional work on the correct use of deoxidisers. Comstock, Sims and Lillieqvist were largely responsible for this elucidation of the aluminium problem, which, particularly to steel foundries equipped with acid electric furnaces, was of real significance.

Further work by Sims and collaborators throws still more light on the subject, and evolves the suggestion that increased aluminium additions in certain conditions will result in a return to normal ductility. The majority of American steel castings are produced in green sand moulds, and the use of aluminium in such circumstances is of undoubted assistance in promoting soundness, by inhibiting porosity due to mould gases. Very often, however, such castings are made to stringent physical test specifications, and the obtaining of freedom from porosity, at the sacrifice of a large portion of the specified ductility, is of more than dubious value.

The present situation on this much discussed question of the effect of aluminium in steel for castings is best indicated by saying that many steel foundries in the United States using acid-lined electric furnaces are carefully and extensively checking the results obtained by large aluminium additions, up to three or more pounds per ton of liquid steel. So far, the reported opinions show a preponderance who claim a decided improvement in ductility, as compared with the normal addition of a half to one pound per ton of steel. There are still producers, however, who fail to experience such benefits, and it seems very probable that steelmaking technique has a decided influence on the response obtained.

The development of the electric furnace in steel foundries of the United States has been largely toward acid linings. Indeed, a recent *questionnaire* addressed to the members of the Sixth Division of the Steel Founders' Society of America disclosed only one basic-lined furnace producing steel for castings in the entire district, covering some thirty foundries—many of them large. This calls for some comment, as it is contrary to conditions in Europe.

The frankly held opinion of American steel founders substantiating their preference for acid practice is that while suitable scrap is available, offering adequate sulphur and phosphorus control, such practice has the following advantages:—

(1) It is speedier, and therefore more economical.

(2) The life of the furnace is much longer using standard refractories.

(3) The technique of the process is more easily acquired by untutored labour.

(4) The steel is much more fluid, and therefore better suited to the pouring of light, thin-section castings.

Item 4 is the most controversial, but in the author's opinion is substantially correct when standard practices of acid and basic types are being compared. The sluggishness in pouring exhibited by basic electric mild steels in certain conditions of manufacture led to the term "over-reduced." "Under-oxidised" would probably be more technically correct.

In normal conditions of practice it would appear that steelmaking methods have resolved themselves into a definite order in the minds of steel foundrymen, based on their ability to produce easily poured steel. Heading the list is the converter, and in America the basic-lined electric furnace occupies bottom position. It is significant that the position on the list occupied by any process is in inverse relation to the degree of reducing conditions normal to its use, at any period of the steelmaking process.

The question of the influence of long maintained reducing conditions on the fluidity of steel for castings is no longer treated with scepticism, and inquiry confirms an almost universal avoidance of such furnace conditions. The improvements in steel castings performance, and consequently in their scope of engineering application, due to a better knowledge of steelmaking technique for castings, have been very considerable, and offer a substantial contribution to the industry by means of metallurgical progress. The subject is extremely live in the United States of America, the Steel Division of the A.F.A., and the trade organisation of the industry, the Steel Founders' Society of America, both devoting special attention to giving it full prominence in committee work and conferences.

Table I gives a bibliography of American

TABLE I.

BIBLIOGRAPHY OF AMERICAN LITERATURE ON STEELMAKING PRACTICE FOR CASTINGS.

Title.	Author.	Publication.	Date.
Furnace Manipulation Governs Inclusions in Acid Open-Hearth Steel.	C. H. Herty, Jr., and J. E. Jacobs	The Foundry	November 15, 1931.
Taking Care of Inclusions in Steel..	Dr. C. H. Herty, Jr.	The Iron Age	December 17, 1931.
Inclusions—Their Effect, Solubility and Control in Cast Steel	C. E. Sims and G. A. Lillieqvist	The American Institute of Mining and Metallurgical Engineers.	February, 1932.
Some Factors Affecting the Cleanliness of Steel Castings.	C. H. Herty, Jr. C. F. Christopher, M. W. Lightner.	American Foundrymen's Association Reprint No. 32-4.	May, 1932.
Points to Causes of Porosity ..	R. A. Bull	The Foundry	January, 1935.
The Preparation of Steel to Avoid Porosity in Castings.	C. E. Sims	Transactions, American Foundrymen's Association	1934.
Physical Appearance of Slag Indicates Quality of Steel.	Earl C. Smith ..	Steel	March 18, 1935.
Report of Committee on Methods of Producing Liquid Steel for Castings	American Foundrymen's Association	Transactions, American Foundrymen's Association	April, 1937.
Slag Viscosity Control Affords Greater Uniformity in Steel.	C. H. Herty, Jr. ..	Steel	June 7, 1937.
Open-Hearth Practices in a Steel Castings Plant.	John W. Porter ..	The Iron Age	November 25, 1937.
Four Decades of Steel Making ..	Pat Dwyer	The Foundry	May, 1938.
Effects of Aluminium on the Properties of Medium Carbon Cast Steel.	C. E. Sims and F. B. Dahle	Transactions, American Foundrymen's Association	September, 1938.

literature on steelmaking practice for casting production.

Alloy Steel Casting Development

One of the major effects of increased metallurgical thought on steel-casting production has been the growth of the idea of "making the casting to fit the job." In other words, it has been realised that mere thickness changes with a standard material do not even approach a solution of certain difficult service conditions. A study of the conditions, in the light of available metallurgical knowledge, has led to a steady and continuous increase in the use of alloy compositions of many types.

In earlier days this growth was menaced seriously by a lack of appreciation of the vital importance of suitably-allied heat-treatment, and foundries, slow to embrace the growing metallurgical influences in the industry, assumed a significance in alloy content, which did not exist apart from correct heat-treatment. Very largely this attitude has disappeared, and reasonably accurate knowledge of this relation is practically industry-wide to-day. The natural result has been an expansion of the scope of application of the steel casting, and its use in very many cases where previously it was not believed advisable.

The steel foundries of the United States have carefully fostered the low alloy types of steel, which, with correct heat-treatment, contain within their range a material highly suitable for almost every engineering application, apart from corrosion or high-temperature resistance.

The practical utilisation of these steels in casting form represents a metallurgical problem with three closely related phases—mass, composition and heat-treatment—and the foundry metallurgist has assisted progress remarkably by realising and elucidating the correlated effects of all three.

The number of alloy combinations in these low-alloy steel castings is to-day very large, many of them manifesting approximately the same physical properties. Choice, therefore, is often dependent upon individual preference on the part of either the founder or the purchaser. A few of the more popular may be briefly described, as a matter of interest, entirely without prejudice to the many others whose properties are probably just as valuable, but whose inclusion could unduly prolong this section.

Manganese-vanadium castings, containing from 1.2 to 1.5 per cent. manganese, and 0.1 to 0.2 per cent. vanadium, constitute a valuable member of the group, responding easily to various heat-treatments with a wide range of resulting properties, and especially high dynamic values.

Manganese-molybdenum steel is an exceedingly popular one for use in castings in the United States. Response to heat-treatment is very complete and easily accomplished, and the steel possesses good foundry characteristics. Where design and mass are suitable, this material, in casting form, can be quenched safely in water or oil, and, followed by a tempering treatment designed to suit the service intended, results in a casting of high tensile and yield ratio, with excellent ductility and resistance to impact.

Some straight copper steels are in use, but commonly this element is present in combination with at least one other alloying element, such as chromium or molybdenum. Such castings correctly heat-treated possess excellent properties, both static and dynamic. They also possess in a high degree good founding qualities, a point of very great importance in view of the difficult and complicated designs commonly encountered to-day.

Nickel steels of varying carbon content are in wide use, in cases where great toughness and shock resistance are essential. Nickel in combination with chromium, sometimes with the addition of 0.2 to 0.3 per cent. molybdenum, has a firm place in the confidence of many founders, and excels where high strength and toughness are demanded in service. The ternary combination also has a following for high-temperature pressure-castings, having good creep resistance properties.

Straight carbon-molybenum steels are being found of increasing value for high temperature and pressure conditions involving creep resistance, and have the added qualities of simplicity in manufacture and good foundry behaviour. A material finding an increasing application, particularly in oil refinery work, where often temperature and pressure occur in somewhat corrosive conditions, is the 4 to 6 per cent. chromium, 0.5 per cent. molybdenum combination. Correctly heat-treated, this steel has remarkable physical properties. For casting uses, low carbon is a distinct advantage, and rarely exceeds 0.2 to 0.25 per cent., great strength being conferred by the alloy content.

A representative set of physical properties appears in Table II, and it is of added interest to note that in the case quoted an impact specification at 25 deg. F. below zero was imposed. The treatment required to break down thoroughly the cast structure of this material is of great importance in such a case, as it was found that high static qualities, even the possession of such elongation and reduction of area as 32 per cent. and 63 per cent. respectively, represented no guarantee of successfully meeting the impact specifications at sub-zero temperatures. As a matter of fact, almost every steel used in worked form finds its counterpart in use for steel cast-

ings in the United States of America to-day, and the engineer has a wide choice of types to meet any service conditions.

Chrome-molybdenum steels of varying carbon content, and possessing good resistance to abrasion, and manganese steel of the Hadfield type, where service conditions involve the necessary work-hardening surface distortion, are produced in large quantities. The higher alloys for heat- and corrosion-resistance are all available in casting form, and constitute a growing branch of the industry. In some plants, many of these alloys are produced in centrifugally spun moulds, with advantages of appearance and soundness where design is suitable.

This section of the Paper should not be concluded without reference to the series of Ford alloys, classified as steels, some containing a high carbon content, which in the presence of silicon as high as 1.10 per cent., causes these materials to be graphitic in type, but possessing appreciable ductility after suitable heat-treatment. Practically all are copper bearing, in amounts from 0.5 to 2 per cent., and some also contain

TABLE II.—*Composition and Physical Properties of Modern American Steels for Castings.*

Steel.	Analysis.							Heat-treatment.
	C.	Mn.	Si.	Mo.	Cr.	Ni.	Va.	
								deg. C.
1. Mn–Mo ..	0.28	1.29	0.46	0.30	—	—	—	926 Furnace cool.
								926 Air cool.
2. Mn–Mo ..	0.28	1.29	0.46	0.30	—	—	—	815 Air cool.
								650 Air cool.
3. Mn–Mo ..	0.28	1.29	0.46	0.30	—	—	—	926 Air cool.
								815 Water quench.
								649 Air cool.
4. Mn–Ni ..	0.23	1.16	0.44	—	—	0.71	—	900 Furnace cool.
5. Mn–Ni ..	0.23	1.16	0.44	—	—	0.71	—	900 Air cool.
6. Mn–Ni ..	0.23	1.16	0.44	—	—	0.71	—	900 Water quench.
								650 Air cool.
								926 Air cool.
7. Ni (2.5 per cent.)	0.21	0.64	0.35	—	—	2.55	—	837 Air cool.
								593 Air cool.
8. 5 per cent. Cr–Mo	0.18	0.55	0.41	0.48	5.1	—	—	982 Furnace cool.
								857 Air cool.
								726 Furnace cool.
								926 Air cool.
9. Cr–Va ..	0.33	0.72	0.41	—	0.93	—	0.19	837 Air cool.
								650 Air cool.
10. Ni–Mo ..	0.24	0.64	—	0.33	—	2.15	—	Normalised and tempered.
11. Ni–Va ..	0.33	1.05	—	—	—	1.58	0.10	Oil quenched. Tempered 677 deg. C.

No.	Physical Properties.					Hardness.	
	Yield point. Tons per sq. in.	Ultimate strength. Tons per sq. in.	Elongation per cent. in 2 in.	Reduction of area. Per cent.	Charpy impact. Ft.-lbs.	Brinell.	Shore scler.
1.	26.8	40.6	21.5	34.40	19.8	187	27
2.	28.9	37.7	28.0	60.58	45.3	179	26
3.	37.4	44.6	23.5	57.04	51.4	212	31
4.	23.2	36.2	30.5	51.67	—	146	22
5.	23.3	39.0	29.5	57.30	—	153	23
6.	32.6	41.5	27.0	61.81	—	207	30
7.*	24.4	33.8	28.2	52.39	25.0	207	30
8.†	28.5	40.4	24.6	60.59	25.6	146	22
9.	29.9	42.1	23.0	44.85	—	196	29
10.‡	31.2	41.3	24.0	50.00	36	—	—
11.‡	45.4	51.4	19.5	48.00	—	—	—

* Charpy test at 50 deg. below zero.
† Charpy test at 25 deg. below zero.
‡ Paper by F. J. Walls and T. M. Armstrong, Western Metal Congress, 1938.

chromium. Introduced originally for crank shaft manufacture as sand castings, their application has been rapidly extended, very great quantities now being produced both at the Ford plant and by other suppliers.

Many interesting details were given in a recent Paper by Mr. McCarroll, of the Ford plant at Dearborn, Michigan, and interested readers are referred to the published details. There is little doubt but that the increasing use of alloy content in an intelligent effort to meet varying service demands has exerted a great influence on the possibilities of utilising steel castings to a greater extent.

Originally, the recommendation of using alloy steels was accompanied by an insistence upon the possibility of decreasing weight by so doing, in many cases this being fallacious as an argument, as it often happens that rigidity has an importance even higher than mere unit strength. Whilst in many cases some saving in weight can be achieved advantageously on existing castings, yet in an even greater number, the sounder argument in support of alloy compositions is the re-establishing of safety margins without adding to weight, in engineering applications where progress demands higher speeds, heavier loads, higher pressures, higher temperatures and so on, each of which rapidly absorbs the available margin of straight carbon steels.

A study of service conditions almost always can result in a foundry recommendation of a suitable alloy steel, the special characteristics of which have a definite value in each particular case. Such work is essentially metallurgical, and represents an incontrovertible proof of the value of metallurgical knowledge to the industry.

Table III gives a bibliography of American literature on alloy steel castings.

Heat-Treatment

Although emphasis is often placed upon the undeniable fact that recourse to alloy composition should be taken only when the service conditions impose loads or strains outside the capacity of carbon steels to bear safely, yet it is true to say that advantage of heat-treatment applied to carbon steel castings has only been taken in any considerable degree since alloy content forced the realisation of the great benefits derivable from correct heat-treatments of various types.

Even to-day, it is doubtful whether such advantage is fully taken, often owing to prejudice on the part of some users, fear of severe treatment causing trouble, or the limiting effect of certain specifications which lag behind metallurgical progress. Steel founders have permitted the idea to remain in the minds of engineering users of their product that in some strange way unworked, cast-to-shape steel articles do not respond in a full degree to more advanced methods of heat-treatment.

It is assumed that the absence of mechanical work of a structure-affecting type, such as rolling or forging, inflicts a form of inherent penalty on the steel casting, slowing or preventing the structural modifications brought about by various

TABLE III.

BIBLIOGRAPHY OF AMERICAN LITERATURE ON ALLOY STEEL CASTINGS.

Title.	Author.	Publication.	Date.
Nickel Alloy Steel Castings	A. G. Zima	The Steel Founder	January-February, 1932.
Excellent Properties Developed by Vanadium Alloy Steel Castings	Jerome Strauss and Geo. L. Norris	The Steel Founder	March-April, 1932.
Chrome-Nickel Steel for Navy Cast Steel Anchor Chain.	T. N. Armstrong	The Iron Age	January 12, 1933.
Better Steel Castings Reflected in Specifications.	David Zuege	Metal Progress	February, 1934.
Studies Physical Properties of Low-Alloy Cast Steels.	T. N. Armstrong	Steel	December 3, 1934.
Specialises in Alloy Steel Castings	Pat Dwyer	The Foundry	March, 1935.
Ford's New Facilities for Casting Alloy Steels.	—	The Iron Age	April 30, 1936
Ford Alloy Castings	R. H. McCarroll and J. L. McCloud	Metal Progress	August, 1936.
Heat-Resisting Castings, Cr-Ni-Fe Alloys.	J. D. Corfield	Metal Progress	October, 1936.
Strong Steel Castings Ride the Rails	Raymond L. Collier	Metal Progress	February, 1937.
Alloy Steels Designed for Specific Uses.	Vincent T. Malcolm	The Foundry	July, 1938, August 1938, September 1938.
Progress in Automotive Steel Castings.	R. H. McCarroll	The Foundry	October, 1938.

forms of treatment. In view of the physical properties daily being produced in a number of American foundries, it is difficult to see why this idea should not long ago have been removed. As a typical instance, the writer was recently informed of the successful production of quite intricate castings, weighing about one and a half tons each, to the following specifications:—

Maximum stress ...	40 tons per sq. in.
Yield point	26.8 ,, ,,
Elongation	30 per cent.
Reduction of area ...	60 ,, ,,
Charpy impact	30 ft.-lbs.

Not very long ago the liquid quenching of such castings would have been looked upon as almost a foolish procedure; but any foundry metallurgist knows that such a specification can be met only by the use of this type of heat-treatment. In the author's plant, low-alloy castings have been water-quenched in very large numbers, and, on occasion, individual castings weighing over 1½ tons have been given a water-quench and temper treatment quite satisfactorily.

A high-temperature breakdown treatment is indispensable if the highest standard is to be attained, and on this account it has become common to fix the heat-treatment temperatures about as follow:—

(1) Anneal or normalise at 926 to 1,010 deg. C.

(2) Normalise or liquid-quench, 815 to 870 deg. C.

(3) Temper at a temperature to suit the intended purpose.

By this means, the cast structure is thoroughly broken down, and on this account the normalising or quenching operation can be carried out from a lower temperature, giving an opportunity for the obtaining of the finest micro-structure and the best combination of physical properties.

At the Western Metals Congress, held in Los Angeles in 1938, the author presented a Paper intended to show the response of sand-cast steels to varying types of heat-treatment. Four types of steel were studied, three of them plain carbon and one a low-alloy steel of a manganese-molybdenum type.

Every care was taken to avoid variables, both in pouring and solidification, and after cooling, and a fixed schedule of thermal treatments was used for all bars. The bars were cast as integral castings, weighing over 70 lbs. each, so as to eliminate the possible reproach of small, separately-cast test-coupons.

After treatment, all bars were machined and tested for the following properties:—(1) Tensile strength; (2) yield point; (3) elongation; (4) reduction of area; (5) cold bend; (6) scleroscope hardness; (7) Brinell hardness, and (8) Charpy impact (standard keyhole notch). In all cases the response to treatment was perfect, and not in any one case had a bar to be rejected or replaced for any defect whatsoever.

The heat-treated test results were of a standard quite equal to many worked steels; the impact results in particular were of an order signifying excellent engineering properties. Tensile strengths ranged from 29.9 tons per sq. in., in the annealed condition, to 58 tons per sq. in., in the quenched and tempered condition. No relationship between impact properties and the results of the static test could be determined definitely, it being very apparent, however, that annealing was of very little value in the development of shock-resisting qualities. In the case of the carbon steels, straight normalising resulted in an increase of over 50 per cent. in Charpy impact value as compared with the annealed samples of the same steels.

A significant feature was that water-quenching, both in the case of the carbon steels and the low alloy steel, followed by a high tempering designed to produce a tensile strength about equal to that in the annealed sample, resulted in Charpy values, in the quenched and tempered samples, up to two and a half times those of the annealed samples of the same steels. Hardness being practically identical, it is evident that, with practically no increase in machining difficulty, special applications demanding great shock resistance can be cared for in this manner.

Details of the complete series will be published in the American Society of Metals Proceedings in due course, and they are only partially quoted now as further proof of the engineering value of correct heat-treatment for steel castings.

There being no directional weakness due to work distortion in a steel casting, it should be apparent that, correctly made and heat-treated, it offers a service performance equal to most worked materials, and in some applications better than many.

Heat-treatment has been dwelt upon considerably, owing to the profound conviction of the author that, as an industry, steel founders have neglected to publicise sufficiently the ready and complete response of their materials to refinement by thermal means, leaving an impression that mechanical work is a necessity to the obtaining of excellent physical properties in steel. Such is definitely not the case, and designers should be so informed on every possible opportunity. One still encounters engineers who fear brittleness, "because it is only a casting." Yet, when confronted with cold bend tests, completely doubled and associated with tensiles up to 58 tons per sq. in., such sceptics are fairly easy to convince. The real trouble is that engineers have no one to inform them of such possi-

bilities but the steel founding industry, and as a whole we have failed to do so effectively.

Table IV gives a bibliography of American literature on heat-treatment of steel castings.

Moulding Materials and Technique

Earlier in the Paper it was pointed out that in approaching metallurgical problems associated with steel castings, it was inevitable that the metallurgist would be led into the investigation of materials and methods used in moulding. It is presumed that the demand for better surface finish and internal soundness experienced in America, has been also experienced in other countries, and this has led to intensified work on sands and other materials used in the making of moulds. This work has become largely the responsibility of the plant metallurgist, and few, if any, foundries in the United States are without a section of their laboratory devoted to sand control, and to some extent, also, investigation of sand properties from the standpoint of sounder and better-surfaced castings.

It is not proposed to discuss any shortcomings of existing sand testing and control methods, or to attempt to compare differing methods. From the essentially practical viewpoint, it would appear to be accepted that the instruments and methods available give results directly comparable in regular conditions and with the same method of operation. This has enabled executives to formulate control schemes using such instruments as guides and indicators, and achieving the practical result of preventing large variations capable of affecting the product.

Though a few foundries still use a naturally-bonded sand, the great majority rely entirely upon synthetic mixtures, and it is the accepted opinion that such mixtures lend themselves more readily to definite quantitative control. From the realisation that permeability to rapidly evolved gases is essential in both facing and backing, there has developed an almost general use of sand handling and reclaiming equipment. Generally speaking, there is no attempt to remove all fines, it being realised that regularity of fines content, at a reasonably low figure, is far more logical and practical.

It is, of course, probable that some part of the improvement in the soundness of steel castings has resulted from improved steelmaking practice, but it is believed generally that by far the greater part of such improvement has occurred as the result of regularised sand conditions and an appreciation of the significance of mould-pressures during pouring.

The preponderance of green-sand methods of mould production in the United States has much intensified work along these lines, and it is typical to find all sand, both facing and backing, for the lighter types of castings subject to careful preparation. Commonly, such sand arrives at the mould with known permeability, green and dry strength and moisture content. The backing sand, where facing sand is used, is regularly higher in permeability and lower in bond than is the facing, thus tending always to automatic venting, and the prevention of trouble due to the building up of gaseous pressures in the body of the mould during the pouring operation.

This method of thought has rendered possible the use of finer grain materials for facing purposes, contributing considerably to the excellent surface finish of American light steel castings, without any increased risk of porosity. Fireclay is still used occasionally as binder for green sand facing, but in by far the greater number of cases bentonite is relied upon, usually with small additions of a cereal binder.

It is interesting here to note that even in very

Table IV.

Bibliography of American Literature on Heat Treatment of Steel Castings.

Title.	Author.	Publication.	Date.
Production and Heat Treatment of Alloy Steels.	R. A. Bull	Metals and Alloys	September, 1931.
New Heat Treatment for Carbon Steel Locomotive Castings.	A. W. Gregg	The Iron Age	February 2, 1933.
Heat Treating Steel Castings	John D. Knox	The Foundry	February, 1935.
Localised Surface Hardening	R. L. Rolf	Steel	November 30, 1936.
A Continuous Heat Treating Furnace in a Steel Foundry.	John Howe Hall	The Iron Age	July 22, 1937.
Report of Steel Division Committee on Heat Treatment of Steel Castings.	—	Transactions, American Foundrymen's Association	August, 1937.
Problems and Practices in the Heat Treatment of Steel Castings.	A. W. Lorenz	Symposium on Steel Castings, American Society for Testing Materials and American Foundrymen's Association	June, 1932.

large castings, it is becoming more common to eliminate fireclay and rely upon bentonite, although such castings are oven-dried before pouring. Improved stripping qualities, less scabbing, and less tendency to blowing are all claimed as a result.

It is almost axiomatic that it is unwise to prophesy, but indications most distinctly are that the steel foundry of the future will deliver all sand to the moulding floors fully prepared to known and understood standards, and not merely the facing sand as in many foundries is the case to-day. The many ill-effects upon the solidifying casting which are traceable to variations and deficiencies in backing sand render this quite necessary and logical if control and resulting regularity of product are to be achieved.

It should here be noted that cement-bonded sands are creating an increasing amount of interest in the United States, and some foundries are operating the Randupson process under licence. The details of the process are known very well in Europe, of course, and need not be described, it being sufficient to say that reports from users of it indicate a considerable improvement when the working details are correctly mastered and understood.

In commenting upon moulding methods commonly in use in America, the author would like to attempt to remove several misconceptions which appear to be commonly held by many of his European friends. The first is the idea that repetition production, or mass production as it is more often called, is common in the steel-founding industry. It is true that with certain specialised types of work, such as railway wagon parts, the demand, periodic in occurrence, is of a type calling for large numbers from individual patterns. Many foundries have been erected and equipped to meet this demand, and have evolved production schemes of a remarkably efficient and economic character. It is equally true to say, however, that for each of such speciality foundries there exists quite a number whose general demand is as wide in scope as the average European foundry, and where large numbers from a pattern are no more frequent than in similar foundries in Europe. Problems can be discussed, therefore, on a much more common ground than is often accepted as fact.

Secondly, it is often stated that the hard-headed practicality of the American user of castings results in a demand satisfied by the technical performance of the part in service, and quite disregarding such matters as accuracy of shape and contour and surface appearance.

If this were the case in some earlier period, it is most certainly not a fact to-day. Accuracy, soundness, and smoothness of finish, with the smallest possible machining allowances, are demanded to a standard in most cases higher than the author experienced in similar work in Europe.

The third and last misconception is one which is being continually disproved by the adoption of identical methods in all parts of the world, and arises from an opinion that repetition production, or mass production, involves some lowering in standards of quality and reliability.

The proof of the fundamentally incorrect nature of this opinion has already been given by the world-wide adoption of the methods previously stated, but, specifically referring to steel castings, it is of value to give in some detail facts in contradiction.

The cost of adequate pattern equipment is of so little significance where very large numbers are to be produced that such patterns are commonly beautifully designed and produced, and are wonders of accuracy and permanence as compared with jobbing patterns. The mould from them is therefore more consistent and accurate. The pattern being made of better materials and more highly finished, the resulting casting benefits also in surface finish.

Pilot castings are made, sometimes many times, and subjected to destructive testing, and in many cases X-ray examination, before final gating and heading methods are decided upon, and the results of this are involved as a permanent part of the pattern equipment, and not left to the operator's variable discretion.

The pattern thus produced is mounted on an expensive accurate machine, and the net result is a casting which—once right—is liable to be permanently so, as very many variables in its production have been eliminated.

Given the same steel and methods of cleaning and heat-treatment, it is logical that one should get a casting of high quality, and what is more important—keep on getting it. Economic exigencies utterly prevent this method of approach to castings produced by older, slower methods, and they frequently represent the final outcome of a gambling hazard, action being controlled by personal opinion rather than by established fact.

Although not entirely relevant, confirmation of the reliability and the often superior intrinsic qualities of the repetition-produced article is found in what constitutes probably the greatest difference between American and European standards of living; that is, the degree to which advantage is taken of labour-performing appliances.

Domestically, practically all forms of household toil are either partially or wholly performed by mechanical appliances, the possibilities of use of which are controlled by, first, their price, and, second, their built-in reliability and capability to perform perfectly over long periods of time

without any skilled attention. All such articles are repetition-produced to fixed high standards, and a period of years observing their almost perfect performance results in one developing a great respect for the products of the repetition-production industries. The somewhat opprobrious term, "mass production," should now give way to one much more indicative of what the adoption of such methods indicates, namely, "planned production."

Whilst it is correct to say that the earlier statement regarding the large demand of a jobbing type holds good, yet first and foremost in the minds of American producers is the possibility of planned methods of production. Wherever possible, machinery reduces the physical demand made upon operators, or reduces certain operations to the quantitative accuracy of the machine. It has been said that the main reason for this is the high wage standard of the United States, but close experience suggests the exact opposite: that the high wage standards have grown inevitably out of the practical results achieved by this method of thinking.

The wage standards generally applicable in America are most decidedly not falling, but rather, owing to increased labour organisation activity, are still rising. Previous high standards being a direct outcome of logical and economic production methods, and the present tendency further to increase being in no way due to an equally sound fundamental cause, it is easy to see that even greater effort must be made to reduce unproductive effort if much higher prices, likely to create a condition unfavourable to progress and expansion, are to be avoided.

It is almost general that steel foundries are subjecting their equipment to rigorous overhaul, with a view to waste-elimination, and this thought lies behind each method adopted even more prominently than at any previous time. Whether jobbing or repetition in type, the slogan of all American foundries is "Control." Control of cost in all its branches, control of all materials used to tested and approved standards, control of steelmaking methods and moulding and coremaking methods, exist in almost all foundries, and as little as possible is left to chance, or to the possibly dubious factor of personal opinion.

This line of thought has led to a great effort on the part of steelfounders to encourage research into those factors of steel casting production usually considered as hazardous, or difficult of accurate and quantitative pre-determination. It is felt that only when one knows why a happening takes place can plans be devised to control such happening and hit or miss results be avoided.

A more careful study is being made of the mechanism of solidification in steel castings, the results of which are evident both in methods of moulding and pouring, and in an increased interest in the part played by design. Improved appearance and behaviour in service have emphasised to many designers that the requests of the foundry for consideration are much more than mere capricious objections to difficulty, but are based on known fundamentals, and the inherent and unalterable characteristics of liquid to solid phase changes. Methods of moulding will keep in line with these logical design changes, so that full advantage can be made available in the final casting of sound and correct solidification.

Mechanically, mould and core production varies little between Europe and America, with the possible exception that in the latter country freer use is made of the machine, and it has long been realised that a moulding machine, or any other production machine for that matter, is of little value if one excepts the absolute necessity for auxiliary equipment permitting the easy and uninterrupted flow to and removal from the machine of both the material used and the produced mould.

Table V gives a bibliography of American literature on moulding materials and technique for steel-casting production.

Research

At the risk of incurring severe criticism from some quarters, the author considers that the steel founding industry has possessed in a high degree the characteristic of endless experimentation, but almost a complete absence of fundamental research. At the time of his first active connection with the castings branch of the steel trade, very few metallurgists were employed directly by founders. Trained metallurgists failed to find either attractiveness or promise of advancement in the industry, and it is not unfair to say that the most prominent attitude on the part of executives and supervising foremen towards such men was one of profound scepticism of their ever being of much use in the manufacture of castings. At this time, some twenty-five years ago, the habit of research and the application of scientific methods of thought were growing rapidly in the major portion of the metal industries, that represented by mechanically-worked products.

The illusion of art was preserved by the foundries to the exclusion of the cold-blooded scrutiny of their processes by science, and the inevitable elucidation of many of the fundamentals governing the production of sound castings. A tolerance was shown for the manifested results of scientific research in several production phases more or less common to all branches of the steel

trade, such as melting methods and heat-treatment, but that intricate composite of contradictions and intelligent guesses, the actual production of the casting itself, was practically sacrosanct: aloof from the type of thought being given to the forging, the rolled products, and their initial stage, the production of sound ingots.

It is believed a fair statement that the production of sound castings represents a combination of practical and theoretical factors offering really great difficulty, and calling for all possible elucidation and understanding, and, as a consequence, this attitude toward scientific development has retarded progress to an extent impossible of quantitative estimation, and, although conditions are changing, future rapid progress rests upon its complete elimination.

The major portion of the rôle of the metallurgist in the advancement remains to be played, and present indications in the United States and elsewhere are that the degree to which such type of effort is utilised will be largely increased. The growing realisation that a steel casting made according to the principles of good metallurgical and engineering design, poured from steel produced by methods controlled to give good casting properties, and given thermal treatment of a regular and understood type, possesses physical properties almost equal to equivalent worked steels, and in certain special applications may even show superior results, is definitely widening the scope of application.

The unrivalled versatility of steel made fully available in cast-to-form condition, and free from irritating defects, represents an engineering material of construction with great application possibilities.

This, then, must be the object of basic research into steel casting manufacture, and it is believed that the engineering industries to whose product steel castings commonly are built, will, over a period of time, absorb and consolidate into design any factual material which is forthcoming as a result.

Points calling for immediate attention include:—First, investigation into various portions of the various steelmaking processes and the effect of composition variation on the strength of steels at temperatures just below solidification.

The practical significance of this is the elimination, or marked reduction in frequency of occurrence, of hot tears or cracks. Very often, indeed, almost the entire blame for such happenings is placed upon design, and whilst such an attitude is probably true in a degree, yet it must be realised that no design variations can be expected which can remove from a large part of the product the subjection of the cooling casting to severe strains, at a time when it is physically least able to withstand them.

It is known that steelmaking method has a marked bearing on this particular trouble. It is not by any means well known why. Fundamental knowledge on this subject, absorbed into steelmaking processes, would be of incalculable benefit to steel-casting producers.

TABLE V.

BIBLIOGRAPHY OF AMERICAN LITERATURE ON MOULDING MATERIALS AND TECHNIQUE FOR STEEL CASTING PRODUCTION.

Title.	Author.	Publication.	Date.
The Relation of Moulds and Cores to Porosity in Steel Castings	George Batty ..	Transactions, American Foundrymen's Association	1934.
The Mechanics of Porosity in Steel Castings.	R. C. Woodward ..	,, ,,	,,
Function of the Steel Foundry Foreman in Preventing Porosity.	R. A. Bull	,, ,,	,,
Controlled Directional Solidification	George Batty ..	,, ,,	,,
Studies on Solidification and Contraction in Steel Castings. Free and Hindered Contraction of Cast Carbon Steel.	Charles W. Briggs and Roy A. Gezelius	,, ,,	,,
The Influence of Temperature Gradients in the Production of Steel Castings.	George Batty ..	,, ,,	1935
The Expansion and Contraction of Moulding Sand at Elevated Temperatures.	H. W. Dietert and F. Valtier	,, ,,	,,
Sand Control in Relation to Steel Foundry Production.	Charles Fuerst ..	,, ,,	October, 1937.
A Study of Steel Moulding Sands..	H. W. Dietert, E. E. Woodliff and J. A. Schuch	,, ,,	December, 1938.

A second point of vital importance, on which there exists a multitude of opinions, but little scientifically established fact, is related to the behaviour of molten steel to mould gases evolved during pouring, and, therefore, practically inevitable. It is known that steel in certain conditions is much more susceptible, even if of identical orthodox analysis. This matter of gas solubility has a great practical bearing on soundness, but the fundamental causes of behaviour variations are far from being clear.

Given perfect soundness, the competitive strength of the steel casting in the engineering industry depends on two outstanding features, surface appearance and response to heat-treatment. Experimental work is in progress continuously on both in almost all American foundries, and remarkable improvement has been accomplished. There are factors in both, however, which remain to be solved, if the regularity of behaviour, which can only come as a result of control of known and understood principles, is to be generally achieved. The rewards of such research will be very great, and until such knowledge is available to the industry, it must necessarily work under a handicap.

Design

The inclusion of remarks on design, in a Paper entitled as this one, will probably provoke the suggestion of irrelevance, but this is precisely why they are so included. The author believes profoundly that the design of castings has too long been purely the business of an engineer, whose mind and imagination quite naturally are concentrated on the engineering significance of his shape and contours, often to the complete exclusion of metallurgical factors. These latter are therefore left to chance, or to the ingenuity of the foundryman in developing ways of countering the natural behaviour of solidifying metal, and the devising of expedients to correct the metallurgical anomalies involved in the design.

The design of an ingot from which forged or rolled products are destined to be produced is accepted as metallurgical, in view of the shape influence on ultimate soundness and usefulness for the intended purpose. The underlying thought is of course control of solidification so that it occurs in an orderly, progressive manner best calculated to produce soundness and homogeneity.

The design of a casting, therefore, to which no later work is applied of a shape-forming type, possesses a definite metallurgical significance. Casting design thus becomes a two-phase problem: primarily, an engineering phase, controlling the matters relevant to general shape, and suitable strength to perform the intended service; secondly, a metallurgical phase, exerting an influence calculated to produce such solidification progression that soundness results naturally, and the casting is thus enabled in all parts to exhibit the physical properties of the metal from which it is made.

It has been suggested many times that a designer should be familiar with the main characteristics of the metal from which his design shape will be produced, so that such knowledge on his part has an opportunity of affecting his ultimate decisions, but, so far, no really practical method of achieving this desirable end has been evolved.

It is worthy of note at this time that the two major organisations dealing with castings in America are making serious and organised attempts to remedy this situation. The American Foundrymen's Association, by means of regular and frequent special conferences held in the various universities and with the effective co-operation of the faculties, has brought before students opportunities of attending technical discussions on many foundry subjects, prominent among them being design. The Steel Founders' Society of America, through newly organised divisional operating groups, has formulated committees in each division whose special duties are to co-operate with university and engineering college authorities in the bringing before engineering students of the essentials of casting production and the possibilities of great improvement by the correlation of metallurgical factors and design shape and form. In each case the underlying idea is to ensure actual foundry information being at the disposal of the embryo designer.

The reaction to these movements has been more than merely encouraging, the utmost willingness being evidenced to allow speakers qualified by experience opportunities of stating the case for castings. The ultimate result of these developments cannot be otherwise than beneficial, as more and more practical facts of design effect are made available to the designers of the future.

A Paper presented to the 1938 A.F.A. Convention, by Briggs, Gezelius and Donaldson, is especially worthy of note in this connection, as it represents an unusual effort to evaluate practically many of the metallurgical effects of conventional design. Actual production of a large number of commonly occurring shapes and junctions, and their exhaustive examination by metallurgical methods which included the X-ray, led the authors to formulate certain rules of design.

It is significant that in all cases these rules, arising from exhaustive testing, parallel almost exactly the recommendations to designers which have been emanating from steel founders for years as a result of their practical experiences

The present author recently stated in an article dealing with casting design that the curse of the steel castings industry was orthodoxy of design, and he has little or no reason to modify this statement as his experience has extended.

Shapes and contours accepted as correct to perform certain services fall definitely into fixed types, many of which became customary when in less developed engineering times grey iron was by far the most commonly used cast material. Changes have usually been in minute detail, minor concessions of local effect, often of value, but not affecting major principles.

It has been truly stated that "Man is a creature of habit," and the design of metal castings is an outstanding example of habit formation. The author can imagine no other single factor in foundry production of such vital effect, nor one which offers greater future possibilities of reward, than the co-operative metallurgical and engineering designing of castings.

Almost everything in the world has been redesigned in order to meet conditions effectively as they arise, and always in the light of new knowledge of controlling factors. It is reasonable to suppose, therefore, that ultimately this method of thought will inject itself into the metal casting industries, and when this time arrives there will be entirely new shapes and forms, metallurgically sane, and possessing even greater capacities of engineering performance because of that fact.

Economy of production, reduction of manufacturing hazards, the manifestation in all parts of the available physical properties of the metal used, greater reliability and regularity, and an increasing application—all are possible of achievement in greater degree when known metallurgical fundamentals are permitted to exert their co-operative influence on engineering design demands.

Table VI gives a bibliography of American literature on the design of steel castings.

TABLE VI.

BIBLIOGRAPHY OF AMERICAN LITERATURE ON THE DESIGN OF STEEL CASTINGS.

Title.	Author.	Publication.	Date.
Economies in Steel Casting Design	F. A. Lorenz, Jr.	The Foundry	October, 1932.
Fillet Profiles for Constant Stress	Dr. R. V. Band	Product Engineering	April, 1934.
How Solidification Affects Steel Casting Design.	F. A. Melmoth	,, ,,	April, 1934.
Steel Casting Design for the Engineer and Foundryman.	C. W. Briggs, R. A. Gezelius and A. R. Donaldson	American Foundrymen's Association Preprint No. 38-28	1938.
Steel Castings Prove Merit as Large Intricate Parts.	F. K. Donaldson	Machine Design	June, 1938.

DISCUSSION

American Locomotive Frame Castings

MR. T. HENRY TURNER (chief chemist and metallurgist of the London & North Eastern Railway), opening the discussion, said his experience of American steel-foundry work was limited to a short visit to U.S.A. and Canadian foundries in 1926. He regretted that illustrations had not been included in the Paper, as he had been greatly impressed by the amazingly large and complicated steel castings which were tackled in the U.S.A. He quoted as an example the steel casting made in one monobloc to include both the long side members and all cross members of a locomotive frame, and the complicated cylinder casting which might include four cylinders.

That all this could be made in one colossal monobloc was a very remarkable achievement, and it seemed hardly necessary to head the Paper "The Renaissance of the Steel Casting" when American foundries had been able to produce such castings and when such castings were in some cases replacing forgings.

The practice in this country and on the Continent was to build up locomotive frames from forged parts, but it was claimed in the United States that these complicated monobloc frame and cylinder steel castings were more economical to maintain than forged frames for the very heavy locomotives used in that country. Moreover, these cast steel frames had been exported to Australia and elsewhere. So far as he could judge, the history of castings in the United States was one of constant progress, and he had been interested to note, in every steel foundry which he visited, the use of electric furnaces.

The author's remarks regarding research and metallurgists deserved especial attention. There was a time when trained metallurgists found the iron foundry unattractive in the way described by the author for the steel foundry, but the development of foundries along better engineering lines had made the foundry a less unattractive

place than it was, and one might therefore feel confident that when the author stated that the major portion of the rôle of the metallurgist in the advancement of steel-foundry work remained to be played, metallurgists would be found to assist the engineers in such developments, and if X-rays were used in the development of new casting designs and magnetic crack detection was employed in the inspection of the finished castings, there was no reason why engineers should not have greater faith in the steel casting than ever before, even if the specifications were stiffened up appreciably.

Mr. R. Chavy (France), referring to the development of some special steels for crankshafts, said that their composition was very different from that of steels used for forging, the property of fatigue strength being rather more important than tensile strength or elongation.

Potentialities of Plain Carbon Steel

Mr. J. Deschamps (Kryn & Lahy) said he would have liked to have asked whether the author was quite satisfied that the potentialities of plain carbon steels for castings had been fully exploited. Was it really necessary to resort to the obvious and easy method of alloying the steel in order to improve it, instead of exercising the necessary care in improving the plain carbon steels? Reference was made in the Paper to an extraordinarily good result obtained with a fully heat-treated steel casting, showing a maximum tensile stress of 40 tons per sq. in., yield point approximately 27 tons per sq. in. (which was about 70 per cent. of the ultimate tensile), elongation 30 per cent., reduction of area 60 per cent., and a Charpy impact figure of 30 ft.-lbs. (the latter figure corresponding with 35 or 40 Izod). Mr. Deschamps urged that such results could be obtained with plain carbon steels, provided they were properly controlled. Why, therefore, should we resort to the relatively expensive method of alloying and heat-treatment, when similar results could be obtained without heat-treatment from properly made carbon steel?

Another question was whether the American steelmakers felt, as some foundrymen did in this country, that the specifications they had to work to were too lenient. Almost anybody could make steels to meet some of the specifications; he was definitely of the opinion that the specifications should be made much more difficult, and that this move would benefit the steel-foundry industry, which was bemoaning the fact that forgings were replacing castings.

Again, he asked whether there were great developments in America in the direction of making composite assemblies of steel castings and welded parts, as, for instance, by welding plates to castings; or, still more interesting, whether there were developments in the direction of replacing intricate steel castings by an assembly of plain steel castings which could be made on production lines by semi-skilled labour and welded together.

Finally, he wondered whether further developments had taken place in America in connection with the application of the hydro-blast to replace shot-blasting.

Mr. A. Tipper commented on the similarity of some of the statements made by Mr. Melmoth, particularly with regard to moulding materials, and by the authors of some other recent Papers, as, for instance, Mr. J. J. Sheehan, in his Paper before the Congress on the subject of core shop control, and by Mr. Hudson in a Paper not very long ago in which he had stressed the importance of the control of grain size. Mr. Melmoth had stressed the importance of obtaining better surfaces on castings, and had pointed out that the moulding material was a very important factor affecting the surface condition. He had also stated that "From the realisation that permeability to rapidly evolved gases is essential in both facing and backing, there has developed an almost general use of sand handling and reclaiming equipment." That was recognised here both as regards iron and steel foundries. The statement that, generally speaking, there was no attempt to remove all fines, presumably meant that, instead of attempting to keep the sand in the right condition in that way, we should select the right type of sand primarily. The work of Sheehan on the fitting-in of grain sizes had an important bearing on that. Another statement which it was important to note was that concerning the selection of a backing sand with a higher permeability and lower bond where one was using separate backing and facing sands. That principle also had proved to be successful when applied to cast iron sands in this country, and he believed it could be regarded as proved for steel also.

AUTHOR'S WRITTEN REPLY

The engine bed, side frame and underframe castings mentioned by Mr. T. Henry Turner have been made for a considerable time in the U.S.A., quite successfully, and illustrations of them have been included in many articles published in the technical Press. It is true that careful records kept by the manufacturers of such castings substantiate claims that integral casting of such members results in considerable economy of maintenance and longer life. It is

equally true, however, that the phase has existed when steel castings were being replaced by other materials, often without rhyme or reason, or on unsubstantiated claims of economy or increased efficiency.

During the past few years, in spite of the very slack state of industry generally in the United States, the value of the steel casting is becoming more and more to be realised, and its scope of application widened appreciably; hence, the choice of title for the Paper. It is believed that a return to normal productive conditions will find the steel-casting industry of the United States in a much stronger position, both technically and economically, as a result of the generally improved methods of manufacture and control which have developed during recent years.

The author is in complete agreement with Mr. Turner regarding the supply of trained metallurgists for the advancement of steel-foundry work, as at no time in his experience has there been such a considerable interest shown by metallurgists in steel-casting production, which interest has been evinced by a desire to become associated with the industry.

When Alloy Additions are Needed

Replying to Mr. J. Deschamps, the author has stated in several Papers that a resort to alloy additions was unnecessary until the potentialities of plain carbon steels were fully utilised. The matter of design and size of casting exerts a controlling influence on the type of heat-treatment to which it can be subjected with safety, and recourse is made to alloy additions frequently only for this reason, that it permits the application of a less stringent form of treatment to produce similar physical characteristics.

In spite of this, the author has regretfully to concede that if Mr. Deschamps can produce intricate steel castings of, say, around $1\frac{1}{2}$ to 2 tons each in weight, with test-bars cast integrally on the castings, and use a plain carbon steel to produce physical test results with regularity equal to those mentioned in the instance he quotes from the Paper, he is well ahead of most exponents of the steel casting. For his own information, the author would welcome the opinions of other producing members of the industry on this matter, as it is of considerable importance in controlling one's opinion as to the stringency or otherwise of existing specifications. Unfortunately, it has to be remembered that specification figures represent minima, which means that, to ensure safety, the potentialities of the material should be considerably higher than the demanded figures.

U.S. Specifications

Replying specifically to Mr. Deschamps' question regarding specifications, it is not felt in the United States that, generally speaking, specifications are too lenient. The author's experience, as a matter of fact, is that they are rather more stringent in America than in Britain. In almost all cases, reduction of area is specified at a certain minimum, which in the author's experience was not the case for many British requirements; and the author thinks that Mr. Deschamps will agree that reduction of area represents the one phase of steel casting properties which is very quickly affected deleteriously by slight imperfections, or microscopic inclusions. Based on requirements of tensile strength, elastic limit and elongation percentage, the author is inclined to agree with Mr. Deschamps' opinion that steels are easily made to meet some of the specifications, but very few such specifications exist in American engineering requirements, it being believed, and quite rightly, that reduction of area represents the most revealing characteristic as to the true value of both the material and heat-treatment.

Composite Assemblies

There have been considerable developments in America in the direction of composite assemblies of steel castings and welded parts. In fact, where fabricated construction has replaced cast iron, a new outlet for many steel castings has thus been produced. The second portion of this question, referring to development in the direction of replacing intricate steel castings, by an assembly of plain steel castings later welded together, is more difficult to reply to positively, although the author has seen several cases of this type of production, and has seen it suggested in many cases. He is not aware, however, of very active development along this line.

The substitution of shot-blasting by the use of the hydroblast has been carried out in some quarters, but where steel castings are concerned the reports of its success are not sufficient to justify one in stating future possibilities in this direction.

Mr. Tipper's remarks are appreciated, and the author would assure him that any similarity of statement as pointed out by him is "purely coincidental." The statement made in the Paper that there was no attempt to remove all fines from moulding sand was based on the accepted fact that the control of the percentage of fines at a limit known not to be harmful was the aim, rather than the taking of uneconomic measures to remove them entirely. The author agrees with Mr. Tipper that one should select the right type of sand primarily, but the question arises: What is the right type of sand?

It would appear that as the industry's knowledge of the effect of grain size, grain shape, permeability and other moulding-sand characteristics is added to by the many able workers who are giving the results of their work freely to the industry, new ideas as to moulding materials may be produced eventually which may enable the industry to take further forward steps in the improvement of the appearance of steel castings. Such work has been highly productive in the U.S.A., where, in spite of opinions to the contrary held by many Europeans, " skin appeal " represents quite a potent factor in the selling of steel castings.

Paper No. 685

Pitting Corrosion of Cast-Iron and Steel Pipes

By Dr. Ing. LUDVIK OLŠANSKÝ (Brno.)

Introduction

After considering the question, which of the two kinds of pipes is the more durable and therefore the more economical when laying gas mains in localities where mechanical strength is of minor import, the author reached the conclusion that it is neither necessary nor equitable to seek a numerical postulation of the time before perforation of the pipes occurs. On the contrary, it is preferable and more advantageous to determine the relative time in which such pipes would perforate through pitting, under the condition that both types are placed in the ground the same time; under identical circumstances and simultaneously in the same position, and carrying prearranged and frequently occurring defective spots in the protective coating and the insulation, largely set up through mechanical influences.

In other words, the correct determination of the relation of times in which these pipes would be perforated through pitting must be so carried out that the corroding action on the outer and the inner surface of the two types would take place under definitely comparative conditions, *i.e.*:—

(1) Identical pressure; temperature; concentration of chemical reagent; quantity of this reagent acting on a given surface of equal size, representing theoretically in the hypothetical case a point. Such conditions cannot be obtained except in a laboratory.

(2) The material examined must be in the state in which it would be after the protective coating or insulation has been destroyed. Every other experimental method, especially the machining of the surface, will give wrong results in the evaluation of pipe material, as will be seen from what follows.

Moreover, it is essential that, when examining the depth of the corrosion, the material lying immediately against the place attacked must be maintained to conform with the original wall thickness dimension, so as to be able to study metallographically the eventual divergences in the depth of the corrosion which might be pursued only in the case of corrosion at one spot.

By insisting upon the above-mentioned comparative conditions, and securing the correct proportion of times in which the material of the pipe had been perforated by pitting, it is possible to state which pipes are the more durable and therefore the more economical. Should, for

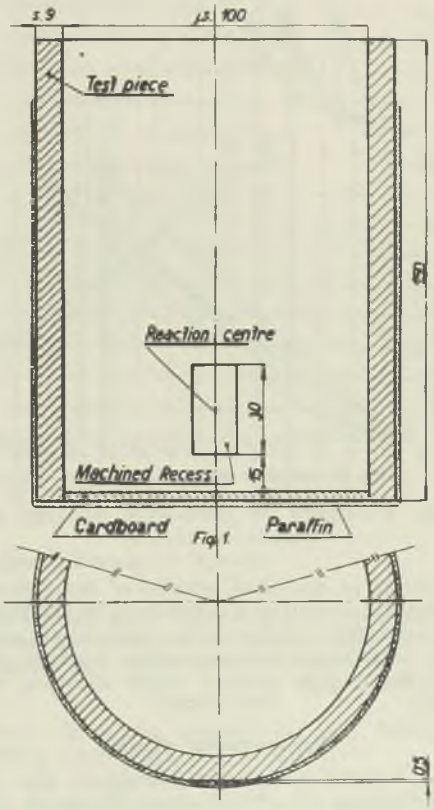

FIG. 1.—TESTING ARRANGEMENTS.

instance, a pipe line last for x years, then in the same locality, under the same condition, another pipe line would last for px years, where p is the number indicating how many times one pipe is more resistant, and therefore more enduring

than another. The cause of the destruction of cast iron and steel pipes has been studied by the author on sections of pipes which had not been machined, *i.e.*, complying strictly to the necessary comparative conditions, and later on machined sections of pipes. For these tests a 5 per cent. solution of HNO_3 was used and the results derived therefrom on sections of both cast-iron and steel unmachined pipes were given before the Paris International Foundry Congress in 1937 under the heading, "Une Étude sur les Effets Corrosifs sur les Tubes en Fonte et en Acier."

In what follows the author proposes to detail the methods used for studying the perforation

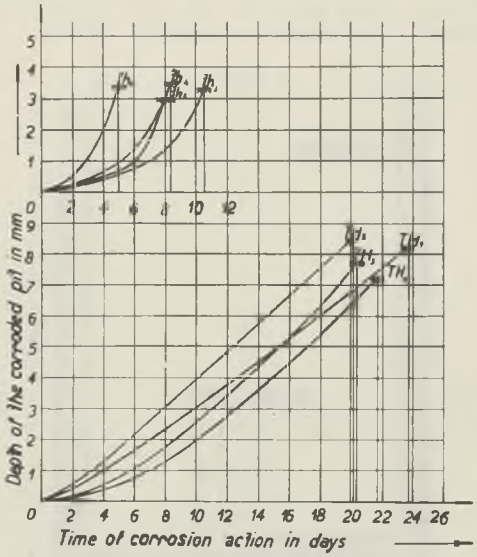

Fig. 2.—Depth of Corrosion Related to Period of Attack.

by pitting of machined sections of cast-iron and steel pipes, as well as a comparison of the results obtained under similar and comparative conditions with those obtained when working with unmachined pipe sections under identical conditions.

Experimental Work

The temperature of the laboratory was controlled during all tests at about 20 deg. C. For the tests sections of cast-iron pipes, marked TH_1 to TH_4, having an inner diameter of 4 in. and 6 in. long, were used, together with sections of steel pipes having similar dimensions which were marked th_1 to th_4. Into these pipe sections, at a distance of 15 mm. from the base, a recess 30 mm. long and 0.5 mm. deep was cut. It was as is shown in Fig. 1.

In order to ensure that the corroding agent will produce a pit only at the required spot, it was necessary to carry out a further and now well-known preparation of the sample. A cardboard sheet was placed in the base of the pipe section, and the test-pieces so prepared were dipped with the cardboard base bottom-most into molten paraffin so that it reached the upper edge in order to obtain, after removing it and allowing it to cool, a good overall protective coating, adhering well to the surface. Once again, as the corroding agent, a 5 per cent. solution of nitric acid was used. Glass containers having a diameter of 10 in. and 5 in. high were used. Before starting a standard quantity of the acid, *i.e.*, 3.5 litres, was poured into each of these containers.

To measure the corrosion effect, a simple arrangement, shown in Fig. 1 of the Paris Congress Paper, was used, which made it

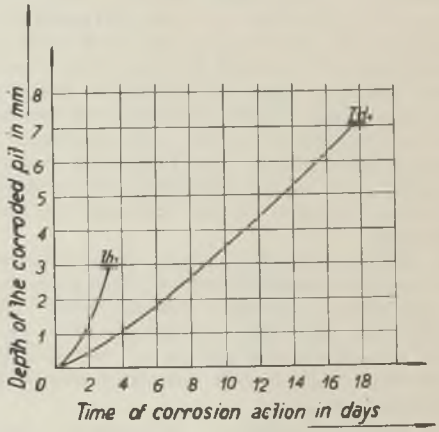

Fig. 3.—Depth of Corrosion Related to Period of Attack.

possible to measure the pits produced by the corrosion in three axes ranged vertically to each other. This measuring arrangement consisted in principle of a cross-support, the shifting of which in two horizontal axes, vertical to each other, was provided with a millimetric scale. This cross-support carried an indicator to measure the depth in the third axis vertical to the two preceding ones. The cross-support was fixed to a support provided with an attachment to hold the parts of the pipes to be measured.

Testing Procedure

From the test-pieces so prepared, the protective coating was destroyed by puncturing it in the same place as near the middle of the surface to be tested as possible, so as to bring the uncovered area beneath the surface of the

liquid agent for the duration of the test. The two test-pieces to be compared were invariably placed into the containers filled with the acid, the cardboard bottom-most, for a time interval of 5 mins. In this series the action of the reagent was periodically interrupted for two days, allowing sufficient time to measure the shape of the pits produced by the action of the acid. During the test, the temperature (*circa* 20 deg. C.) was constantly measured.

A graph showing a numerical indication is given in Fig. 2. These tests were repeated on sections of the cast-iron pipe TH_1 and the steel pipe th_1, the depth of the cylindrical recess being increased to 1 mm. The results obtained are illustrated in Fig. 3.

In order to be able to compare the progress of the destruction of the material of machined and unmachined pipes exposed to the corroding agent under exactly similar conditions, it has been deemed necessary to construct the diagram in Fig. 4 on the basis of numerical records. In the diagrams (Figs. 2 to 4) the time in days has been set out on the horizontal axis, whilst on the vertical one the respective maximum depths in mm. of the pits produced by the action of the 5 per cent. HNO_3 at an average temperature of 20 deg. C are given. The thickness of the walls of the pipes is limited by a horizontal axis and lines parallel to it by cross-hatching.

From a study of the curves of Fig. 2, showing the progress of the pitting corrosion in depths in both types of pipes at places which have been machined, it is evident that these curves have nearly the same shape and the same trend as the curves in Fig. 4, showing the magnitude under similar conditions for the same materials extending from 0.5 mm. and initiating a progressive corrosion.

Similarly, from a study of the curves of Fig. 3 showing the progress of pitting in depths for both types of pipes at places which were machined to a depth of 1 mm., it is shown that these curves again have practically the same shape and the same trend as the curves in Fig. 4, showing the progress of pitting of the same materials, but this time extending from 1 mm.

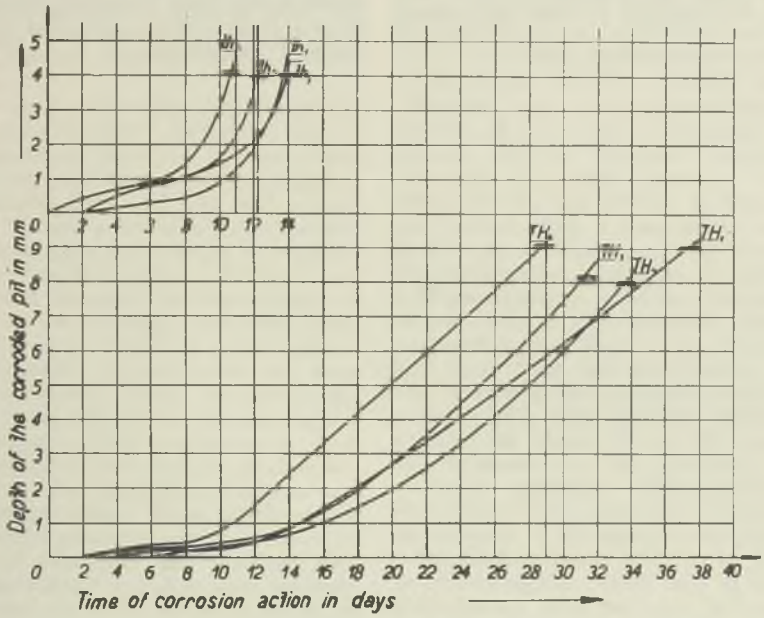

Fig. 4.—Depth of Corrosion Related to Period of Attack.

Conclusions

From the above comparisons and tests the following conclusions can be drawn:—

(1) The widely-held opinion as to the importance of the as-cast skin for increasing the resistance of cast-iron pipes to corrosion set up by the influence of corroding media is a sound one.

(2) The scale (magnetic oxide) formed during rolling has the same importance for increasing the resistance of steel pipes to corrosion as the as-cast skin in the case of cast-iron pipes.

(3) The outer layer of the material of pipes situated immediately beneath the as-cast skin,

or beneath the scale, is much more resistant than the internal layers.

(4) The as-cast skin or the scale and the layers of the surface situated directly behind them at those places which are opposite to points where the corrosion began, have no influence on the resistance to corrosion.

(5) It is only desirable to make a comparative test on cast-iron or steel pipes with an unmachined surface, *i.e.*, as they are used for laying gas mains.

(6) It is impossible to evaluate the resistance of cast-iron and steel pipes to corrosion on the basis of machined cylinders as has been indicated by the author under the signature H. B.* for, by machining, the qualities of both the casting and the steel are completely changed with regard to the influence of corroding agents.

* Strojnický Obzor, 1936, p. 45.

Composition

The chemical composition of the cast-iron pipe and plugs used in these tests was:—T.C, 3.67 to 3.71; C.C, 0.88 to 0.97; Si, 1.64 to 1.83; Mn, 0.60; S, 0.075 to 0.08, and P, 0.19 to 0.45 per cent.

The composition of the steel pipes and plugs was:—C, 0.38; Mn, 0.73 to 0.8, and P, 0.03 to 0.031 per cent.

The author considers it his duty to express his thanks to Dr. Mont. Ing. Fr. Písek, Professor at the Czech Technical University of Brno, for his great interest and kind help during the study of this subject.

Paper No. 686

Foundry Education and Training in Great Britain

By J. G. PEARCE,* M.Sc., M.I.Mech.E., M.I.E.E., F.Inst.P. (Member)

Introduction

Much has been written from time to time on this subject, and it is intended that the present Paper shall be in the main a record of facts. In particular, it gives an account of the aim and work of the British Foundry School, which opened in 1935.

Until recent years, foundries were conducted mainly on a basis of skilled craftsmen, led by foremen and managers who had in many cases had long practical experience in the patternshop or on the foundry floor and who had proved their capacity to hold posts of higher responsibility. This system gave this country an enviable reputation for craftsmanship. To-day, two developments have changed the whole aspect of many sections of the industry, and seem likely to change it still more. The first is the application of those methods of continuous and mass production which have already so profoundly influenced the remainder of the engineering industry; the second is the establishment of a vast body of technical and metallurgical knowledge relating to the materials, processes and products of the industry. These developments have brought about great changes in outlook on the problems of education and training and, indeed, are responsible for raising them seriously for the first time, since the ordinary system of apprenticeship and promotion sufficed to meet the needs of an industry working on a jobbing basis.

The main source of supply of operatives is inevitably the primary school, and the normal school-leaving age of 14 has recently (Education Act, 1936) been raised to 15, except in cases where the parents wish the boy to enter employment and the education authority is satisfied that this employment is "beneficial." There is a strong body of opinion in favour of no exemptions at all, that is, a universal leaving age of 15, and some associations of employers and employed have already intimated that it is preferable to recruit employees at 15. Sound apprenticeship schemes enrol young people for trade apprenticeship up to 16, since it is found that the extra educational period easily outweighs in value any loss from a shorter apprentice period. At the same time, the closing of blind-alley occupations to young people under 15 as non-beneficial employments (*i.e.*, offering no training of value or future prospects) should react favourably on firms who could take more young people than they normally can obtain.

Certain types of senior or central schools take boys at 11 or 12 for a three-year or four-year period. Junior Technical Schools take boys, who wish to enter industry, from primary schools at 13, and provide a two-year or three-year course, with a pronounced vocational bias in the case of those preparing boys for entry to the constructive industries, in such subjects as workshop practice, machine drawing, etc. Such schools form a very desirable source of trade apprentices, but there is no information as to how many from this source enter the industry. The secondary and grammar schools also receive young people from primary schools (public or private) at about 11 or 12, and take them approximately to the standard required for university entrance. Comparatively few boys from these schools enter the industry, except for employment in laboratories and offices.

The Hadow report (1931)[1] is accepted generally as indicating the future lines of development of post-primary education in this country, and, broadly speaking, these aim at a primary school training to the age of 11 and then transfer, according to ability, desires of pupil and parents, etc., to another type of school, senior, secondary, etc. The raising of the leaving age was a logical consequence. The Spens report recently issued (1939)[2] marks a further development of the Hadow scheme, and envisages the growth of types of school which, without sacrificing the demand for a good general education, will recognise that activity and experience are important channels to knowledge and will prepare boys more directly for industrial employment, and thus meet the criticism that ordinary secondary schools prepare boys for the so-called black-coated posts. Thus it envisages the development of technical high schools, ranking with the secondary schools, but directing pupils to industry as the present type of secondary school tends to do to commerce.

* Director, British Cast Iron Research Association.

The school-leaving certificate forms a suitable criterion of standard reached by secondary-school boys, and until recently this has been accepted, subject to certain conditions, as a substitute for matriculation or university entrance examination, although this tended to such undesirable modification or specialisation of curricula that the plan has recently been abandoned. A university entrance examination in a limited number of subjects is not a desirable form of certificate for boys who are not in the main preparing for the university. Nevertheless, a suitable leaving certificate is very useful to employers as an index to standard reached, and invaluable to its owner as a basis for acquiring a professional certificate by part-time study. Some boys stay long enough at the secondary or grammar school to take the higher school certificate, which roughly covers the first year of a university degree course, *i.e.*, to the intermediate degree examination, at any rate in scientific subjects, mathematics, physics, chemistry. Young men leaving school for industry with the intention of securing a professional qualification or external degree would do well to get the higher school certificate from school. Such qualifications are those of the Institution of Mechanical Engineers, Institution of Electrical Engineers, Institute of Chemistry, Institute of Physics.

The number of universities in Great Britain having departments of metallurgy, or offering instruction in metallurgy, is about ten, but the number of students actually taking degrees in metallurgy is small[3]; so much so, that no great recruitment of university graduates to the industry is to be expected, although further reference is made below to institutions offering full-time foundry training. For university men who are without industrial experience, the author firmly believes in the advantages of a short works apprenticeship, in which experience is gained of various departments and in which both the apprentice and the employer have opportunities of finding out whether staff employment is suitable. Part of this is most advantageously taken between leaving school and entering the university.

One can thus picture the bulk of those who go into the industry doing so with a primary education, a very small proportion with a secondary or higher education, and a still smaller proportion with a university qualification. Continued education takes place after entry to industry through part-time evening study in local technical colleges, although some colleges also offer facilities for part-time training during the day for one or two days a week. Little provision of this kind is made for or used by the foundry industry. Part-time continued education is treated further below. It is understood that part-time evening continuation education, which, of course, is entirely voluntary, attracts about 5 per cent. of those eligible to attend (*i.e.*, those between 14 and 18 not pursuing a full-time educational course), while a further 5 per cent. of those in industry already taking part-time education attend part-time day, as distinct from evening courses. These figures refer to industry as a whole. Employers can greatly assist attendance by encouraging apprentices to attend, paying fees, and so on.

Apprenticeship

In days when industry was mainly a "mystery," and an affair of practical experience and individual craftsmanship, developed from a long period of training, indentured apprenticeship was the method of training. After serving a master, the apprentice gained further knowledge and experience by working elsewhere, as a journeyman. The changes in industry have, except in a comparatively small number of cases, resulted in a decline in apprenticeship, and young people entering the industry obtain their experience of the industry on whatever work is going through the shops, without entering into an obligation binding on either employer or apprentice. A distinction, however, does still persist between the young man who works on an apprentice basis and the handy youth who works to satisfy his immediate need for employment rather than to learn the trade. Learning from experience, however, cannot strictly be regarded as training, which involves two things.

Whatever the limitations of a shop in size or scope of work, young people being trained should have opportunities of working on all the types of work in the shop, with, if possible, periods in patternmaking as well as moulding and coremaking, as well as a brief spell in a machine shop. The drawing office and laboratory could be included in exceptional cases. Secondly, young people should be taught the operations instead of being allowed merely to pick them up by watching older men. Such training is not only valuable in conferring manual skill. The experience of shop discipline, shop organisation, of co-operation to a common end, are also very valuable parts of the training, and, more than anything else, a spell in the shops shows a young man whether he finds the industry congenial and his employers whether he has the qualities needed for practical foundry operations. It will be obvious that such training can only be obtained in an industrial establishment, and that no school or college can usefully offer or claim to offer practical training in lieu of this.

At the same time, provided this is understood, the limited provision offered by technical colleges serves a useful purpose, in facilitating experiments impracticable in a works, and

in providing instruction in elementals to those engaged in engineering and other metallurgical operations and not in the foundry trade itself. The same applies in lesser degree to the small training shop for apprentices in larger works, such as are often found on the Continent. It has the advantage of offering work carefully graduated in difficulty to the boy in his early stages, but the period there should not be unduly prolonged.

In one large British works, a scheme is found which admirably combines the need to-day for combined practical experience and technical knowledge. Six months' probation is served after education, preferably at a junior technical or central school, and a physical examination is passed. Skilled apprentice instructors supervise the practical training, which is tested every six months, and instruction in subjects of general and technical education is provided in the works' school. Facilities exist whereby every ambitious young man may rise to a post of superior responsibility. In training university men for engineering posts, the same company arranges for the three months of the first year to be spent in the foundry or patternshop.

Such a scheme well illustrates not only the requirement to-day of a combination of manual skill and technical knowledge, but also of an adaptability of mind to meet the changes industry will produce. As a whole, it must be regretfully admitted that only a small proportion of those entering the industry are practically and technically trained for whatever grade they hope to occupy within it.

The main objection to an apprenticeship confining the young man to one foundry is that, even in a good general foundry, the variety of work is limited. One interesting proposal to overcome this difficulty, due to Ingall,[4] provided that apprentices undergoing a full-time two-year course of training in the area served by the Constantine Technical College, Middlesbrough, should regularly visit and work in the whole of the shops sending apprentices to the group. It is unfortunate that this scheme of full-time training is at present suspended, although it may be revived on a sandwich basis of six months in the College and six months in the works.

It is now proposed to consider the facilities offered to and qualifications open to the operative, the technical and the executive grades for technical training, bearing in mind that experience in a foundry is not necessarily foundry training and that foundry education is only one factor in success in foundry executive work.

Technical Training for the Operative or Craftsman

In providing facilities for young people to acquire some knowledge of the technical basis underlying the industry, the technical schools have to face two conditions which materially affect the nature of these. The first condition is that attendance is on a voluntary basis, and it is only in recent years that technical schools have been able to induce students to take a course in closely allied or grouped subjects, as distinguished from isolated subjects. The consequence of this is that attendance is undertaken only by those more able and far-sighted young people who desire to make use of the education in securing positions of higher responsibility. This is a perfectly natural and desirable procedure, and gives valuable help to those who would previously have risen purely by virtue of qualities of character, personality and perseverance, but who would to-day find themselves unduly handicapped by lack of technical knowledge. Were the education system faced with providing instruction for all young people in industry, that is, on a compulsory basis, the method of approach would necessarily be entirely different.

The second condition is that the schools cannot confine instruction in foundry subjects to purely foundry students, with the result that in foundry classes there is always, apart from moulders and patternmakers, a proportion of students from other branches of engineering and others who for various reasons desire to learn something of foundry science. This materially affects the attitude of the technical colleges to practical work, for students outside the industry have no opportunity of gaining any insight into practical founding except through such provision as is made by the technical colleges, although the foundry apprentice can only learn his trade in the foundry itself. There is also difficulty in obtaining suitable teachers of foundry subjects. The skilled practical man does not always possess the necessary gift for imparting his knowledge and the trained teacher has seldom had training either in foundry science or practice. This deficiency is now, however, being made good.

In formulating courses for the technical training of young foundrymen, it is generally considered that, for evening study, two years' part-time work is required in calculations, science and drawing, in order to establish the necessary foundations beyond the work of the primary school, and a further three years' work to enable the apprentice to reach a qualifying standard. Secondary and junior technical school boys may, of course, short-circuit the preliminary course. The qualifying standard is admirably provided by the examinations of the City and Guilds of London Institute, which conducts each year two examinations in patternmaking, intermediate and advanced, and one examination in foundry science and practice, which at a later date may be similarly divided into two grades. The examinations are controlled through an Advisory Com-

mittee, largely nominated by this Institute. The examinations are wholly written and without the wholehearted co-operation of the industry it would not be possible to arrange practical examinations at a large number of centres, but for the reasons indicated above, the written examination meets the requirements of the present voluntary basis very satisfactorily. The syllabuses for these City and Guilds examinations are available to those interested on application to the Institute.

So much criticism is directed at examinations and examining bodies that it is satisfactory to report the favourable influence of these particular examinations on the growth of foundry instruction, for there is little doubt that the existence of the City and Guilds syllabus has facilitated the provision of classes by the technical colleges. In 1930 Ingall reported that 27 technical colleges providing classes in foundry technology had barely 200 students. In a recent inquiry, the author had replies from about 40 technical colleges, providing classes in pattern-making and/or foundry work, about 30 of which specifically provide courses leading to the City and Guilds examinations, while several others are making provision for this in the near future. In several other cases students are prepared for the examinations of various regional bodies, such as the Union of Lancashire and Cheshire Institutes, or the East Midlands Educational Union.

While no specific inquiry was made about numbers, the information received suggested that in eight of these institutions the number of students totalled nearly double that recorded by Ingall, although there was very general admission of the difficulty of securing the presence and regular attendance of foundry students. At the same time, from the scanty data available, it is thought that the foundry industry is at least up to the average of other industries in the proportion of young men undertaking voluntary part-time education. The provision of syllabuses for these examinations and the preparation of examination papers by those closely in touch with the industry have undoubtedly had a favourable influence, and the technical colleges are to be congratulated on their efforts to establish classes.

Technical Training for Intermediate Grades

The development of the industry has resulted in a very much more diversified group of occupations and a greater demand for men needing some technical knowledge than was the case a few years ago, such posts including chemists, laboratory assistants, inspectors, testers, estimators, rate fixers, progress men, and so on. Those who have such posts, or the more ambitious workmen who hope to get them, are provided for by the endorsement in foundry science of the National Certificate in Mechanical Engineering, ordinary or higher, of the Institution of Mechanical Engineers.

The national certificate, resulting from a co-ordinated and progressive course of study in a particular group of subjects, is the natural result of the development of the course system in technical schools, and usually a certificate can be obtained after three years' study for the ordinary certificate and about five years for the higher certificate, which is regarded as reaching university degree standard in its particular subjects. About eight of these certificates are now available in various branches, mechanical, electrical and gas engineering, chemistry, etc. Since no such certificate exists in metallurgy and since the production of castings is as much an engineering as a metallurgical task, arrangements were made by the Institute for the endorsement in foundry science and practice of ordinary and higher national certificates, issued under the ægis of the Institution of Mechanical Engineers. This can be done by the student taking a course subsequent to obtaining the certificate or during the certificate course.

In accordance with the usual practice governing national certificate examinations, the syllabuses and examination papers are arranged by the technical college and externally assessed, while the scripts are marked by the college and assessed externally. The college is therefore much freer than those teaching to an external syllabus, and local industrial requirements can be kept in mind. While the present position with regard to qualification for the intermediate technical grades cannot be regarded as entirely satisfactory, the arrangement does offer something until a better basis can be established. Information received suggests that eight technical colleges offer or are prepared to offer courses leading to the foundry endorsement of the Higher or Ordinary National Certificate, and one college offers a Foundry Engineering Course leading to the Ordinary Certificate in subjects best calculated to assist the foundry engineer. For those who are in a position to begin the course with the aim of foundry endorsement in view, such a foundry engineering course is to be warmly commended.

Technical Training for Executive Grades

The growth of foundry science necessitated provision for the technical training of those who exercise executive responsibilities. Furthermore, the growth in size of foundries and of mechanisation makes it desirable that in such establishments there should be several men in various key positions who are adequately qualified technically, and it will be clear that while this training is indicated for executive grades, it is also intended for those whose responsibilities are mainly technical or both technical and executive.

Although universities form a natural reservoir of men with the highest technical qualifications, as indicated above, the number of graduates leaving these departments annually does not encourage the belief that a large accession of university-trained men to the foundry industry can be expected, either now or in the immediate future, although, of course, a small number of graduates do find their way into the industry.

Loughborough College makes provision for foundry teaching, but mainly for its engineering students, as far as day instruction is concerned. A few years ago the University of Sheffield, with the co-operation of the Institute and with the financial assistance of a number of firms in the industry, made provision for instruction in foundry science, and it is understood that candidates for the honours degree in metallurgy, involving three years' study after the intermediate examination, may take either ferrous metallurgy, non-ferrous metallurgy or foundry metallurgy. Since the scheme was begun in 1935, sufficient time has not elapsed to see to what extent the scheme yields recruits to the industry, although there is already little doubt that it has had, from a foundry point of view, a beneficial influence on the training of metallurgists in general. Further reference to the Sheffield scheme will not be made here, as it is understood that fuller treatment is being given in another Paper.

The difficulty of training men through institutions outside the industry is heightened by the difficulty of knowing whether a given candidate so trained will find the industry congenial to him and, as in other fields of activity, the higher branches of foundry work call for qualities of personality, character and experience, not necessarily brought out or developed by a formal scheme of education. The skilled foundry executive can comparatively quickly make up his mind whether a young man has the necessary qualities for success in foundry work, and another proposal for a full-time training scheme put forward by the author in 1934 was based in part on a recognition of the impossibility of teaching practical foundry work in a school and of the fact that the industry itself was in a measure the best possible sieve for determining what men were likely to be successful in it. It was furthermore thought that, to be successful, any school for training foundrymen should be associated with the industry in a way which has not perhaps been fully achieved either in this or in any other sphere, and these considerations led to the establishment of the British Foundry School, of which a brief description can now be given.

The British Foundry School

The School opened for its first session in 1935 and is now in its fourth year. The course lasts for one academic year, from September to July. The School is financed in part by a group of ten institutions, of which the Institute is one, being research associations, trade associations or technical institutions connected with the industry (Appendix I gives a list of the initial group concerned), in part by donations from industrial firms, in part by students' fees, and in part by a grant from the Board of Education. The subscribing institutions and bodies nominate representatives to the Governing Body, to which a number of prominent industrialists have also been co-opted, and the author has the honour of being its Honorary Adviser and Honorary Treasurer.

The School is thus entirely controlled by the industry through its Governing Body, but it is necessary to make amply clear that the fullest co-operation is exercised with the educational authorities, both national and local, and both the Board of Education and the Birmingham Education Committee are represented on the Governing Body. Indeed, it would not be too much to say that without the broad-minded and continuous help of the Board of Education and practical assistance from the local authority, the School could neither have come into existence nor continued to function. Birmingham was chosen as a convenient central city in what is perhaps the most densely populated foundry area in the country, and for convenience the School is housed in the buildings of the Birmingham Central Technical College, by arrangement with the Birmingham Education Committee. The School is national in character and awards a Diploma on the result of its annual examination, which is endorsed by the Board of Education.

It is necessary to emphasise the fact that the whole range of foundry production is covered by the School, grey iron, white and chilled iron, malleable cast iron, cast steel and cast non-ferrous metals, since the principles of founding are common to all and the student is not permitted to specialise. The curriculum is available to those interested.

The number of students can in the nature of the case never be large. Thirty-six students have been enrolled to date, and an annual enrolment of twelve to fifteen students will justify its continuance. Judging by the experience of the French Foundry High School in Paris, to which the British Foundry School has similarities, there should be no difficulty in securing a minimum of twenty students per annum, which would for the time being be regarded as a maximum.

The School aims at attracting young men who have already entered the industry, who have obtained some practical experience in it, and who have some technical knowledge, at least equivalent to that of an ordinary or higher

national certificate, and who give evidence that they are suitable for advancement to higher responsibilities. In the large majority of cases these young men are nominated by their employers, who both pay the School fee (£30 for the session) and maintain the student during the period of instruction (£110 to £120 is a reasonable minimum for this period). At the same time, nothing prevents a suitably qualified student from taking the course on his own initiative and in some areas local Education Committees are prepared to aid suitable students who would otherwise find financial difficulty in entering. The average age of the students is about twenty-four, and about one-seventh of the candidates have been to public schools, and a similar proportion have university degrees. The Governing Body preserves a measure of elasticity in assessing entrance requirements, being prepared to balance more or less technical education with less or more practical experience, if they are satisfied that the candidate is of the right calibre. The mixing for a year of a group of young men with varying experience and training is of the highest value to them and, apart from the United Kingdom, students have been sent to the School from New Zealand, South Africa, India and Egypt.

The curriculum is such as to make a very hard year's work, and considerable demands are made on the students' own time, so that they are not permitted to take additional work, although in certain cases part-time classes are specified in the College to equalise variations in experience and training. The basic part of the curriculum consists of lectures by the lecturer-in-charge, Mr. J. Bamford, B.Sc., and the permanent staff, with practical work in metallurgical analysis, microscopic examination, mechanical testing, sand testing, pyrometry and foundry work. No attempt is made to teach practical founding, since practical experience in a foundry is a requirement for admission to the course; neither are students taught to become laboratory workers, but rather to understand and interpret the results of laboratory tests. They do, however, carry out practical work in metal mixing and melting practice, and various aspects of management such as costing and time study are illustrated.

Apart from this basic work, the curriculum has certain special features. The first of these is a series of lectures, 100 to 120 in number, by nationally-known foundry specialists, and not only is an exceptional range of practical knowledge thus placed at the disposal of the students, but contact is provided with the outstanding men in the industry, and each lecture is followed by full discussion. As opportunity offers, lectures are given by outstanding visitors from overseas.

The second special feature of the curriculum is the arrangement each week of a foundry visit, about forty being paid during the School year, including a group of visits once a year to a centre away from the Midlands, and so far Scotland, London and the South and Belgium and France have been visited. The visits are of the highest possible value to students, and the Governing Body is greatly indebted to those foundries, blast furnaces, etc., which permit visits to take place.

The third special feature of the curriculum is the time and attention devoted to what are conveniently termed moulding and casting studies and foundry planning. In the moulding and casting studies, the student is furnished with a blue-print (or a casting or a pattern) and is expected to provide the whole of the data required for the complete foundry production of the job, based on the number of pieces required. He is expected to detail completely the material equipment, tests and number of man-hours required. He also plans foundries to meet given production requirements or modifies existing plans.

The Diploma examination papers and the scripts by the students are assessed by well-known experts in the industry and the Annual Reports of the School, giving details of the curriculum, lectures, visits and financial support, are available to all interested, and the Diploma examination papers are also available. Four papers are given at the Diploma examination in the three subjects of foundry metallurgy, foundry technology (equipment, methods, processes, materials, etc.), and foundry management (costing, estimating, organisation, administration, etc.). There are two other papers, to which the highest importance is attached. In one the student is usually offered the choice between an iron casting and a steel casting, and expected to produce a complete scheme of foundry production on the lines indicated above. In the remaining paper he is expected to choose similarly and deal with a non-ferrous casting, say, one in brass or one in aluminium. An alternative to one of these questions is a foundry layout. Typical examination questions are detailed in Appendix II.

Ex-students of the School have an active body among themselves for maintaining social and professional contacts known as the Foundry Technical Group, which has its own officers, annual meeting, etc. Ex-students return to their employers, and in nearly all cases have been promoted to positions of responsibility in the foundry.

Firms who would like to send students to the School, but who do not have suitable candidates, are recommended to employ a suitably educated

young man for an apprenticeship of from two to four years' duration. For a university man two years' apprenticeship may be regarded as adequate, but four years is necessary for a secondary school boy of, say, 17. The last year of this apprenticeship irrespective of its length should be spent at the School. Such apprentices may be ready for admission at 20. A scheme is briefly outlined in Appendix III, and ordinary apprenticeships can be modified on these lines for the more promising men.

It will be clear that since students taking the course return to their employers by prior arrangement, Foundry School students are not normally available for employment. Young men employed on an apprentice basis and desiring admission are recommended to complete their technical education to the standard required for admission by part-time study in the appropriate technical colleges. The problem of how they can be absorbed into the industry does not arise with students of the Foundry School.

The author is frequently approached by firms desiring to engage men for the industry, and in a high proportion of the cases the specification is that which could be filled by a diploma student of the Foundry School, *i.e.*, a young man about 25 to 30 with some practical experience and sufficient technical knowledge to be able to deal with foundry problems, both of production and personnel. Of the people who might normally be considered, without the School training, they usually lack either the practical knowledge (such as chemists and other laboratory employees) or the technical knowledge (such as patternmakers and moulders), although a suitable man from either side might be capable of dealing with the work after a period at the School. The author believes in and uses the principle as far as possible of training and promoting men who prove themselves inside the organisation, although this, of course, by no means meets every case. In other words, the only way in which the industry can get trained men is to train them. This procedure will raise the numbers and quality of itself, because good men respond to the possibility of training and appreciate the standing of an industry in which training is regarded as important, and a greater choice of applicants is the result. The wider employment of trained men will help to promote the proper preparation of younger men.

Worshipful Company of Founders

It is impossible to conclude without reference to the recent proposal of the Worshipful Company of Founders, based on their conviction that the "development and progress of founding and the science of metallurgy must depend very largely on attracting to the industry highly trained men of outstanding talent." They propose to award a Fellowship of £250 per annum to men of character and initiative who have the scientific training usually associated with an honours degree. The selected candidate may do research, may spend a period in a works or may go abroad. As the fellowship is renewable for a second year, there will ordinarily be two fellowships in existence. This scheme will be welcomed by all who have the future well-being of the industry at heart, for it promises to be as broad-mindedly applied as it is carefully conceived.

Conclusion

Modern foundry training must be based on good general education for all grades of work and responsibility. It must comprise both practical experience and technical knowledge appropriately balanced for each grade. It must attract adequate numbers of workers both from the ranks and from higher educational institutions, and the industry must offer adequate incentive and possibility of promotion to men who prove to be of first-class calibre, irrespective of the level at which entering to the industry is made. Trained men can only be got by training, and the more difficult it becomes for foundries to do this themselves, the more important it becomes to make use of the institutions described.

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APPENDIX I

Institutions Supporting the British Foundry School

British Cast Iron Research Association.
British Non-Ferrous Metals Research Association.
City and Guilds of London Institute.
Institute of British Foundrymen.
Institution of Automobile Engineers.
Institution of Mechanical Engineers.
Iron and Steel Industrial Research Council of the British Iron and Steel Federation.
Iron and Steel Institute.
The National Light Castings Ironfounders' Federation.
Welsh Engineers' and Founders' Association.

APPENDIX II

Examination Papers for British Foundry School

The work on moulding and casting studies in iron, steel or non-ferrous metals is illustrated by a typical question, below, while one is also given on foundry design.

(1) Plan the production in grey cast iron of the housing casting shown. Ten castings are required, with a possibility of future small orders. The plan-

ning should be in accordance with the following schemes :—

(*a*) Calculate the weight of the casting, making suitable allowances for machining. Indicate the allowances you have made.

(*b*) Sketch and describe the pattern and core-boxes in detail, stating the material used in their manufacture.

(*c*) Design the moulding boxes to be used, including all details.

(*d*) Indicate the types of sand to be used for the mould and cores, giving the necessary test figures.

(*e*) Describe in detail the method of moulding, core-making and closing, and illustrate by sketches.

(*f*) Give the composition of the cast iron suitable for the casting. Explain why this particular composition has been chosen.

(*g*) Work out the mixture to be charged into a 4-ton per hr. cupola and indicate the melting losses.

(*h*) Estimate the total man-hours required per casting.

(*i*) Assuming some nominal values for cost of metal and overheads, work out the selling price.

(*j*) What modifications, if any, to the casting design would you suggest to aid production and produce sounder castings in future orders?

(2) A new non-ferrous foundry is to be built to take the place of an existing older shop. It is to use the existing pattern plates, patterns and boxes. The required output can be obtained with :—

12 squeeze machines (size of box part is 16 in. by 14 in. by 4 in. deep, production 80 boxes per man per day per machine).

12 hand-ram pattern draw machines (size of box part is 18 in. by 18 in. by 4½ in deep, production 26 boxes per man per day per machine).

6 jolt machines (size of box part 24 in. by 21 in. by 5 in. deep, production 70 boxes per day per machine with 2 men per machine).

In addition to the area required for the above machines it will be necessary to provide about 1,000 sq. ft. for loose-pattern moulders.

For the melting plant a further space of approximately 500 sq. ft. should be provided.

Design a foundry to suit the above requirements, incorporating the following features :—

(*a*) Offices, foundry and pattern stores, laboratory.

(*b*) Mechanised sand plant to feed machines.

(*c*) Roller conveyor(s) to serve machines, and other handling appliances.

(*d*) Core shop suitable for about 12 core-makers (young persons).

(*e*) Stoves for oil sand cores and dry sand moulds.

APPENDIX III

Staff Apprenticeship

The existence of the Foundry School has brought home to some foundry managers and proprietors the fact that there is no systematic method of entry of better-educated young men into the industry, since they find they have no suitable candidates to send. In order to remedy this, the following suggestions are made, the common feature of which is the final year of apprenticeship at the Foundry School. Foundries differ so much in size and character, and posts differ in requirements and responsibility, that a rigorously defined system of entry is undesirable. The proposals are based on the foundry employing an apprentice with a view to training him for a staff post.

Graduates.—University graduates in metallurgy, engineering, or in some branch of applied science, form an admirable source of suitable men. These men will, in general, have no practical training except, possibly, vacation courses in works, and it is suggested that a two years' foundry apprenticeship should be arranged, of which ten months at the latter end of the period should be occupied by the normal Foundry School course, the remainder being spent in acquiring practical experience in as many types of work—moulding, coremaking, etc.—as the foundry offers. The experience should be made as broad as possible and opportunities offered to see the work of the drawing and design office, costing, planning, purchasing and other related departments, as well as machining, finishing and enamelling shops in works where these operations are pursued. Apprenticeship should not be limited to teaching manipulative and operative skill if executives are to be trained.

Secondary School and Public School Men.—These may be expected to be ready for entry between the ages of 16 and 18 and a four-year or five-year apprenticeship is suggested, ten months of which at the end of the course should be spent in the Foundry School. The age of entry to the latter should not be less than 20. Assuming that matriculation standard is reached at entrance, the early years of the apprenticeship should be spent in acquiring practical experience in the foundry and in part-time classes, to some extent in the day-time, leading to the ordinary national certificate and preferably higher national certificate in engineering, with as much metallurgy as possible Two years should be adequate for the ordinary certificate, and the higher certificate could be taken prior to the Foundry School on a five-year apprenticeship.

Primary School Men.—An ordinary apprenticeship usually provides ample practical experience and part-time classes adequate technical knowledge, but experience has shown that good men may be sent to the Foundry School with profit up to 30 or over.

Engineering Apprentices.—Many firms have suitable courses of training for engineering apprentices on these lines, and it may well happen that a young man who has already started on such a course would be suitable, by test and inclination, for foundry work. Provided some practical engineering experience has been obtained, a year or eighteen months in the foundry would be adequate training prior to entry to the Foundry School. Apart from the training in foundry operations, apprenticeship is chiefly valuable in inculcating works discipline, in teaching ideas of the sequence of operations in production and in teaching the apprentice whether he is really suited to industrial work. From these points of view, engineering and foundry training may be regarded to some extent as interchangeable and, indeed, some time in machine and assembly shops where castings are machined and used is highly recommended for foundry apprentices.

Paper No. 687

The Work of the Technical Committee of the Institute of British Foundrymen

By J. W. GARDOM*

It was to the International Foundry Congress held in London in 1929 that the first technical report of the Institute of British Foundrymen was presented, and it is thought, therefore, that a general review of the work which the Technical Committee has done during the intervening years may be of interest. To those who are members of the Institute of British Foundrymen, such a review will serve as a progress report, but even to those outside, and particularly those engaged in the industry abroad, this Paper should be of interest, for it reflects to a large extent the progress which has been made in the industry which this Institute seeks to serve.

Although a Test Bar Committee had been in existence for several years prior to 1930, it was not until April 12 of that year that the Council of the Institute sanctioned the formation of the Technical Committee.

The Technical Committee is composed of a Convener, a Deputy Convener, and at the present time 62 members, and several corresponding members. All these gentlemen are engaged in the industry, and on election to the Technical Committee serve on a sub-committee dealing with the subject in which they have specialised. The work which they do on behalf of the Institute is entirely voluntary, and through the courtesy of the firms with whose works they are associated, many members of the Committee are able to carry out work of an investigational character.

The Institute has under its control no metallurgical laboratories, and this is one of the major reasons why primary research is not undertaken. When any research connected with the Committee's work cannot be satisfactorily carried out by individual members, the co-operation of one of the research associations is sought. These associations, such as the British Cast Iron Research Association and the British Non-Ferrous Metals Research Association, not only specialise in fundamental research, but have in the past co-operated with the Institute in any such work which it desired to undertake.

Meetings of the full Technical Committee are held at least four times per annum, and meetings of individual sub-committees may be called whenever they are required. These sub-committees were appointed by the Technical Committee to deal with cast iron, malleable cast iron, non-ferrous metals and sands and refractories, and to investigate problems in these specific fields. At a later date the Sands and Refractories Sub-Committee was divided into two, namely, the Sands Sub-Committee and the Refractories Sub-Committee, and in addition a Melting Furnaces Sub-Committee and a Costing Sub-Committee were appointed. Since the forerunner of this Committee had devoted its attention to the formulation of specifications and the work of standardisation, it was only to be expected that these subjects should also form the basis of procedure which the Technical Committee should adopt. This, in fact, was the case, and each of the Sub-Committees proceeded to obtain as many specifications covering their particular aspect of foundry practice as was possible. The Non-Ferrous Sub-Committee eventually accumulated 67 specifications, covering 47 different alloys, whilst the Steel Castings Sub-Committee collected 21 different specifications for plain carbon steel castings for various purposes.

Naturally, this information had to remain confidential to the members of the Technical Committee, but as a result of the close study which members made of these specifications, each Sub-Committee was able to decide upon a programme of work. In this standardisation of practice and specifications covering all branches of the foundry industry, the results of works' experience is, of course, essential.

The Institute, mainly through members of the Technical Committee, is represented on various committees of the British Standards Institution which deal with foundry subjects, and in this way the Institute is able to safeguard the founders' interests when new specifications are being drafted, or when revisions are being made to existing specifications. Owing also to the organisation of the British Standards Institution, the Technical Committee is able to examine the drafts of any new or revised specifications dealing with foundry subjects and to make recommendations to the appropriate British

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Standards Institution Committee when such new drafts have, in the opinion of the Technical Committee, not been drawn up in accordance with the best foundry practice, or with due regard to the founders' viewpoint.

Another factor which arose from the examination of the various specifications was that it was found possible to reduce the number of specifications and use British Standard Specifications in their stead. In the cast-iron, steel, malleable cast-iron and non-ferrous sections of the industry, this was found to be possible to quite an appreciable extent, and largely as a result of the Committee's recommendations, several private specifications were either replaced by British Standard Specifications, or the British Standard Specifications were quoted as alternatives.

The Technical Committee is keenly sensible of the work which is carried out in other countries, and, where it is desirable or necessary, the Committee co-operates with the foundry technical associations abroad. A particularly interesting example of the progress in this sphere is the work which the Cast Iron Sub-Committee is doing in conjunction with the International Committee on Testing Cast Iron. It is hoped that through Mr. J. E. Hurst, who is a prominent member of the Cast Iron Sub-Committee, and President of the International Committee on Testing Cast Iron, further useful work will be done in this direction.

THE REPORTS OF THE TECHNICAL COMMITTEE

Cast-Iron Sub-Committee

After its first year of work, in which a collection and examination was made of specifications for grey cast iron, the Cast Iron Sub-Committe was enlarged and it was decided that it could best assist the industry by pursuing investigations in the following four directions:—

(1) To investigate the theory that the properties of cast iron in relation to strength and soundness were at their worst when the phosphorus content was approximately 0.4 to 0.6 per cent.

(2) To compile a series of photomicrographs representative of various grades of cast iron, which might be used as a reference standard by metallurgists in the industry.

(3) To attempt to evolve rules for the contraction of cast iron, according to composition, section and pouring temperatures.

(4) To examine existing methods of wear testing, with a view to recommending a standard form of test.

All these subjects were investigated, and the Sub-Committee's results were published in the form of a report in 1934[1], and in a Paper by Neath.[2] Various members of the Committee were also, at that time, engaged upon researches connected with these investigations, and through their kind co-operation, the Sub-Committee was enabled to study those results which were of interest to them.[3, 4]

The work of compiling a series of standard photomicrographs was satisfactorily completed in conjunction with the British Cast Iron Research Association, and the complete series has been published,[5] and includes microstructures of both blackheart and whiteheart malleable cast iron.

Before the work on the foregoing subjects had been completed, the Sub-Committee had prepared an internal report on the physical properties of cast iron. This was not published generally, but made available only to members of the Institute. However, the majority of the data presented is now included in the Sub-Committee's latest report and will be made generally available in the near future. It has already been presented before several Branches of the Institute, and a report of the discussions will also be published, together with the Cast Iron Sub-Committee's reply.

It was largely as a result of the Sub-Committee's work on the various properties of grey and high-duty cast iron that it was decided to seek a revision of British Standard Specification 321/1928, which they felt to be somewhat out of date, as a result of technical progress in the industry. In order to obtain such a revision, further work had to be completed so that the Institute's representatives on the British Standards Institution's Committee could be supplied with relative data. In due course, the revision of this specification was completed, and a new specification, No. 786, covering high-duty cast iron was issued. After this the Sub-Committee prepared and published its second report.[6] The Sub-Committee is now continuing its work by investigating the relationship between various mechanical tests.

The question of the classification of graphite has also been considered by the Sub-Committee, but unfortunately it has been found necessary to abandon this investigation owing to the lack of facilities for the extensive research that it was found to involve. The Sub-Committee appreciates the need for the continuance of this work, and owing to the character of the investigational work necessary, has suggested that this problem might be taken up by the British Cast Iron Research Association.

Steel Castings Sub-Committee

When first the Steel Castings Sub-Committee started on its work of collecting and comparing existing specifications for steel castings, it was

found that in this country there was but little deviation in the requirements of the various issuing houses, and that in general they all conformed quite closely to British Standard Specifications already existing. Little further could, therefore, be done with the exception of recommending that those specifications which showed any wide divergence from the British Standard Secifications should be revised to conform more closely with standard practice. In several cases such recommendations met with success.

At a somewhat later date, the Steel Castings Sub-Committee turned its attention to four main problems:—

(1) Impact testing of steel castings.

(2) The heat-treatment of carbon steel castings.

(3) The soundness of steel valve castings.

(4) Fluidity (flowing power) of molten steel.

A considerable amount of data has been collected from industry in connection with all four of these investigations, and it is expected that three reports will be issued in the very near future.

Particularly interesting are the data on the heat-treatment of carbon steel castings, for the information presented will cover typical British practice, and it is hoped that this Report will show where improvements may be possible. The Izod impact test results show remarkable variations in all classes of steels on which these tests were made.

For the third investigation, some twelve valve castings were made and subjected to severe testing before cutting for examination.

The Steel Castings Sub-Committee has also played a not unimportant part in investigations carried out under the auspices of other investigators and institutions, particularly the Iron and Steel Institute,[7] on whose Steel Castings Research Committee the Institute is represented. It was, in fact, in a report of the Iron and Steel Institute that the data which the Steel Castings Sub-Committee had collected on fluidity (flowing power) was published.

Non-Ferrous Sub-Committee

With the extended use of aluminium, magnesium and nickel in non-ferrous foundries to-day, an enormous range of commercial alloys has been developed. Very often, only very slight modifications in composition are evident in the different alloys, each of which is deemed by its proprietors to have some property which makes it far more useful than other similar alloys. With this ever-growing complexity, the work of this Sub-Committee has been particularly difficult. In order to simplify its programme to a large extent, the Non-Ferrous Sub-Committee has, so far, concentrated upon the heavier types of non-ferrous alloys.

Its first work was to examine the various specifications which had been drawn up for the different alloys, and it was as a result of this work that it was decided to simplify the position by standardising upon a smaller number of alloy compositions. In a large measure, the work has been successful, and negotiations are now in hand with the British Standards Institution for the preparation of specifications for two leaded gunmetals, which formed the subject of a Report issued by the Sub-Committee in 1936. This Report made a serious endeavour to bring about some standardisation of composition in the alloys commonly used, and led to the preparation of a further report, which is being presented to this Congress,[9] on the properties of three leaded phosphor bronzes.

This work now being complete for the time being, the Sub-Committee has turned its attention to the degasification and deoxidation of non-ferrous alloys, and is at present engaged upon the preparation of a report on this subject.

Malleable Cast Iron Sub-Committee

The Malleable Cast Iron Sub-Committee has, during the whole period of its existence, devoted its attention to an examination of the British Standard Specifications Nos. 309 and 310, 1937, for whiteheart and blackheart malleable cast iron, and it is believed that when a report of this work is published, it will form one of the most authoritative statements which have been made concerning malleable cast iron.

Already two interim reports[10, 11] have been published upon the Sub-Committee's work, which, although of considerable interest, have, it is thought, not received the attention which they deserve. The second of these reports dealt with dimensional tolerances for castings—a subject which was inadequately covered in all existing specifications, not only for malleable cast iron, but also for grey cast iron, steel and non-ferrous alloys. That a report dealing with a question of such vital importance to the foundry industry as a whole should have received so little attention has astonished the Technical Committee, especially as this Report, together with an investigation carried out by the American Foundrymen's Association on grey cast iron, forms probably the only recent work upon this subject.

A suggestion that a yield point : tensile strength ratio should be included in the malleable specification has received the consideration of the Sub-Committee. A considerable amount of data has been collected on this subject, and the present views of the Committee are tending against the inclusion of such a ratio in the specification. Experimental data have shown that the yield

point: tensile strength ratio varies considerably, and in many cases high results are obtained on imperfectly annealed material. Under such conditions, such a ratio would be of no service to the inspecting engineer, who wishes to ascertain whether the material has undergone correct annealing treatment.

In this country, literature upon the subject of malleable cast iron is particularly scarce, whilst in the United States of America there is not only considerably more literature, but also the product is receiving ever-increasing attention. Government departments, motor-vehicle manufacturers and other potential users in this country seem often to overlook the possibilities of malleable cast iron. This has been attributed largely to the existing specifications, which, being over a decade old, do not now faithfully reflect the position in the industry to-day. In spite of the seemingly undeveloped state of the industry, the Technical Committee is aware that considerable improvements have been made in practice during the past few years, and it is thought that the work which the Malleable Cast Iron Sub-Committee is doing will materially assist in the development of the malleable cast-iron industry in this country.

Sands Sub-Committee

Methods of testing dry sand, green sand and loam have occupied the attention of this Sub-Committee during the past few years. As is well known, this subject is one which has assumed great importance in recent times, particularly since the mechanisation of foundries has been accelerated.

Two main sand-testing methods were in existence at the time the Sands Sub-Committee began its work, namely, those recommended by the American Foundrymen's Association, and the British Cast Iron Research Association's methods. Members of this Sub-Committee were of the opinion that neither of these methods was in itself the ideal one, and they considered that a useful purpose would be served by examining and comparing the procedures and apparatus recommended by these two Associations.

The work was very carefully carried out, and in 1933 a report on "Routine Methods for Testing Green Sands" was presented to an Annual Conference of the Institute.[12] The publication of this Report was followed by an investigation into the testing of dry sand and loam, and a report on this subject has now been published.[13]

The subject of sand testing has not yet been exhausted and the Sub-Committee realises that a considerable amount of work has yet to be done. The Sub-Committee feel, however, "that next in importance to investigating and recommending simple and satisfactory methods of testing sands, is the need for a campaign to urge upon founders the benefits which they will obtain by systematically using such tests daily in the foundry." Their contribution to this campaign has been the preparation of these reports, which have aroused considerable interest in the industry.

At the present time the Sub-Committee is engaged upon the following lines of investigation, and is surveying the sand mixtures as used at the present time in Great Britain for various classes of castings.

(1) Casting defects attributable to moulding materials.

(2) Drying ovens: (*a*) for dry sands, and (*b*) for oil sands.

(3) Testing oil sands, including the grading and sampling of silica sands.

(4) The compression-strength testing machine and the measurement of deformation of moulding sands.

The first of these is proving to be a most interesting study, and to assist the Sub-Committee in its work the co-operation of industry has been sought with a view to obtaining samples of castings, defects in which may be attributable to the moulding material used. The second investigation will, it is expected, result in a report being issued upon various drying stoves and practices which are in common use to-day, whilst the third study will assist in the completion of the Sub-Committee's work on recommended methods for testing various sands.

It is realised that the values obtained under the heading of green compression strength are of great importance in evaluating a moulding sand. It is, however, appreciated that when this strength is at its maximum the sand is brittle and unsuitable for moulding. Other qualities of the sand must be taken into consideration in association with the green compression strength in determining the sand's suitability in practice. One of the factors is a capacity to deform under load, and methods of measuring it are under consideration by the Sands Sub-Committee.

Mention should be made of the Joint Committee on Sands which has recently been set up in this country. On the Committee are representatives of the British Non-Ferrous Metals Research Association, the Iron and Steel Institute, the British Cast Iron Research Association and the Institute of British Foundrymen.

The aim of this Committee is to produce an agreed statement on routine methods of testing, to be adopted as standard, and recommended to the industry. This necessitates the most careful scrutiny and consideration of all present methods and testing apparatus, and although the work is

not complete, considerable progress has already been made.

Melting Furnaces Sub-Committee

Formed at a later date than the majority of the other sub-committees, the Melting Furnaces Sub-Committee was appointed with the primary object of preparing a report upon cupola melting practice. This work has, however, been extended to cover all types of melting furnaces for cast iron. A most thorough and comprehensive treatise has now been drawn up and will be published within the next few weeks.[14]

No pretension is made that this Report contains any really original matter; its value lies rather in its completeness, for not only does it cover the design and operation of cupolas, electric furnaces and various types of rotary and crucible furnaces, but there is also a section dealing with melting costs. It will, therefore, be seen that it will be an invaluable document for students, and all those who wish to make a study of the fundamentals of this phase of foundry work. A serious endeavour has been made throughout this Report to include some reference to every well-founded opinion which has been expressed upon any of the furnaces dealt with in its pages.

Refractories Sub-Committee

As has already been mentioned, the Refractories and Sands Sub-Committee was divided in 1936 into two—the Sands Sub-Committee and the Refractories Sub-Committee. The work of this comparatively new Sub-Committee on refractories has necessarily been slow, for after its initial work of drafting a specification for cupola firebricks, it has been necessary to test the recommended material in practice before any definite recommendation can be made to a standardising body. Meanwhile, preliminary tests of a practical nature have been carried out with a view to preparing a similar draft specification for cupola ganister. It is expected that a comprehensive report will shortly be published giving details of these investigations.

In furtherance of this work, the Convener of the Sub-Committee has presented many valuable Papers before several Branches of the Institute, and also to foundry associations abroad.

Costing Sub-Committee

The Costing Sub-Committee, like the Melting Furnaces Sub-Committee, was also appointed to carry out a specific piece of work, and in this case to try to make definite recommendations on costing systems suitable for the foundry.

As is well known, there are few subjects in which the foundryman is more interested, and similarly there are but few phases of foundry work which are so beset with intricate problems, each of which has been dealt with by many well-known authorities. It is interesting to mention that considerable discussion took place amongst members of the Sub-Committee and officials of the Institute, as to whether the question of costing came within the scope of the Technical Committee, or even of the Institute.

Eventually, it was agreed that the Costing Sub-Committee should be formed. Its Report[15] is probably the most complete which has been published on this subject, at least in this country, and its value to industry can be gauged from the number of large and important foundry companies who have installed the system outlined therein. Naturally enough, considerable comment and discussion took place upon this report when it was presented to the 1936 Annual Conference of the Institute, before Branches and also before other associations, but it is significant to note that none of the contributions to the discussions necessitated any alteration being made to the recommendations.

The work completed, *pro tempore*, the Sub-Committee was dissolved in 1938, but if at any time there arises the necessity of continuing its work upon this subject, the Costing Sub-Committee will be reconvened.

Conclusion

In this report, an endeavour has been made to present, in a small space, a picture of the work which the Technical Committee has so far carried out, and it is hoped that, at least to the members of the Institute of British Foundrymen, this will prove of interest and value.

In some stages of the Technical Committee's work, it may be thought that progress has been

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2 F. K. Neath, Proceedings, Institute of British Foundrymen, Vol. XXVI, p. 526.
3 W. West, Proceedings, Institute of British Foundrymen, Vol. XXVI, p. 392.
4 J. E. Hurst, Journal, Iron and Steel Institute, 1933, No. I, p. 229.
5 Appendices to Proceedings, Institute of British Foundrymen, Vol. XXVII and Vol. XXIX.
6 Institute of British Foundrymen, Special Report No. 1.
7 Iron and Steel Institute, Special Report No. 23, Section II, Part B, p. 35.
8 Proceedings, Institute of British Foundrymen, Vol. XXIX, p. 349.
9 Institute of British Foundrymen, Preprint, Paper No. 688.
10 Proceedings, Institute of British Foundrymen, Vol. XXV, p. 254.
11 Proceedings, Institute of British Foundrymen, Vol. XXIX, p. 360.
12 Proceedings, Institute of British Foundrymen, Vol. XXVI, p. 61.
13 "Foundry Trade Journal," Vol. 57, 1937, No. 1,105, p. 327.
14 Institute of British Foundrymen, Special Report No. 2.
15 Proceedings, Institute of British Foundrymen, Vol. XXX, p. 100.

comparatively slow, but it must be remembered that all the reports which have been mentioned have been prepared by men engaged in industry. The members of the Technical Committee are conscious that progress in some spheres has not been made as rapidly as could be wished, and a review has therefore recently been made of the Committee's work. As a result of this, and because of recent reorganisations in the Institute's working methods, it is believed that in future the Technical Committee will prove of even greater value to members of the Institute of British Foundrymen, and others engaged in the foundry industry.

The author wishes to express his thanks to Mr. J. Bolton, Assistant Secretary of the Institute of British Foundrymen, for his help in the preparation of this report.

Paper No. 688

Recommendations for Three Leaded-Bronze Bearing Alloys

By the Non-Ferrous Sub-committee of the Technical Committee of the Institute of British Foundrymen

Bronze bearing alloys containing appreciably high percentages of lead are widely used in a variety of applications. These alloys are covered by a large number of individual specifications, many of which differ only in minor respects, while no recognised standard specifications have been drawn up. The purchaser of such materials has therefore either to draw up his own specification or to adopt one of the many existing private specifications, which may or may not exactly meet his requirements. Further, this multiplicity of specifications makes for undue complications in the foundry, while the engineering industry loses by the absence of any standard materials of uniform properties.

With the intention, therefore, of recommending the drafting of standard specifications covering leaded-bronze bearing alloys, the Sub-Committee undertook the study of these materials. It was felt that the establishment of such a standard specification would materially assist the engineering industry to select appropriate and recognised alloy compositions for particular purposes, and would also help to eliminate much of the present complexity in supplying to a wide variety of specifications. The only material of a similar nature so far covered by a British Standard Specification is a phosphor-bronze for gear blanks, covered by B.S.S. 421.

TABLE I.—*Composition of Bronze Bearing Alloys.*

I.B.F. designation.	Sn, per cent.	Pb, per cent.	Zn, per cent.	P, per cent.
LB. 1 (B. S.S. 421)	11 to 13	0.5 max.	0.30 max.	0.15 min.
LB.2 ..	9 to 11	2.5 to 3.5	0.50 max.	0.35 max.
LB.3 ..	9 to 11	9 to 11	0.50 max.	0.35 max.
LB.4 ..	8 to 10	14 to 16	0.50 max.	0.35 max.

Three compositions of leaded bronzes were chosen for investigation, and the present Report summarises the results of a large number of tests carried out in various bronze foundries with these selected alloys in order to determine what reasonable values of final properties could be consistently obtained and specified. The three compositions chosen, together with the composition of the B.S.S. 421 alloy, are set out in Table I. For purposes of reference the latter material has been designated LB.1 in this Report.

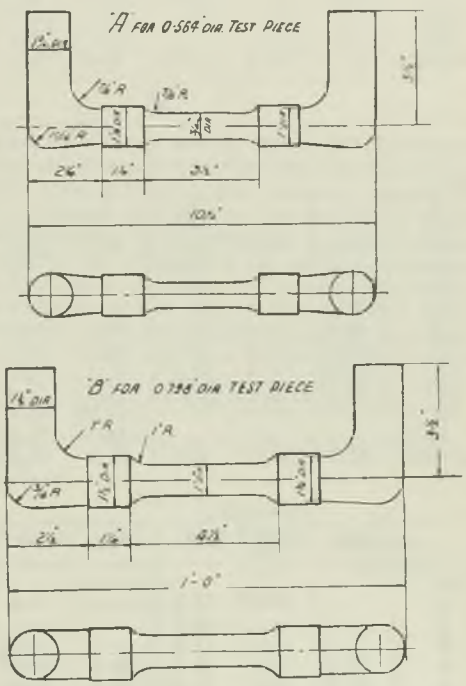

FIG. 1.—STANDARD CAST TEST BARS ADOPTED FOR LEADED BRONZES.

It will be remembered that in a previous Report by this Sub-Committee on "Recommendations for Two Leaded Gunmetals," presented to the Glasgow Conference in 1936, details were

* Convener: Dr. L. B. Hunt.

given of the standard test bar adopted for use in the investigation for these leaded gunmetals. The shape of test bar finally selected, shown in Figs. 1 and 2, was adopted after a great deal of investigation as being one which would give the greatest uniformity of results throughout the majority of foundries. This bar, in the two standard sizes, was again adopted for the work on leaded bronzes.

Three standard casting temperatures were chosen, and with a few exceptions one large and one small test bar was cast at each temperature. These casting temperatures were as follows:—LB.2, 1,050, 1,100, and 1,150 deg. C.; LB.3, 1,000, 1,050, and 1,100 deg. C.; LB.4, 1,000, 1,050, and 1,100 deg. C. The test results obtained in this way by various members of the Sub-Committees are summarised in Table II.

TABLE II.—*Summary of Mechanical Tests on Three Leaded-Bronze Bearing Alloys.*

	Maximum stress, tons per sq. in.						Elongation, per cent.					
	Large bar.			Small bar.			Large bar on 3 in.			Small bar on 2 in.		
	Casting temperature, deg. C.						Casting temperature, deg. C.					
	1,050	1,100	1,150	1,050	1,100	1,150	1,050	1,100	1,150	1,050	1,100	1,150
LB. 2												
A	—	16.6	15.1	—	17.1	16.2	—	14.0	9.5	—	11.0	9.5
F	—	13.8	13.9	—	14.8	14.0	—	7.0	6.0	—	8.0	7.0
G	—	15.9	11.1	—	10.8	17.2	—	11.0	3.0	—	3.0	16.0
H	—	17.6	—	—	15.4	—	—	15.0	—	—	10.0	—
H	—	16.9	—	—	10.5	—	—	13.0	—	—	2.0	—
I	17.0	17.7	18.2	14.9	17.9	19.1	22.0	19.0	27.0	11.5	20.0	30.5
L	17.0	15.8	14.5	14.2	16.0	15.2	9.0	9.0	8.0	4.0	8.0	10.0
M	—	—	—	15.6	15.6	14.4	—	—	—	5.0	7.0	5.0
M	—	—	—	16.0	18.0	16.8	—	—	—	6.0	11.0	10.0
Average	17.0	16.3	14.6	15.2	15.1	16.1	15.5	12.6	10.7	6.6	8.9	12.6
	15.7						11.2					
	1,000	1,050	1,100	1,000	1,050	1,100	1,000	1,050	1,100	1,000	1,050	1,100
LB. 3												
A	—	—	15.4	—	—	14.4	—	—	10.5	—	—	4.0
A	—	—	12.0	—	—	11.6	—	—	7.0	—	—	5.0
C	14.6	15.0	14.2	19.2	19.2	16.8	4.0	6.0	4.5	4.0	4.0	4.0
F	—	—	11.8	—	—	11.5	—	—	5.0	—	—	6.0
G	—	—	13.1	—	—	12.2	—	—	6.0	—	—	4.0
I	14.5	13.8	15.1	14.4	14.1	15.2	9.0	13.0	11.0	9.0	14.0	10.5
J	16.8	15.0	15.1	16.8	14.2	17.2	15.0	11.0	12.0	17.0	12.0	21.0
J	16.2	12.8	12.1	16.4	14.4	16.5	14.0	9.0	5.0	18.0	10.0	20.0
K	13.9	13.8	12.1	14.4	13.9	12.9	9.0	9.0	7.0	10.0	9.0	10.0
L	14.5	13.6	11.8	12.4	11.4	11.6	9.0	8.0	4.0	6.0	3.0	4.0
M	—	—	—	12.56	12.4	15.2	—	—	—	4.0	3.0	9.0
M	—	—	—	14.74	12.48	14.4	—	—	—	2.0	4.0	7.0
Average	15.1	14.0	13.3	15.1	14.0	14.1	10.0	9.3	7.2	8.8	7.4	8.7
	14.3						8.6					
	1,000	1,050	1,100	1,000	1,050	1,100	1,000	1,050	1,100	1,000	1,050	1,100
LB. 4												
A	—	13.8	15.2	—	14.8	16.0	—	6.0	13.5	—	6.0	11.0
F	—	—	12.5	—	—	13.2	—	—	6.0	—	—	7.0
G	—	—	14.0	—	—	15.2	—	—	6.0	—	—	7.0
I	15.2	15.5	15.5	15.3	15.5	16.8	11.7	13.3	15.0	10.0	10.0	17.5
J	14.6	13.9	13.66	15.0	15.0	14.4	14.0	14.0	13.0	14.0	22.0	18.0
J	14.6	13.0	13.8	14.4	14.8	14.8	20.0	12.0	16.0	20.0	24.0	21.0
K	12.9	12.7	11.4	12.7	12.1	12.4	9.0	7.0	6.0	11.0	9.0	9.0
Average	14.3	13.8	13.7	14.4	14.4	14.7	13.7	10.5	10.3	13.7	14.2	12.9
	14.2						12.6					

These data do not include the analyses of the alloys employed, as this would give rise to undue complication in the tables, but each worker has satisfied the Sub-Committee that his alloy fell within the results set out in Table I. Similarly, no details are given as to the use of virgin or secondary metal in the charges. These results are, however, considered to be indicative of those to be obtained in normal works conditions with reasonable metallurgical control.

Table III.—*Summary of Mechanical Tests on Modified Composition of Alloy LB. 2.*

	Maximum stress, tons per sq. in.						Elongation, per cent.					
	Large bar.			Small bar.			Large bar on 3 in.			Small bar on 2 in.		
	Casting temperature, deg. C.						Casting temperature, deg. C.					
	1,050	1,100	1,150	1,050	1,100	1,150	1,050	1,100	1,150	1,050	1,100	1,150
LB. 2												
I	14.2	14.0	16.5	15.8	12.5	19.2	5.7	6.0	10.7	5.0	2.5	20.0
J	15.6	16.6	16.2	13.0	16.8	13.9	26.0	23.0	14.0	5.0	22.0	12.0
J	16.4	15.6	14.2	18.4	17.6	18.4	23.0	15.0	13.0	32.0	31.0	22.0
K	13.0	14.9	14.0	13.8	14.8	14.9	9.0	11.0	8.0	9.0	10.0	10.0
Average	**14.8**	**15.3**	**15.2**	**15.3**	**15.4**	**16.6**	**15.9**	**13.7**	**11.4**	**12.7**	**16.4**	**16.0**
	15.4						14.3					

Subsequent to the completion of these results, it was decided to modify the composition of LB.2 by increasing the lead content to 4 to 6 per cent. A further series of tests was therefore undertaken using this modified composition, and the results of these tests are summarised in Table III.

From a full consideration of all the results given in Tables II and III, the Sub-Committee proceeded to draw up their recommendations upon which the drafting of a standard specification might be based. These recommendations are set out in Table IV, but some comment upon these figures is necessary. In considering these recommendations, it must first be remembered that the castings to be represented by the proposed specification are not normally used as structural members, but are fully supported in the form of bearings, liners, etc. The major importance of the proposed specification is not therefore one of tensile properties, but of classification. The comparatively low values for percentage elongation are also made necessary by the relatively high maximum phosphorus content permitted. It will be remembered that B.S.S. 421, "Phosphor Bronze Castings for Gear Blanks," calls for a minimum tensile strength of 14 tons per sq. in. and a minimum elongation of 7 per cent. on sand-cast test bars.

Table IV.—*Recommended Composition and Mechanical Properties to be Specified for the Three Leaded-Bronze Bearing Alloys.*

	Composition.						Maximum stress. Tons per sq. in.	Elongation, per cent.
	Sn, per cent.	Pb, per cent.	P, per cent.	Zn, per cent.	Ni, per cent.	Per cent. of other impurities, maximum.		
			May be present up to :					
LB 2	9 to 11	4 to 6	0.30	0.50	1.0	0.5	12	5
LB. 3	9 to 11	9 to 11	0.30	0.50	1.5	0.5	11	4
LB. 4	8 to 10	14 to 16	0.30	1.0	2.0	0.5	10	4

Some explanation is also necessary regarding the percentage of nickel to be allowed in these leaded bronzes. In an attempt to obtain fuller information on the effects of small percentages of this metal on the properties of the alloys, some investigations were carried out by the Sub-Committee, but after consideration of the data obtained, it was felt that no definite inference could be drawn in respect to the effect upon maximum stress and percentage elongation. It is, however, well known, and has been further substantiated by the Sub-Committee's work, that additions of nickel to leaded bronzes do result in improved and more uniform mechanical properties (particularly in a higher yield point) and the reduction of segregation of lead, especially, of course, with the higher lead contents. The amount of nickel required depends upon the composition of the alloy and upon the

type of casting being made. The nickel contents given in Table IV are therefore those which the Sub-Committee felt it reasonable to associate with the proposed lead and phosphorus contents of the three alloys in question, and are those which correspond in general with good practice in order to obtain the benefits of nickel in reducing segregation and increasing the yield point.

The Sub-Committee will welcome the fullest co-operation and opinions on these recommendations from both makers and users of this type of material, with a view to their making representations in the appropriate quarters for the drafting of standard specifications along these lines, subject to any modifications that may be deemed advisable after all opinions have been secured.

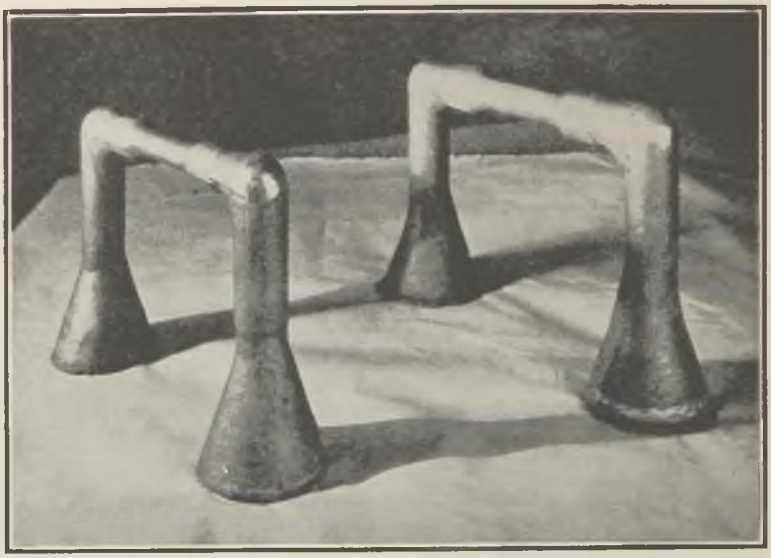

Fig. 2.—The Standard Test Bars as Cast.

Paper No. 689

Influence of Repeated Remelting on the Properties of Light Alloys

By M. HÁJEK and J. KORITTA

In recent years aluminium alloys have been steadily gaining in importance as a material for construction. The reasons for the continually increasing use of this material in machine construction are the demand for light and simple designs of engines, where higher outputs are required, and a number of advantages which the light alloys offer in the direction of mechanical and other properties. The increased production of light-alloy castings demands, under present economic conditions, the solution of the problem of utilisation of foundry scrap.

In this Paper, which is the first part of a more exhaustive study of this problem, the authors attempt to determine the influence of repeated melting on the mechanical properties of cast aluminium alloys.

TABLE I.—*Composition of Alloys used for Testing.*

Designation.	Si. Per cent.	Cu. Per cent.	Fe. Per cent.	Zn. Per cent.	Mn. Per cent.	Mg. Per cent.
A ..	0.18	8.12	0.27			
B ..	0.58	4.26	0.25	5.80		
C ..	12.42	0.89	0.35	—	0.28	
D_{1-2} ..	12.90	—	0.28	—	0.42	0.25

In the light-alloy foundry, sometimes more than 50 per cent. of the material melted takes the form of runners, risers, rejects and other foundry scrap, which is added to the new material and so subjected to repeated melting.

Such material is to be divided in two classes:

(1) Material originating in the foundry itself, *e.g.*, runners, risers, rejected castings, and borings from machine shops directly connected with the foundry. Such material, when properly classified, represents metals of known chemical composition and of known quality.

(2) Material purchased from outside sources. The use of this material is always associated with a certain risk, as its quality, even when covered by a guarantee as to chemical composition, may not be satisfactory.

The use of material scrapped during the manufacture of aluminium castings is always a controversial subject. The remelted material is usually considered as inferior and as a material suitable only for second-grade castings to be utilised for less stressed parts. The qualities of remelted aluminium scrap were studied by Irmann,[1] who has given directions for compounding various aluminium alloys. He reached the conclusion that a simultaneous charging of two or more types of aluminium scrap may result in a melt which is practically useless for foundry purposes. Fig. 1 shows, in a graphical form,

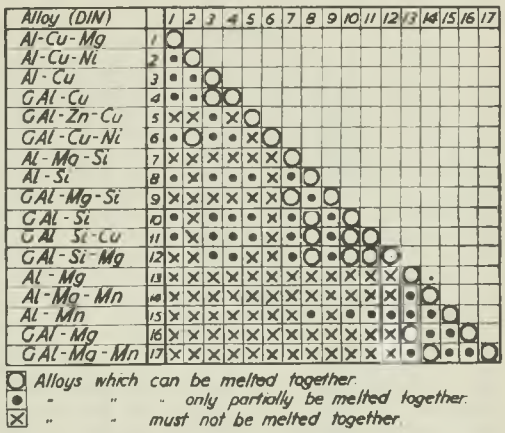

FIG. 1.—GUIDE IN THE MELTING OF ALUMINIUM SCRAP (IRMANN).

types of aluminium scrap which may and which must not be mixed in the same melt.

In the literature available to the authors only a few data on the influence of repeated melting of aluminium alloys have been found. Anderson[2] states that the qualities of aluminium alloys are not actually affected by remelting, but in his book, "Secondary Aluminium," he does not substantiate this statement numerically.

Rosenhain and Grogan[3] studied the influence of remelting on the mechanical properties of the commercial aluminium of 99.65 and 98.51 per

cent. purity, and they came to the conclusion that this material did not lose any of its mechanical properties after a tenfold melting and rolling.

In order to throw more light upon this question, the authors studied the influence of repeated melting on the following four standard aluminium alloys:—

Aluminium-copper alloy, designated ... A
Aluminium-copper-zinc alloy, designated... B
Aluminium-silicon-copper alloy, designated C
Aluminium-silicon-magnesium alloy, which in the as-cast condition is designated D_1 and in the heat-treated condition is designated ... ... D_2

The chemical compositions of these alloys are given in Table I.

The alloys were melted in coke-fired Morgan furnaces in graphite crucibles. For the first melt only pure metal was charged. The alloys A and B were prepared from aluminium of 99.69 per cent. purity, the alloys C and D were used as delivered by the manufacturers.

TABLE II.—*Tensile Properties of Repeatedly Remelted Alloys.*

Number of melts.	Average tensile strength. Tons per sq. in.	Average elongation. Per cent.	Scattering of results in percentage of the average tensile strength.	
		Alloy A.		
1 ..	10.4	1.5	−11.4	+20.2
2 ..	10.3	1.9	−22.0	+ 7.0
3 ..	10.6	2.3	− 9.0	+ 9.1
4 ..	10.6	2.2	− 1.0	+ 3.2
5 ..	9.0	1.1	− 4.5	+ 3.5
6 ..	10.2	1.9	− 3.5	+ 3.5
7 ..	9.6	1.8	− 2.6	+ 1.8
8 ..	9.3	1.5	− 3.5	+ 2.6
9 ..	9.8	1.9	− 7.0	+ 5.3
10 ..	9.0	1.7	− 2.6	+ 2.6
		Alloy B.		
1 ..	10.2	2.4	− 3.7	+ 2.5
2 ..	10.7	3.5	− 4.2	+ 4.2
3 ..	11.4	3.3	− 4.2	+14.3
4 ..	10.7	2.3	− 6.3	+ 2.4
5 ..	9.8	2.0	− 6.4	+ 4.2
6 ..	9.5	2.4	− 5.4	+ 8.3
7 ..	8.5	2.1	− 7.2	+ 5.3
8 ..	9.7	3.2	− 3.6	+ 4.2
9 ..	9.8	2.6	− 3.6	+ 1.8
10 ..	9.5	2.0	− 3.6	+ 3.6
		Alloy C.		
1 ..	12.3	4.8	− 5.6	+ 5.2
2 ..	12.6	5.6	− 5.0	+ 3.5
3 ..	11.9	5.0	− 6.7	+ 3.2
4 ..	11.4	4.8	− 5.6	+ 3.3
5 ..	11.2	3.9	− 1.1	+ 2.3
6 ..	12.7	5.8	− 1.0	+ 1.6
7 ..	11.9	6.0	− 5.3	+ 2.1
8 ..	12.4	4.7	− 0.5	+ 1.0
9 ..	12.5	6.5	− 1.0	+ 1.0
10 ..	12.0	4.2	− 9.0	+ 4.2
		Alloy D_1.		
1 ..	10.3	1.6	− 1.2	+ 1.2
2 ..	10.7	1.8	− 1.8	+ 1.8
3 ..	10.7	1.6	− 4.7	+ 5.3
4 ..	10.9	1.6	− 0.6	+ 1.2
5 ..	10.7	1.5	− 1.8	+ 3.6
6 ..	11.0	1.6	− 3.5	+ 2.3
7 ..	10.8	1.3	− 5.9	+ 2.4
8 ..	10.6	1.3	− 1.8	+ 1.8
9 ..	10.7	1.3	− 1.2	+ 3.6
10 ..	10.5	1.0	− 1.2	+ 0.8
		Alloy D_2.		
1 ..	18.2	0.6	− 2.8	+ 2.5
2 ..	19.5	0.4	− 1.0	+ 1.0
3 ..	18.7	0.6	− 2.4	+ 3.6
4 ..	18.4	0.6	− 9.6	+ 7.0
5 ..	19.8	0.5	− 1.3	+ 0.7
6 ..	19.5	0.5	− 5.4	+ 4.0
7 ..	18.6	0.4	− 2.0	+ 3.1
8 ..	18.5	0.4	− 2.8	+ 1.4
9 ..	18.5	0.4	− 2.1	+ 2.0
10 ..	17.7	0.4	− 7.5	+ 5.4

For each melt 100 kg. (220 lbs.) of material were charged. No flux was used during the melting process as its influence on the quality of aluminium alloys is doubtful. The fluxes currently used do not have a decisive influence on the reduction of the aluminium oxide on account of the high oxidation temperature of the aluminium. Moreover, the current practice involves the danger of hydrogen absorption in the melted metal when moist fluxes are added to it. Another reason for avoiding the use of fluxes was the desire to prevent any factors influencing the results of the repeated melting.

The alloys A and B were cast at the temperature 730 deg. C. measured by means of a iron-constantan thermocouple. The melting of alloys C and D was carried out according to the recommended procedure, *i.e.*, refinement by means of sodium and sodium fluoride at 760 deg. C. and casting at 730 deg. C.

From each melt of alloys A, B and C, nine tensile test-pieces were cast in green sand. The diameter of the test-piece castings was 12.5 mm., their test length was 50 mm. (2 in.). The dimensions of the test-piece are shown in Fig. 2.

From each melt of alloy D, eighteen test-pieces were cast. Nine of the test-pieces of this alloy were tested in the "as-cast" condition (D_1); the other nine were subjected to a heat-treatment consisting of heating to 530 deg. C. for 3 hrs., quenching in cold water and annealing at 175 deg. C. for six hours (D_2).

In addition to the test-pieces some intricate green-sand castings were produced from each melt and of each material to determine the susceptibility of the alloys to cracking and faults due to shrinkage.

The test-pieces were machined to 12 mm. diameter and then tested. The broken test-pieces, risers and experimental castings were

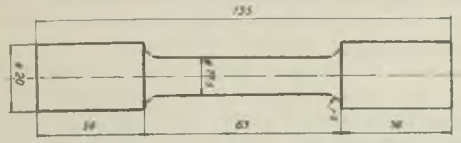

Fig. 2.—Test-Piece for Testing of Remelted Alloys.

then used for the next melt, which was carried out exactly in the same way as the preceding one. The procedure of melting, testing and remelting was repeated altogether ten times with each alloy.

All test-pieces D_2 from all ten melts were heat-treated simultaneously to prevent any possible

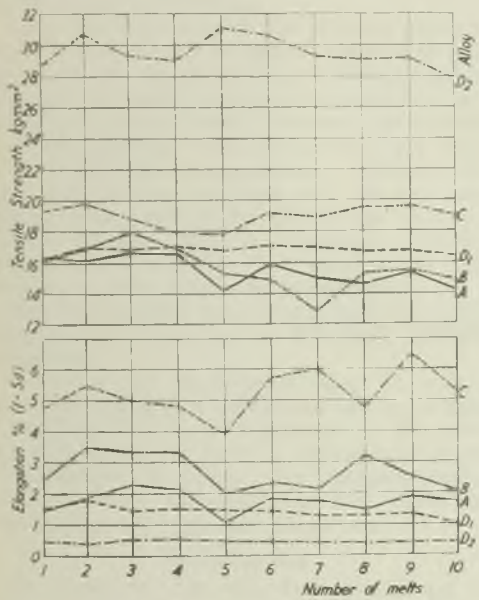

Fig. 3.—Effect of Repeated Melting.

influence of slight differences in quenching and annealing temperatures.

The results of the tests are set out in Table II. The figures given show an average of nine test results. Despite the fact that cast test-pieces were used, the test results show a noteworthy uniformity. The highest and lowest figures for the tensile strength are shown in Table II as factors of the calculated average tensile strength. In Fig. 3 the results are shown in a graphical form.

The results of the tests show that the repeated melting of the aluminium alloys tested, to which no new material was added, has no marked effect on their quality. The same can be said about the castings produced from the remelted material, which even after ten meltings did not show any inferiority as compared with the castings produced from the first melt. The repeated melting has also no effect on the quality of the heat-treated alloy D_2.

In order to find any possible variation in the chemical composition of the tested material an analysis was made from every first, fifth and tenth melt, the results of which are shown in Table III.

Table III.—*Compositional Change after Remeltings.*

Alloy.	Melt No.	Si. Per cent.	Cu. Per cent.	Fe. Per cent.	Zn. Per cent.	Mn. Per cent.	Mg. Per cent.
A ..	1	0.18	8.12	0.27	—	—	—
	5	—	8.12	0.27	—	—	—
	10	—	8.10	0.27	—	—	—
B ..	1	0.58	4.26	0.25	5.80	—	—
	5	—	4.17	0.26	5.73	—	—
	10	—	4.05	0.26	5.27	—	—
C ..	1	12.42	0.89	0.35	—	0.28	—
	5	12.40	0.89	0.34	—	0.27	—
	10	12.54	1.00	0.35	—	0.27	—
D_{1+2}	1	12.90	—	0.28	—	0.42	0.25
	5	13.02	—	0.26	—	0.40	0.29
	10	12.95	—	0.29	—	0.40	0.22

The analyses show that the chemical composition of the alloys, A, C and D practically did not change with the repeated melting. The alloy B containing zinc lost about 0.5 per cent. of its zinc content after ten meltings. The magnesium content of the alloy D was kept in the limits of 0.2 to 0.3 per cent. by addition of small quantities of metallic magnesium to each melt.

It should be emphasised that the tests were carried out under normal foundry conditions and without the use of any surface protection of the melted metal. The test showed that a repeated melting has no harmful effect on the quality of the four aluminium alloys tested. The inferiority of remelted material often experienced in foundry practice has to be ascribed therefore to the use of scrap material

of unknown composition or to a lack of care during melting rather than to the remelting itself.

DISCUSSION

Mr. G. L. Bailey, referring to the influence of repeated melting on the properties of light alloys, asked for enlightenment as to the significance of Fig. 1. It appeared that in melting and re-melting metal, one must not mix such alloys as aluminium-copper-magnesium with aluminium-copper, or that one could melt them only in limited proportions. If that were the correct understanding, he could not follow it, because one was not introducing foreign elements or any incongruous materials by putting aluminium-copper into aluminium-copper-magnesium.

Fluxes for Reducing Alumina

Mr. A. Logan pointed to the statement in the Paper that the fluxes currently used did not have a decisive influence on the reduction of the aluminium oxide. As far as the statement in the Paper went, it was correct, he said; but it did not follow that one could not lower the aluminium oxide content in a charge of molten metal by the use of fluxes. It was quite possible, and he believed it was current practice, to reduce the aluminium oxide content of molten metal by using suitable fluxes. The oxide was not actually chemically reduced, but could be eliminated or partially eliminated by mechanical action; and the reduction of the aluminium oxide content was a factor of very great practical importance in aluminium founding. He would welcome the experience of others concerning the amount of aluminium oxide permissible, for he had fairly definite ideas about it. He had indications that the presence of aluminium oxide beyond a certain limit was in itself sufficient to cause considerable trouble.

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Paper No. 690

Industrial Legislation In South Africa*

By A. H. GUY (Member)†

The foundry trade in South Africa is comparatively young, as indeed is most industrial development in the Union. It virtually owes its inception to the gold mining industry on the Witwatersrand, and its earlier growth, and even its present major activities, are roughly parallel to the development of gold mining.

The industry therefore may be said to date back only as far as 1886, at which time it was extremely elementary, being employed on such jobs as the making of firebars and such simple castings as could only be imported with considerable delay, holding up work in consequence, and which might be contrived under the difficult conditions then prevailing.

Since the beginning of the present century, foundry activity has developed roughly in proportion to the expansion of gold mining, and its technique is largely designed to cater for that market. In recent years, however, foundrymen have been seeking extended markets, and there is no doubt that scope exists. Hitherto the bulk of production has been on a general engineering basis, probably because of the restricted market offering, but as technique develops further and conditions of employment are adapted to the needs of manufacture, it is reasonable to expect considerable progress by the industry in a number of directions hitherto unexplored.

Conditions of employment are, of course, based upon existing legislation for the control of industry, and such legislation is advanced. The following Acts have a direct application to industry:—Factories Act, Apprenticeship Act, Workmen's Compensation Act, Industrial Conciliation Act and the Wage Act.

Factories Act

The Factories Act was first introduced in 1918 and brought up to date in 1929. It provides for the licensing of factories and generally for matters germane to factory hygiene. A 48-hr. week is laid down, with time and a quarter to be paid for overtime, public holidays are regarded as holidays without pay—there are eleven statutory holidays during the year in South Africa—while provision exists for the care of female labour and juveniles (the latter under 16 years of age may not be employed). Regulations require the proper safeguarding of health and life, and are administered by Factories Inspectors under the control of the Department of Labour.

Changing room accommodation must be provided to "the satisfaction of the inspector," which, in the case of foundries, entails the provision of hot and cold water in changing rooms, showers and individual lockers for employees. The Regulations also provide for first-aid equipment, the supervision and control of machinery and boilers, generation and distribution of electricity, elevators, and also lay down procedure in the event of accidents and inquiries in relation thereto.

Apprenticeship Act

The Apprenticeship Act, which was introduced in 1922 and brought up to date in 1930, is designed to regulate apprenticeship and the carrying out of contracts of apprenticeship in designated trades. The Act makes provision for the scheduling of the industries in which it is to apply, and thereafter committees are set up to advise the Minister on the designation of the trades in the industry concerned which are to be controlled under the Act. Such committees consist of an equal number of representatives of employers and employees under a chairman appointed by the Minister, and it is their function to recommend *inter alia* the qualifications a youth should possess before he may be indentured, in regard to age and education, and further to recommend what number of apprentices may be employed in any shop, the rates of wages, the period of apprenticeship, courses of training and any other conditions which it deems desirable.

Further functions of apprenticeship committees embrace disputes which may arise over contracts, the type of educational class which an apprentice may be called upon to attend, the examination of proposals for indentures of youths submitted by employers, and generally the ability to inquire into any matter relating to appren-

* Presented on behalf of the South African Branch of the Institute.

† President, South African Branch.

ticeship in the industry in the area for which the committee has been appointed.

Briefly, the procedure which must be followed before a boy can be apprenticed to the moulding trade is as follows:—The employer makes application to the committee for the indenture of a certain youth on a prescribed form. The committee, if it is satisfied that the boy is over sixteen years of age and has passed Standard VI, and that sufficient training facilities exist in the establishment of the employer to ensure that this particular individual will be given the opportunity of becoming a properly qualified journeyman, will then recommend the indenture, which is thereafter more or less automatic.

A contract is then entered into between the employer and the boy's guardian, being binding in civil law for a period of six years, and subject to the supervision of the apprenticeship committee. During the first five years of his indenture the boy must attend technical classes. For the first two years he is given a certain amount of time off by the employer, but thereafter he must attend evening classes for three nights each week.

Practically no other type of moulder than a journeyman exists in South Africa to-day. Negotiations are on foot between the employers' organisation and the trade union with a view to dilution in order to encourage manufacture, but at the time of writing no concrete steps have been taken, except in Durban where a large foundry is engaged in various forms of repetition work with employees under repetitive conditions.

The question of technical training in the trade in conjunction with apprenticeship is occupying the close attention of the South African Branch of the Institute, which aims at developing the status of foundrymen in South Africa, and creating the necessary technical educational facilities to enable professional qualifications to be obtained to that end.

Workmen's Compensation Act

The Workmen's Compensation Act is the next statute with which the industry is concerned. Workmen's compensation insurance in South Africa is compulsory, but while there are one or two mutual associations in existence, the bulk of the business is conducted by private companies, under an arrangement with the Workmen's Compensation Commissioner, whereby they undertake to return 65 per cent. of the aggregate premiums in benefits. Premiums are of course adjusted in accordance with the risk.

A workman is entitled to compensation under the following circumstances:—

If an accident occurs to him during the course of his employment, providing that such disablement is not due to his serious or wilful misconduct—unless he is killed or seriously disabled under these circumstances leaving dependants, but this exception will not apply if the accident was directly attributable to drunkenness.

He is also not entitled to compensation if disablement or death is due to a pre-existing diseased condition of which his employer was unaware but of which the workman had cognisance.

Accident resulting in serious disablement or death counts for compensation even though the workman at the time was acting unlawfully or against instructions, providing that he was so doing for the purpose of and in connection with his employer's business.

If negligence on the part of the employer be the cause of the accident, application may be made for increased compensation. Compensation is payable to dependants, including widows, children under sixteen, parents, brothers and sisters, provided that it can be shown that they were wholly or partially dependent on the workman's earnings at the time of the accident.

The administration of the Act is entrusted to the Commissioner of Workmen's Compensation, provision being made for questions in dispute to be determined by a magistrate, and for medical and technical assessors and medical arbitration, appeal to a higher court being admissible on certain specified grounds. Control of the payment of compensation is in the hands of the Commissioner.

Compensation for temporary partial or total disablement is at the following rates:—At the rate of 60 per cent. of the monthly earnings, up to £20 of such earnings, together with 35 per cent. of his monthly earnings in excess of £20 up to £33 6s. 8d.: Provided that such compensation may be increased to an amount not exceeding the rate of the workman's earnings or £6 10s. per month, whichever may be the less:—

(i) When the workman was at the date of the accident causing disablement under 21 years of age; or

(ii) When the workman, although above that age, would be unable to maintain himself and those dependent on him upon the periodical payment.

The period of temporary disablement is six months, which may be increased to twelve months, and may be further increased on a different scale of payment.

The compensation in the case of permanent disablement, including permanent injury or serious disfigurement, shall be according to the

degree of disablement of the workman and in accordance with the following rules:—

(*a*) Where the degree of disablement is 40 per cent., a lump sum equal to sixteen times the monthly earnings of the workman up to £20 of such earnings, together with nine times his monthly earnings in excess of £20 up to £33 6s. 8d.

(*b*) Where the degree of disablement is under 40 per cent., a lump sum bearing the same proportion to a lump sum calculated in accordance with paragraph (*a*) as the degree of such disablement bears to 40 per cent.

(*c*) Where the degree of disablement is over 40 per cent. and under 70 per cent., then in respect of one-half of the percentage of disablement, a lump sum calculated according to paragraph (*b*), and in respect of the other half of the percentage of disablement, a monthly pension calculated in the manner provided in paragraph (*e*).

(*d*) Where the degree of disablement is 100 per cent., a monthly pension equal to one-half of the monthly earnings of the workman up to £20 of such earnings, together with one-quarter of his monthly earnings in excess of £20 up to £33 6s. 8d.

(*e*) Where the degree of disablement is 70 per cent. or over, but under 100 per cent., a monthly pension bearing the same proportion to a pension calculated in accordance with paragraph (*d*) as the degree of such disablement bears to 100 per cent.

The compensation where the workman dies from an injury caused by an accident shall be as follows:—

(*a*) If the workman leaves as a dependant a widow or invalid widower and no children, an amount not exceeding two years' earnings of the workman or £500, whichever is the less.

(*b*) If the workman leaves as dependants a widow or invalid widower and one or more children, an amount not exceeding eighteen months' earnings of the workman or £375, whichever is the less, to such widow or widower together with a pension in respect of such children as provided in paragraph (*c*): Provided that, if the amount of compensation payable under this paragraph is less than the amount payable under paragraph (*a*), such amount may be increased to an amount not exceeding that payable under paragraph (*a*).

(*c*) If the workman leaves as dependants one or more children, a monthly pension in respect of the children amounting to the undermentioned percentage of the pension which would have been granted to the workman if totally and permanently disabled as provided in paragraph (*d*) of sub-section (1) of Section 48, according to the number from time to time of such children who are entitled to receive a pension, that is to say:—

1 child	20 per cent.
2 children	35 ,, ,,
3 children	50 ,, ,,
4 children	60 ,, ,,
5 children	65 ,, ,,
6 children or more	70 ,, ,,

subject to certain provisos which regulate the position.

Medical aid is also provided by the Act, and first-aid and transport for an injured employee. Medical expenses, in addition to compensation, may be defrayed for a period up to a year on a scale deemed reasonable by the authorities, up to £100. The fees and charges to be made by practitioners are prescribed by regulation, the workman having freedom of choice in the selection of his medical and surgical treatment, unless provision has already been made therefor by his employer on a scale approved by the Commissioner.

The Act further provides for industrial diseases, and the compensation of native (African) employees on a scale different from Europeans, to whom the foregoing provisions mainly apply. It should be borne in mind that most of the lower-paid occupations in South Africa are filled by natives. Provision for compensation in the Act is relative to the general requirements for civilised as opposed to less civilised standards of existence. Insurance is, of course, compulsory and is conducted, as indicated, through private insurance companies which require to be licensed to conduct workmen's compensation business.

Industrial Conciliation Act

The measure which probably plays the greatest part in the regulation of industrial relations is the Industrial Conciliation Act, which was introduced in 1924 and brought up to date in 1937. It is perhaps significant that no major strikes have taken place in South Africa since this Act became law, which appears to indicate that the primary purposes of the measure—the prevention and settlement of industrial disputes—have been served.

Broadly, the Act provides two classes of machinery for the control of relationships; conciliation boards and industrial councils. A conciliation board is brought into existence either on the application of a trade union or of an employers' organisation. Alternatively, the Minister may decide to create such a board. A condition precedent is that the matter in dispute is one which falls to be dealt with under the Act, and it is provided that no strike or lock-out may take place until the Board

has reported to the Minister on the matter in dispute.

If agreement is reached by the parties through a board, then the agreement may be given the force of law for a specified period. Mediators may be appointed at the discretion of the Minister and arbitrators may be called in if the parties agree.

The second class of machinery is the industrial council. It is possible for individual trade unions and employers' organisations, or groups of such associations, to come together and draw a constitution in terms of the Act, which is then registered by the Industrial Registrar and has the effect of creating the industrial council as a body corporate. It becomes the function of this body, consisting of an equal number of representatives of employers' associations and trade unions, to endeavour to settle any disputes which may arise in the particular industry concerned, and to enter into agreements regulating wages and conditions.

The method of handling disputes is similar to that employed under the conciliation board system, the existence of the council making strikes and lock-outs illegal until the council has failed to settle them and has reported to the Minister accordingly. Mediation and arbitration proceedings may be invoked as under a conciliation board.

If (as is the invariable practice) an industrial council decides to negotiate an agreement to govern wages and conditions in the industry, it may, on completion of the agreement, request the Minister of Labour to give it the force of law for a given period. The Minister gazettes the agreement by virtue of the powers conferred on him in terms of the Act, and it then has the force of law, penalties for breach being prescribed under the Statute.

The Minister may go further with reference to an agreement—and indeed usually does. He may indicate in gazetting an agreement that, since he is satisfied that the parties are sufficiently representative of the industry, it is to be binding not only upon the parties but on all employers and employees in the industry in a given area, irrespective of whether they are members of any of the employers' organisations or trade unions comprising the industrial council.

Power is given to industrial councils by the Act to appoint agents, and the Minister may, if he approves of such agents, invest them with the powers of an inspector in the government service, so that they may enter upon premises either of parties or non-parties, call for books and make investigations with a view to ascertaining that any industrial agreement in force is being properly carried out.

The Act requires that any association of employers or employees who come together with the object, *inter alia,* of regulating conditions of work, must register under the Act, submitting their constitutions to the Registrar within three months of formation. The Registrar, if he is satisfied that the constitutions contain nothing contrary to the objects of the Act, or to the public interest, then registers the body concerned for a given area, and it becomes the body representative of the particular interest concerned in that area. No unregistered body has any status in law.

The Act defines, among other things, the term "employee" and excludes from such definition persons falling under the pass laws of the Union —that is to say pass-bearing natives. Any question affecting the interests of native employees therefore does not fall within the scope of the Act, being rather a matter for the Native Affairs Department, although industrial agreements commonly lay down wages for the type of occupation which is usually filled by native employees —such as labouring work.

The Minister is given power, however, to extend the terms of an agreement to natives, to prevent their exploitation in occupations common to European classes of labour, which might be possible if an agreement were not designed to lay down a wage for a particular job, irrespective of race.

The Wage Act

The Wage Act, the final industrial measure, provides for the creation of a permanent wage board which may make investigations into the conditions of any particular trade or industry on application to it by a representative body of employers or workers in the trade or industry concerned, or on a reference issued to it by the Minister.

The board, having investigated, reports to the Minister and may make a recommendation as to the wages and conditions which should apply in the particular sphere under reference. The Minister may accept such a recommendation, publish it for objection, cause such objections to be considered, and gazette it in order to give it the force of law.

Thereafter the recommendation becomes a determination and has the same force as an industrial agreement, save that it is not administered by an industrial council, but by the Department of Labour whose inspectors are responsible for seeing that it is carried out.

The Wage Act is usually brought into operation in relation to unorganised trades or industries or in the interests of the class of workers

(natives) who are not classified as employees falling under the scope of the Industrial Conciliation Act.

Conclusion

The foregoing very brief summary of some of the main provisions of the industrial legislation of the Union serves to indicate the wide scope of the Acts, in their relation to industrial welfare. It indicates also that the social legislation of South Africa is abreast of and in some cases ahead of that in operation in many older industrial countries. It takes cognizance, too, of the peculiar social conditions of South Africa, where the wage gap between skilled and unskilled occupations has always been wide—although there is a strong tendency now to narrow the gap—and where there is a natural tendency for occupations to fall into two categories: those generally carried out by employees enjoying a civilised standard of living, and those (such as labourers' work) which are usually carried out and remunerated on a lower scale.

Paper No. 691

Solution Heat-Treatment of Aluminium Casting Alloys

By Dr.Ing. R. IRMANN

Although the hardening of aluminium forging alloys by means of solution heat-treatment has been known since the invention of Duralumin in 1906, and has been applied technically since about 1910, yet the solution heat-treatment of aluminium casting alloys for the purpose of improving their strength did not come into practical use until after the discovery of "Y alloy" by Rosenhain in 1917. As shown in Fig. 1 the historical development of aluminium casting alloys is in part due only to the technological point of view. The aluminium casting alloys may be classified as follows:—

Group I.—Alloys to which hardeners such as Cu, Zn, Mg and Si are added which improve the strength and corrosion resistance of the alloy. (*a*) Improvement of strength by adding Cu and Zn (Al-Cu and Al-Zn-Cu). (*b*) Improvement of strength and corrosion resistance by means of Mg (Al-Mg). (*c*) Improvement of strength and of casting properties by means of Si; unsuitable for sand casting unless the grain is refined simultaneously by means of a refining with Na (Al-Si).

Group II.—Alloys to which Cu, Mg, Si are added for the purpose of obtaining a hardening effect (Al-Cu-Ni, Al-Cu-Mg, Al-Mg-Si, Al-Si-Mg, and Al-Mg).

Group III.—Alloys to which small quantities of an element such as Ti are added for the purpose of refining the grain and improving the mechanical properties, particularly by solution heat-treatment.

This classification shows that high strengths are only obtained in Groups II and III, which are subjected to a solution heat-treatment.

Heat-Treatment Processes

Solution heat-treatment can be applied only to alloys containing a constituent, the solubility of which increases with rising temperature. As shown in Fig. 2, Cu, Si, Mg_2Si, Zn and $MgZn_2$ are such constituents. The solution heat-treatment consists in annealing the alloy at a temperature ranging above the solubility curve of the added element, so that this element becomes soluble. At a temperature of 550 deg. C., for instance, about 5.5 per cent. Cu becomes soluble. By means of quenching the alloy from this temperature, the precipitation of the added element Cu is prevented, so that at room temperature a homogeneous solid solution of an unstable nature and containing 5.5 per cent. Cu is obtained.

The solid solution now has the tendency of acquiring a state of stability by means of precipitating the surplus Cu, thus producing changes in the space-lattice and a hardening effect. In the case of some alloys, this increased hardness is already noticeable when aged at room temperature, and with others only after precipitation heat-treatment. The solution heat-treatment, and the ageing at room temperature and precipitation heat-treatment, are shown diagrammatically in Fig. 3.

Furnaces for Solution Heat-Treatment

The temperatures necessary for the solution heat-treatment of casting alloys are very close to the solidus point; therefore, very uniform temperatures ranging between about $\pm$ 5 deg. C. are required. Likewise, the temperature for the precipitation heat-treatment (say, for instance, 160 deg.) which follows upon the solution heat-treatment and quenching must of necessity be within a range $\pm$ 3 deg. C.

If, therefore, a maximum solution heat-treatment temperature of 500 deg. C. is prescribed, the furnace must be set at 495 $\pm$ 5 deg. C., this temperature to be evenly maintained in all parts of the furnace and throughout the solution heat-treatment process, taking usually from 2 to 4 hours. Only electrically-heated furnaces with air circulation and automatic heat control can fully satisfy these requirements. Air circulation is essential in any case, because the rate of heating would be two or three times slower without it.

Two pit furnaces separated by the quenching tank may be used. One of the furnaces is used for solution heat-treatment and the other for the precipitation heat-treatment. The heating elements are fixed in the brickwork or on the cylindrical element of non-scaling steel which separates the furnace chamber from the heating

elements. A motor, driving a centrifugal fan, is installed on the cover of the furnace. The hot air is sucked past the heating elements and blown into the furnace chamber through the open element. By means of a thermocouple inserted into the cover, the furnace current is regulated automatically.

The power rating of a furnace for solution heat-treatment having a diameter of 40 in. and 60 in. deep, is 35 kw. For precipitation heat-treatment about 6 kw. are required for a furnace of the same size.

Apart from the temperature and duration of the solution heat-treatment, the total power consumption, of course, depends also on the size of the castings. Smaller castings are introduced into the furnace in a light charging basket of non-scaling steel by means of a jib crane. Upon completion of the solution heat-treatment the basket with the castings in it is dipped into the quenching tank.

Large castings are hung on to chains so that no basket is used. As the strength of aluminium alloys is greatly reduced at solution heat-treatment temperature, the castings may occasionally be deformed on account of their own weight. Where this risk exists, the casting must be protected from deformation by means of special steel supports. Fig. 4 shows the reduced strength of an Al-Mg-Si alloy (Anticorodal) at elevated temperatures.

When a charging basket is used, the electric power consumption for each pound of castings is, of course, higher, because the basket is heated with the casting and often weighs more than the charge. For castings of 25 to 50 lbs., the power consumed by a solution heat-treatment of 3 hours at about 530 deg. C. and a subsequent precipitation heat-treatment of 12 hours at 160 deg. amounts to about 0.25 to 0.7 kw.-hr./lb., the lower figure pertaining to heat-treatment without the basket and the higher to heat-treatment with the basket.

In order to make the fullest possible use of the solution heat-treatment furnace, several precipitation heat-treatment furnaces should be provided for each solution heat-treatment furnace, their number depending on the relative duration of the two processes.

In order to avoid internal strains, distortions or even cracks, complicated castings should in some cases be sprinkled vigorously with water until they are cold. Castings made of Al-Si-Mg alloys are quenched. Before treating large castings such as motor casings, it is recommended to machine the faces to be matched in a longitudinal and transverse direction, so that a gauge is obtained for eventual adjustments after the solution heat-treatment—these adjustments to be made immediately after the quenching, *i.e.*, prior to the precipitation heat-treatment. In the case of some alloys no precipitation heat-treatment is applied, as these age at room temperature and reach their maximum strength in about three days.

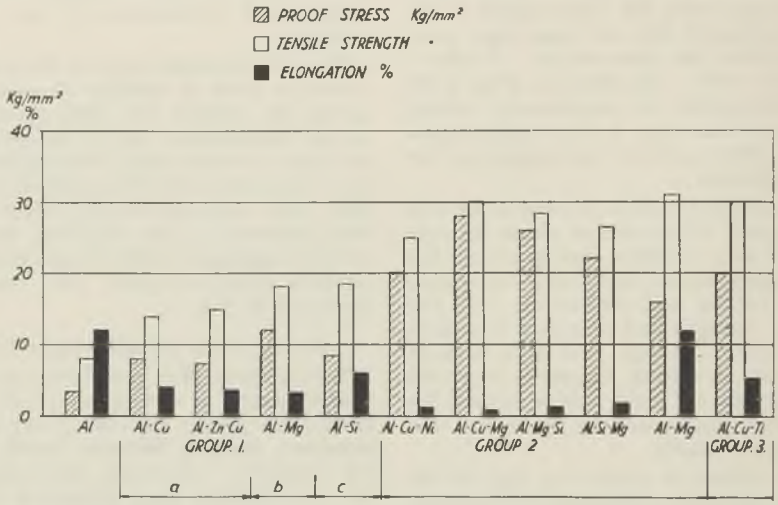

FIG. 1.—TECHNOLOGICAL GROUPS OF ALUMINIUM CASTING ALLOYS (SAND-CAST).

Effect of Heat-Treatment on Mechanical Properties

Mention has already been made of the effects of the solution heat-treatment temperature. This should be kept as close as possible to the limit of solubility of the hardeners, without ex-

ceeding it, however, because this would result in overheating. The duration of the solution heat-treatment also has a considerable effect on the mechanical properties. This effect varies according to the type of casting (whether sand or chill cast) and the composition of the alloy. It should be realised that the term " duration of the solution heat-treatment " includes both

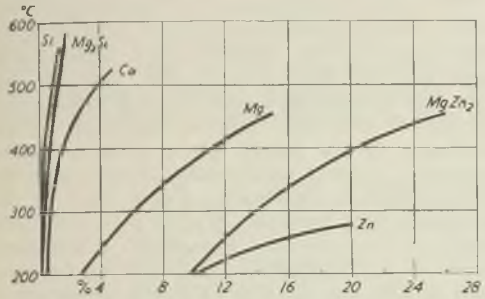

FIG. 2.—SOLUBILITY OF HARDENERS IN ALUMINIUM.

the time during which the casting remains at the heat-treatment temperature as well as the period of warming-up. It would not be advisable, for instance, to try to warm a casting in a salt bath to the solution heat-treatment temperature in too short a time. On the contrary, the casting should, as a rule, be warmed-up for over an hour, so that it gradually loses its casting stresses caused by the different speeds at which the various parts of the casting solidify in the mould. Very quick warming-up of the castings may have an effect directly

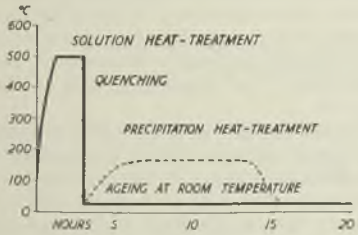

FIG. 3.—HEAT-TREATMENT OF ALUMINIUM ALLOYS SHOWN DIAGRAMMATICALLY.

opposite to that of a decrease in stresses, namely, induced stresses and distortions.

The solution heat-treatment generally leads to increased strength, hardness and elongation. While further improving strength and hardness, subsequent precipitation heat-treatment induces a decrease in elongation which varies according to the temperature and duration of the process. This is illustrated by the stress-elongation diagram for Anticorodal shown in Fig. 5. The strength and the elongation of untreated castings (Curve No. 1) are increased by the solution heat-treatment and the quenching (Curve No. 2); a subsequent precipitation heat-treatment lasting 8 to 10 hours at 160 deg. C. causes the strength to increase still further, but the elongation to decrease considerably (Curve No. 3). The precipitation heat-treatment temperature is of utmost importance, as some alloys attain the same strength combined with greater elongation, if a lower temperature of, for instance, 140 deg. C. combined with longer duration is used.

As regards the heat-treatable alloys at present used by industry, experience has led to the

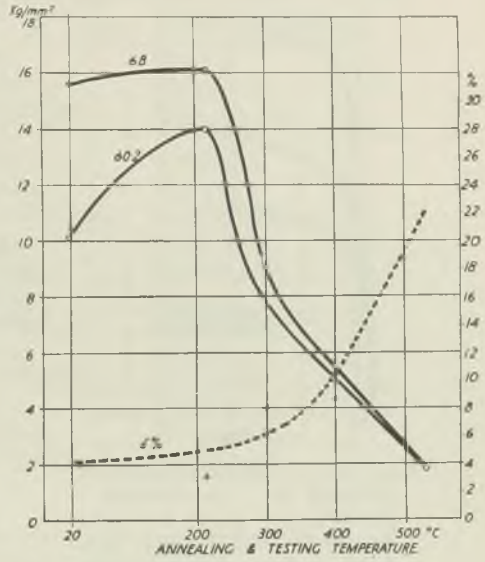

FIG. 4.—MECHANICAL PROPERTIES OF " ANTICORODAL " (CHILL-CAST), TESTED AT ELEVATED TEMPERATURES.

application of the solution heat-treatment and precipitation heat-treatment temperatures and times shown in Fig. 6, the actual temperatures and periods being so selected as to give the alloy the mechanical properties required by the purpose for which it is used.

" Alufont 2 " is an alloy made up of scrap from the Al-Cu-Mg forging alloy and 4 per cent. Cu, 2 per cent. Si, 0.5 per cent. Mn, 0.2 per cent. Mg, and 0.2 per cent. Ti. As shown in Fig. 7, a solution heat-treatment greatly improves its mechanical strength, which is further enhanced by precipitation heat-treatment at 140 deg. C. or still better at 160 deg. C., but the latter treatment causes a substantial decrease in the elongation. The loss in elongation is much

smaller for "Alufont 3," an Al-Cu alloy which contains 4.5 per cent. Cu but only negligible Fe and Si impurities (each under 0.2 per cent.), and has a very fine structure due to the addition of about 0.2 per cent. Ti. Although sand-cast test-pieces of this alloy reach a high tensile strength and elongation (Fig. 8) by means of this treatment, their proof stress is far lower than that of the previously mentioned "Alufont 2." "Alufont 3," therefore, is particularly suitable when high plasticity is required—a property which is not possessed by most other heat-treated casting alloys.

The heat-treatable Al-Mg alloys with about 10 per cent. Mg have also recently gained in importance, especially because it has been made possible to simplify the technique of sand casting—which was complicated by the necessity of adding substances forming a protective gas to the moulding sand—by means of adding very small quantities of beryllium (French invention). The beryllium added to the metal makes the addition of substances forming a protective gas unnecessary.

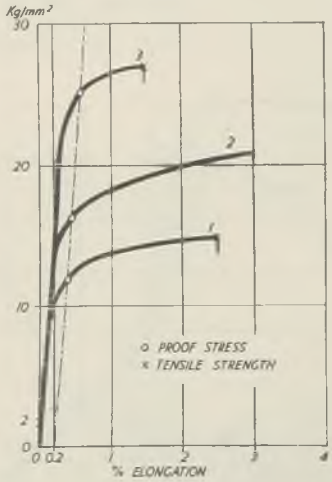

Fig. 5. — Stress-Elongation Diagram of "Anticorodal" (Sand-Cast): (1) As Cast; (2) Solution Heat-treated and Aged at Room Temperature; (3) Solution Heat-treated and Aged at 160 deg. C.

Castings made of the Al-Si-Mg alloy "Silumin" also have their tensile strength and their proof stress increased while their elongation is reduced, when they undergo a solution heat-treatment followed by a precipitation heat-treatment. The same hardening effect caused by the precipitation of Mg_2Si is also noticeable with the Al-Mg-Si alloy "Anticorodal," which was discovered before the Al-Si-Mg alloys came into use. The solution heat-treatment followed by ageing at room temperature or by precipitation heat-treatment is also applicable to the Al-Si-Mg alloys.

Influence of Casting Conditions on the Result of the Solution Heat-Treatment

The rate of solidification in the mould affects the mechanical properties of the "as-cast" alloy. This rate can be varied within large limits, especially in the case of chill castings, but actually it depends mainly on the casting properties of the alloy and on the form of the castings. If the mould has a rather low temperature, a rapid solidification should cause the strength to be increased, whilst most of the hardeners (for instance, Mg_2Si) remain in solution and re-precipitate by ageing. Test-pieces made of "Anticorodal" at a casting temperature of 700 deg. C. and at mould temperatures of from 50, 200 and 400 deg. C. show practically no difference in strength after 5 days of ageing at room temperature, no matter whether the casting was effected in hot or cold moulds. However, different results are obtained if the samples are quenched at temperatures of from 200 to 300 deg. C. The various conditions are shown in Fig. 9. This simplified hardening method can be applied solely to chill casting, and even then only if the casting has a rather simple form.

In the case of a very high speed of solidification, as in the case of pressure die-castings, the solution heat-treatment has only a slight effect, and a precipitation heat-treatment is sufficient in most cases. It is, indeed, to be preferred to a solution heat-treatment followed by quenching, as it does not cause the thin pressure die-castings to become so easily deformed. So far as "Anticorodal" is concerned, this is illustrated in Fig. 10.

If the casting be allowed to cool down slowly in the mould, an ageing and an increase of hardness can take place in the mould itself, and especially so in the case of alloys which respond more easily to precipitation heat-treatment, such as "Y alloy." The differences in strength which are present in practically every casting are almost completely removed by a solution heat-treatment followed by quenching.

Different speeds of ageing are also noticeable in the case of precipitation heat-treatment. When a solution heat-treatment has first taken place, a precipitation heat-treatment at 100 deg. C. endows maximum strength to the "Y alloy" in less than 1 hour, whereas for "Silumin" the maximum strength is not even attained after 10 days, and for "Anticorodal" after about two days, as is shown in Fig. 11.

On account of these lower speeds, the precipitation heat-treatment must take place at a higher temperature for " Silumin Gamma " and " Anticorodal," and the duration of the treatment has to be increased.

The type of structure of the alloy in its " as-cast " state is the deciding factor for obtaining the optimum mechanical properties by means of solution heat-treatment. Liquation and coarseness of grain make it more difficult for the hardeners to go into solution. Likewise, longer times are required for the heat-treatments in order to obtain a state of complete solution. In the case of solution heat-treatment, the size of the grains may be increased also owing to recrystallisation, particularly if stresses caused by the speed of solidification have remained in the castings. This explains why, for certain sizes of grains, a solution heat-treatment causes the mechanical properties initially to decrease, and to increase again only after a rather prolonged period, as is shown in Fig. 12, which has reference to the hardness of " Y alloy."

This diminution in hardness is greater for coarse-grained castings; for fine-grained ones, it is smaller because a shorter solution heat-treatment, of a quarter of an hour, for instance, is sufficient for bringing into solution a fair amount of the hardeners, whereby the diminution in hardness is somewhat compensated. For coarse-grained castings a longer period is necessary until the maximum hardness is reached.

The above examples show that for fine-grained castings, shorter solution heat-treatments are required and a greater increase of mechanical properties is obtained. Furthermore, the speed of ageing at room temperature or elevated temperature is higher for fine-grained castings.

In actual practice, a middle course must be taken, as each casting, whether sand or chill cast, is composed of grains of any size. Fig. 13 shows an example in which a longer solution heat-treatment has brought about a considerable improvement in the mechanical properties of a sand casting of " Alufont 3 " alloy containing 4.5 per cent. Cu and 0.2 per cent. Ti.

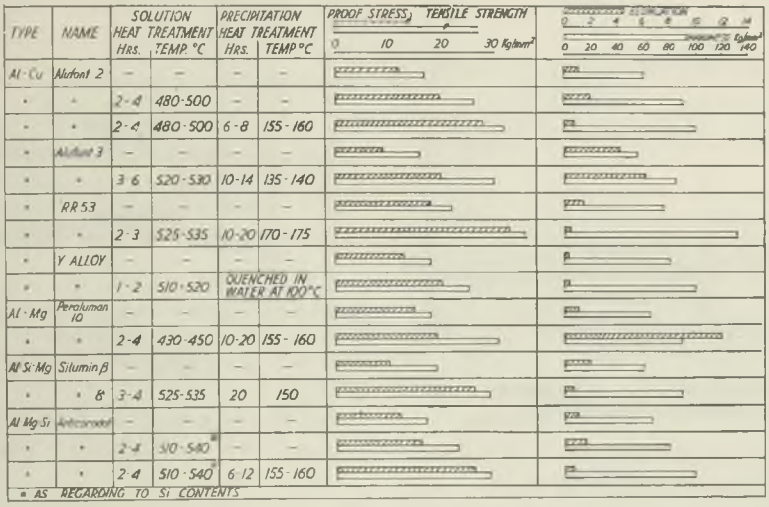

Fig. 6.—Solution Heat-treatment and Mechanical Properties of Aluminium Casting Alloys (Sand-Cast).

Loss of Strength of Heat-Treated Alloys due to Annealing at Elevated Temperatures

With the exception of piston alloys, castings are not usually subjected to elevated temperatures. It should not be forgotten, however, that a long period of annealing at less than 200 deg. C. is sufficient to reduce substantially the highest mechanical properties obtained by solution heat-treatment. At elevated temperatures and after annealing, the heat-treated alloys containing copper retain their mechanical properties for a longer period than some others. For " Anticorodal " (Al-Mg-Si), for instance, the loss of strength is smaller than for " Alufont 2," as is shown in Fig. 14.

The duration of annealing is of utmost importance; therefore, this should always be indicated when figures on heat resistance are quoted. Typi-

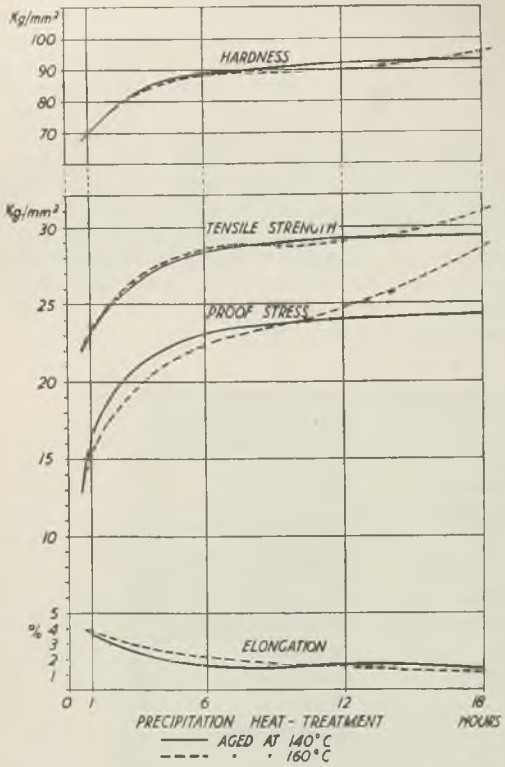

FIG. 7.—MECHANICAL PROPERTIES OF "ALUFONT 2" (SAND CAST).

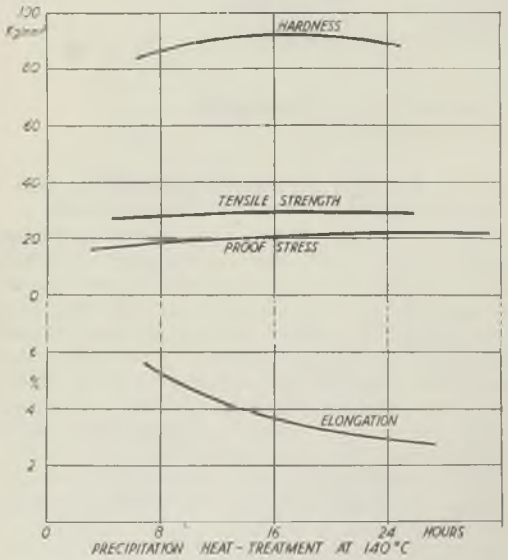

FIG. 8.—MECHANICAL PROPERTIES OF "ALUFONT 3" (SAND-CAST).

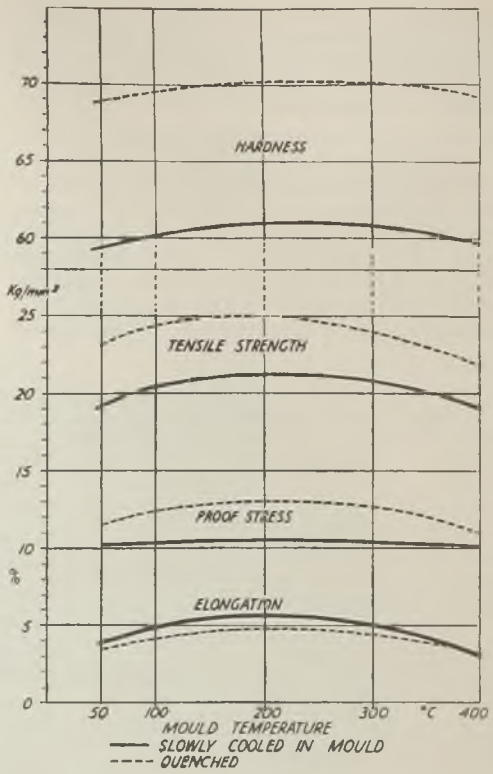

FIG. 9.—INFLUENCE OF RATE OF SOLIDIFICATION ON "ANTICORODAL" (CHILL-CAST).

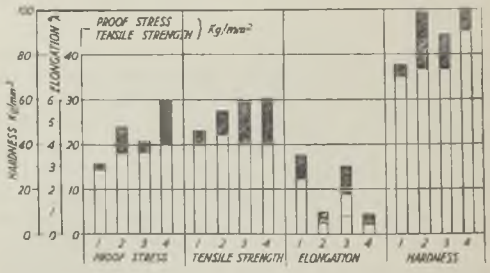

FIG. 10.—INFLUENCE OF HEAT-TREATMENT ON "ANTICORODAL" (PRESSURE DIE-CAST): (1) AS CAST; (2) AGED AT 160 DEG. C.; (3) SOLUTION HEAT-TREATED AND AGED AT ROOM TEMPERATURE; (4) SOLUTION HEAT-TREATED AND AGED AT 160 DEG. C.

cal of alloys with a high heat-resistance are the piston alloys.

Classical amongst alloys is the "Y alloy," whilst the "RR" alloys, which are variations of the former, possess better casting qualities. The piston alloys with copper contents of over 10 per cent., such as "Bohnalite" and "U 20"

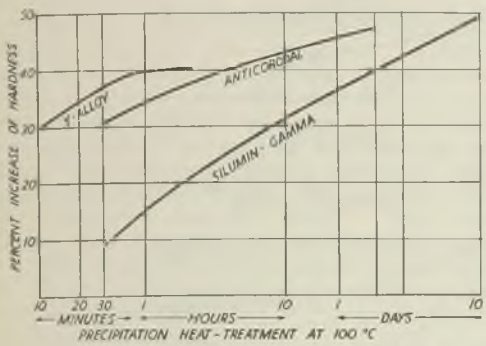

Fig. 11.—Increase of Hardness by Precipitation Heat-Treatment at 100 deg. C.

are another type of heat-resisting alloy. All these alloys are heat-treated. After having been annealed for one month, castings tested at room temperature show that no reduction of hardness takes place before they are heated to temperatures in excess of 160 deg. C. This applies to all the alloys with exception of "Y alloy," which,

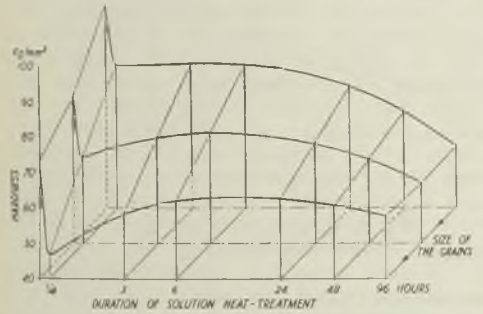

Fig. 12.—Effect of Grain Size and Duration of Solution Heat-Treatment on the Hardness of "Y Alloy."

on the contrary, attains increased hardness due to a precipitation phenomenon (see Fig. 15). At higher temperatures there are only slight differences in hardness between the "Y," "RR 53" and "Bohnalite" alloys, and only the "U 20" alloy is harder.

After annealing at elevated temperatures during a year and testing at room temperature, these differences in hardness continue, though to a lesser extent, and this is shown in Fig. 15.

At lower temperatures, on the contrary, a marked increase of hardness caused by precipitation phenomena takes place also in the "RR 53," the "U 20" and "Bohnalite," for which the precipitation hardening speed is slower than for "Y alloy." By comparing the hardness curves of "Peraluman 2" (Al-Mg) it could be inferred that such an alloy, which is not suited for solution heat-treatment, would be just as good as the heat-resisting piston alloys, in so far as exposure to heat over a long period is concerned, especially at high temperatures.

This may be the case as regards hardness,

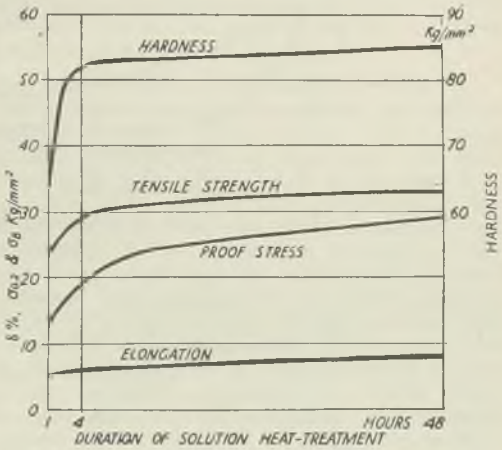

Fig. 13.—Mechanical Properties of "Alufont 3" (Sand-Cast) as Related to Duration of Solution Heat-Treatment.

but respecting the continuous static stress, comparison is rather in favour of the piston alloys, that is, if the creep limits were taken into account. Anyhow, the curves show that it is useless in some cases to exaggerate the initial hardness by means of solution heat-treatment followed by precipitation heat-treatment, as this would make the alloys unnecessarily brittle. However, a precipitation heat-treatment following upon the solution heat-treatment is required in order that the expansion of the metal takes place before the pistons are machined and assembled.

Conclusion

In the present Paper an endeavour has been made to give a brief survey of the heat-treat-

ment processes for casting alloys. These may be briefly summarised as follows:—

(1) The furnaces required for the solution heat-treatment should make it possible to obtain a long duration of the solution heat-treatment and of the precipitation heat-treatment together with great accuracy in temperature.

(2) The mechanical properties obtained are dependent on the rate of solidification within the casting and on the duration of the solution and precipitation heat-treatments.

(3) The high mechanical properties obtained by heat-treatments may be lost if the castings are exposed to elevated temperatures during a long period.

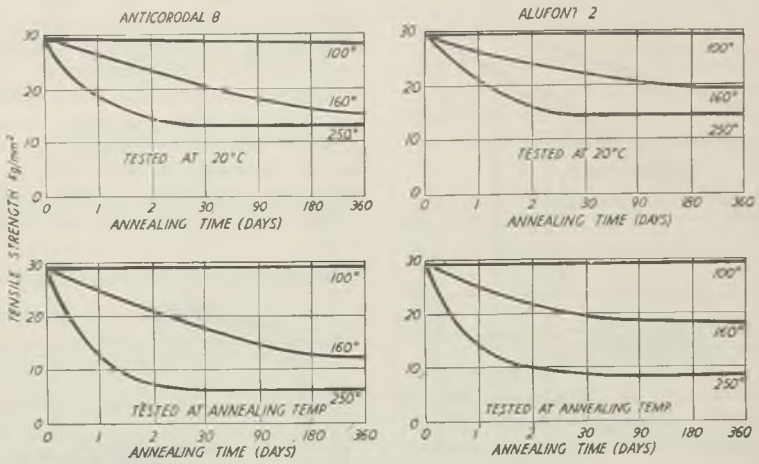

Fig. 14.—Loss of Strength by Annealing "Anticorodal B" and "Alufont 2" (Chill-Cast).

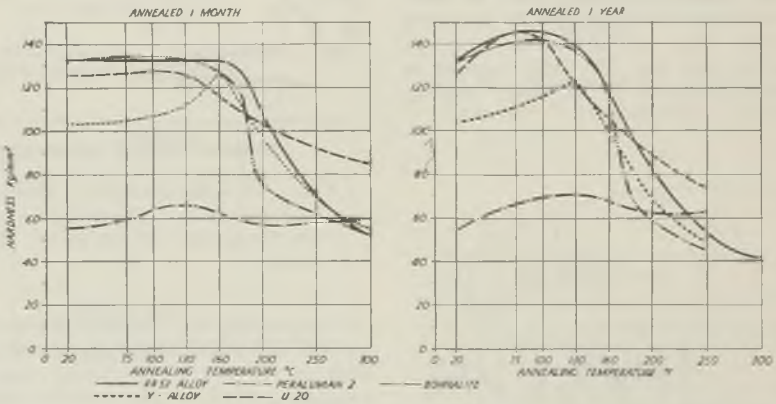

Fig. 15.—Loss of Hardness of Aluminium Casting Alloys (Chill-Cast) after Annealing for One Month and for One Year.

The Compounding of Alloys*

The International Committee of Foundrymen's Associations has been well inspired by adopting the French proposal requesting that the rules governing the preparation of alloys should be examined or simply emphasised at the London Congress. Not that the authors have been influenced by the assertion read a short time ago that "for melting and making up alloys, it is considered that a labourer, even superficially trained, suffices for carrying out this often very delicate work." This was perhaps true 20 years ago, but it is no longer so. The really remarkable results obtained in the foundry industry indicate a technical and scientific control which can be exercised only by an efficient technician.

The literature is abundant and opinions are often in agreement. The authors do not know whether foundrymen—or more exactly foundry executives—have attained a level permitting them to perceive, appreciate and control all the factors involved. The object of this Report is not to widen their horizon, but to compare the general problems engaging the attention of foundrymen, and to point out that they are on the same plane, regardless of the metal of the alloy to be melted or prepared.

The foundryman must know the characteristics of the alloy which is to be made: those specified by the customer, by the user of the casting, and those demanded by the foundry for producing a sound casting. In chronological order, he will, in the first place, have to devote his attention to the raw materials to be supplied with regard to their nature and quality. The latter should be observed both in new material and in scrap. The impurities of metals employed in the production of alloys are capable of exerting a considerable influence on their properties, the latter varying with the quantity and nature of the impurities (Broniewski). This is true of all ferrous and non-ferrous metals. A few tenths per cent. of oxygen appreciably diminish the capacity of deformation of copper. They considerably reduce all the properties of steel (tensile strength, elastic limit, elongation, notched-bar impact strength). Foundrymen producing cast iron are well aware of the phenomenon of heredity.

Some metallurgical operations have a sufficient refining effect to permit the use of more or less impure charges. It is to be expected that the slags utilised in making steel, cast iron and other metals will be studied more and more, and that their scientifically rational application will result in remarkable purification by chemical equilibrium, because taking an example experienced in the metallurgy of iron and steel and quoted by Prof. Portevin, it is the art of the metallurgist to be able to produce something very good from something mediocre. This is fortunate, because, generally speaking, the foundryman is obliged to use scrap, which during melting or use has retained or absorbed harmful elements, often of the same nature as those found in raw materials.

Rusty Scrap in Malleable Practice

Foundrymen who make malleable castings are cautious of this. They dislike "old" scrap, which is always more or less rusty, and they recommend that scrap should be stocked in a dry place under cover. They advise against the use of puddled iron, and it can be added that they ought, as far as possible, to classify their steel scrap according to whether it be basic Bessemer, acid open-hearth or electric, characterised by a different order of compounding and taking the origin of the scrap into account. In the old-fashioned Herstal crucible method of producing malleable castings, the latter were cleaned outside the moulding shop, and in damp weather the runners had a tendency to oxidise, but the old foundryman, the "shop" foreman, who had the entire responsibility of casting and melting, would never use them without having first removed the layer of oxide by passing them through a tumbling barrel. This took place as long ago as fifty years. In one Belgian shop there can be seen the influence exerted by the more or less accentuated alteration of castings in service on the qualities of the castings produced by remelting the old castings. Ingot moulds for steel perish after a more or less considerable number of castings. They deteriorate chiefly in the lower two-thirds, the upper third near the head remaining almost intact. The cupola charges consist of 50 per cent. scrap, 35 per cent. new hematite pig, and 15 per cent. special iron, the function of which is primarily to de-oxidise the molten metal by the action of an element such as titanium, and secondly to prevent the excessive graphitisation, by de-oxidising, through the action of a second element, chromium or vanadium. The resultant of these two actions is plain, but it is affected

* From the Association Technique de Fonderie de Belgique.

by the quality of the scrap. If the latter be composed of runners or used ingot moulds which have been only slightly altered, that is only slightly oxidised by their service in the steel plant, this resultant is extremely and very favourably effective. If the scrap consists solely of pieces of heavily " worn " ingot moulds, it has a very pronounced effect in causing a reduction of possibly up to about 20 per cent. in the life of the new ingot mould produced therefrom.

High-Sulphur Scrap

Another example, also culled from ferrous practice, shows the danger of certain kinds of scrap. In the demolition of a battery of coke ovens, the very abundant rust on the steel pieces absorbed 5 per cent. of its weight of sulphur, sufficient to upset the operation of an open-hearth furnace. This scrap should have been wire-brushed.

This influence of scrap, the contamination of which is known, should be considered by the producers of raw materials, some of whom still deny the influence of elements incapable of estimation in ordinary practice and in all probability constituting the reason for the heredity, of which iron founders are no longer ignorant. One may cite Belgian experience with the open-hearth furnace where, despite long-continued refining and corrective additions, the influence of the pig charged—basic pig or refined iron—the average manganese content of the charge being respected, may be clearly shown by a test for the rapidity of attack by acids.

Non-Ferrous Scrap

Cleanliness of scrap is not to be judged solely from the point of view of rust. In the aluminium foundry, for instance, scrap containing greasy products should not be introduced into the bath without prior burning-off. The influence of oxidised materials may also be recalled because hydrates of aluminium in the mass and in full contact with the molten aluminium liberate water which, in its turn, reacts as indicated later on. The observation on the influence of greasy materials is applicable to any alloy.

Even though the foundryman always endeavours to start with a choice of raw materials to be charged, he will sometimes, often in most cases, find himself under the necessity of employing materials imposed by local conditions. The least which he ought to endeavour to know is the result of any alteration in nature and quantity.

Advantages of Ingotting Scrap

The uncertainty of the composition of scrap should also be cited, especially but not always the " bought " variety. It is germane to recall the advantage of running down the scrap into ingots to give an average composition, and to emphasise the necessity of conducting this operation according to all the rules of the art, just as if it was a matter of making castings, since badly conducted melting may add appreciably to the deterioration in quality of the remelted ingots and dangerously accentuate their shortcomings.

The choice of raw materials may be suggested from other considerations:—the raw materials may have very different densities or very different melting points. In the first case, double melting may be necessary or the type of furnace should be chosen so as to correct the tendency to separation by density, such as the high-frequency electric furnace, where the natural mixing is very vigorous. In the second case, the complete ingotting or alloying to give an intermediate composition may be considered. Cast iron, like the non-ferrous metals, provides examples of running down scrap into ingots or pigs.

TABLE I.—*Influence of Atmospheric Humidity on Cupola Conduct.*

Temp. Deg. C.	Wt. of water in grams per cub. m. (saturation at 100 per cent.)	Corresponding oxygen.	Per cent. of oxygen relative to the wt. of iron melted in the cupola on the assumption of 10 per cent. coke and 12 cub. m. of air per kgm. of coke.
− 5	3.23	2.87	0.3444
0	4.9	4.35	0.522
5	6.99	6.21	0.7452
10	9.8	8.71	1.0452
15	13.70	12.17	1.4604
20	18.60	16.53	1.9836
25	25.80	22.93	2.7516
30	35.00	31.11	3.7332
35	47.00	41.77	5.0124

Influence of Atmospheric Humidity

In every case, the metal to be melted will be brought under the influence of air while at a high temperature. The air comes from the atmosphere which is essentially variable. In a report published on the occasion of a presentation to Prof. Pisek, one of the authors laid stress on the variations occurring during the operation of the open-hearth furnace, in particular, in relationship to the humidity of the air and that of the gas. Moisture appears to have a much more considerable influence than an excess of air for the same quantity of oxygen. The influence of the seasons, that of night relatively to day, in a word every variation of temperature makes itself felt. Table I gives figures illustrating this.

At 35 deg. C., therefore, the air *may* bring into contact with the iron a weight of oxygen,

derived from water, equal to 5 per cent. of the weight of the iron melted. In winter, at − 5 deg. C., the danger is only 1/15th of that which is incurred at the highest temperatures (35 deg. C.).

It should be noted that the figures given in Table I are maxima, and that in order to attain them, there should be the necessary temperature and also a source of water for producing saturation. Executives are not often in control of the latter, which leads to the statement that in the industrial world there are privileged persons whose plants are situated in a dry climate. There are cases where this notion may be applied, and one which has been tried was that of the passage of hot air through a valve having a wide water seal, resulting in a saturation with water having a very definite effect on the oxidation of the bath.

The fuel should be dry when it comes into contact with the metal at a temperature below the melting point. Metal at red heat is affected by oxidation. This remark does not apply to cupola coke, the moisture of which is expelled in the upper zones. Artificial fuels in particular are concerned because they are made from more or less moist coal. If, for instance, producer gas is employed hot, it contains all the moisture of the coal. Experience has shown that, on changing from a coal having 6 to 7 per cent. moisture content to one having 9 to 10 per cent., there was a marked change in the behaviour of the bath of an open-hearth furnace. The authors greatly appreciate those metallurgists who, in abandoning the perhaps illusory advantage of the conservation of the sensible heat of the gas leaving the producer, cool the gas, thus condensing the maximum amount of the water vapour which it contains.

It is worth emphasising that the water vapour of the fuel has a different effect from that of the water formed by combustion. As the authors have always been led to make these observations in the case of the open-hearth furnace, the reason for this distinction may reside in the fact that the current of gas is projected violently against the bath, and the contact of the water vapour of the gas is more intense than that of the vapour formed during combustion and disseminated in the mass of burnt gas, the contact of which with the bath is relatively very slight.

Schuz and Stotz, in their work "Malleable Iron," indicate that the reaction $Fe + H_2O = FeO + H_2$ takes place in contact with the molten iron. This view confirms those now postulated for a different alloy from steel, and may invalidate the conclusions made in a recent article in "The Foundry," stating that moisture has no effect on the working of the cupola. It is true that the author of the article cited merely draws up a thermal balance sheet and does not deal with the influence of oxidation.

Impurities Absorbed during Melting

Combustion actually takes place in the vicinity of the metal and produces near the latter either solid, liquid or gaseous entities capable of being absorbed—the carbon and sulphur of the coke, hydrogen, carbon monoxide, carbon dioxide, nitrogen and hydrocarbons. It cannot be said that any metal is protected from such absorption. Good examples are afforded by steel, cast iron, copper and its alloys and aluminium. In this connection, it may be mentioned that prior work conducted under the direction of Mr. Moressée, President of the Belgian Foundrymen's Association, has provided information concerning the occluded gases of different types of steel and that this work is being continued on cast iron. The results will be published shortly.

As a matter of general interest the following may be cited from some literature on aluminium:—

"Gases may be classified in decreasing order of solubility in aluminium as follows:—Hydrogen, town's gas, methane, carbon dioxide, oxygen, carbon monoxide, nitrogen. At melting temperatures (700 to 800 deg. C.) the first three of these gases, and hydrogen in particular, are to be feared the most. Radiographic tests have shown that water vapour formed in a damp mould in contact with the molten metal reacts on the latter and gives up hydrogen to it, this being effected with considerable facility due to the fact that the vapour is momentarily under pressure. It is reported that aluminium has been caused to absorb 200 per cent. of its volume in hydrogen by passing water or hydrogen through it."

In this reference, there is again apparent the influence of water which is similar in the case of aluminium to that mentioned by Schuz for malleable iron. The reaction involved is:—

$$Al_2 + 3H_2O = Al_2O_3 + 3H_2$$

The dissolved gases are generally contained in the fuel or are the products of incomplete reaction. Their contact with the metal should be reduced to a minimum, whence the advantage of rapid melting, and as their solution is a function of the temperature, the latter should likewise be limited.

Rapid melting may be effected by a multiple and judicious distribution of the fuel and air in order to increase the surface of contact, or by employing fluids under high pressure in the form of thin streams, or by preheating one of the fluids, or again by selecting a fuel having the maximum speed of flame. The following figures for the speed of flame are taken from Le

Chatelier's "Leçons sur le carbone, la combustion, les lois chimiques":—

$CO + \frac{1}{2} O_2$ ..	.. 6 ft. per sec.	Maximum speeds.
$H_2 + \frac{1}{2} O_2$	.. 66 ft. per sec.	
$C_2H_2 + 3 O_2$	..660 ft. per sec.	
CH_4 ..	..12 to 15 ft. per sec.	

A well-known furnace designer has kindly supplied the following additional figures:—

	Speed of Flame.
Blast-furnace gas	18 to 33 ft. per sec.
Producer gas	27 ,, 50 ,, ,,
Water gas	53 ,, 73 ,, ,,
Town's gas	37 ,, 53 ,, ,,
Natural gas	27 ,, 40 ,, ,,

The variations in the speed of flame of this latter list of figures is explained by the fact that the individual gases vary widely in composition. These variations ought to be taken into consideration as is shown by the following example:—

Coke-oven gas has been investigated and it has been concluded that a content of 47 to 48 per cent. of hydrogen can in no way be compared advantageously from the point of view of the operation of an open-hearth furnace and the quality of steel with a content of 55 per cent. of hydrogen. It has been pointed out on a previous occasion that, with this latter percentage of hydrogen, operators have obtained carbon steels which were very particularly resistant to shock and which possessed the feature of coming within the fine grain category of the A.S.T.M. classification.

The melter ought therefore to take note of the atmosphere of his furnaces and endeavour to become better acquainted with the influence of each of its elements. It should be pointed out that the protection afforded by the crucible is by no means complete, because the latter is more or less porous, and intensified melting brought about by forcing the combustion through an increase in the volume of air and in the pressure between the crucible and furnace may cause air or furnace gases to pass through the wall of the crucible, resulting in contamination of the metal.

Occluded Gases

The metal will thus become contaminated whilst melting. It will oxidise by virtue of the general law governing the solution of an oxide in its metal, and it will absorb gases in various proportions. These gases will remain partly dissolved or occluded in the casting or ingot after it has cooled. Are these oxides and gases dangerous?

At the commencement of this Paper the authors recalled the harmful influence of oxygen on the mechanical properties of steel and copper. The influence of nitrogen is also well known. In steel it exists either in the free state in the blowholes or occluded in the metal, or in the state of nitrides. Tchischewski's investigations show the influence of increasing nitrogen content, which in varying from 0 to 0.15 per cent. increases the tensile strength from 28 to 50 tons per sq. in. and reduces the elongation from 37-38 to 3-4 per cent. In malleable iron, on the contrary, according to Wüst, nitrogen has no effect at all.

Dissolved hydrogen is retained in steel after cooling, and seriously affects the capacity for deformation. It is liberated by prolonged heating at a low temperature. Schuz states that "hydrogen is very easily absorbed by molten iron, but it is also easily liberated. It does not appear to have any influence on the properties of the finished castings." It must be pointed out, however, that in the periods of heating and cooling during the annealing operation, the castings are in the necessary conditions for the removal of gas from the steel, and the eventual elimination of hydrogen will be complete.

Gas Content of Grey Iron

According to Perry, grey iron when heated for 165 hrs.—the abstract of the article in the authors' possession does not state the temperature—gives off 205 times its volume of hydrogen and 135 times its volume of carbon monoxide. They do not know of any Papers giving the figures for the mechanical properties of this alloy before and after the removal of gas.

In an endeavour to summarise the subject, however, the following facts may be correlated as follows:

(1) Specimens of rolled steel improve in course of time at the ordinary temperature. They tend towards the figures for elongation and reduction in area given by a degasification process.

(2) Degasification at 100 deg. C. requires 24 hrs.' heating.

(3) Degasification at 500 deg. C. only requires a few hours (4 to 5).

Is not the first improvement caused by degasification which is slow because it takes place at the ordinary temperature?

On the other hand, the ageing of iron castings improves their value. Is there not a parallel between the two actions, and while knowing that one may be running contrary to accepted opinions—perhaps personal ones—may one not ask what part is played by degasification in the treatment at 600 deg. C. carried out for removing internal stress?

Eilender and Oertil in "Stahl und Eisen" for April 26, 1934, state that occluded hydrogen produces high external tensions.

Influence of Melting Temperature

A high melting temperature promotes reactions and the absorption of various gases.

Schuz, with reference to the air furnace in malleable iron foundry practice, states that unnecessary superheating increases the melting losses and renders the iron too viscous on account of the carbon content. At the same time, the gas and oxide content of the metal increases, and there is a risk of producing "blown" castings. In the case of the rotary furnace, the author states that if the operation is protracted, the carbon burns very rapidly having regard to the high temperature. Much silicon passes into the slag, the bath becomes charged with oxides and gas, and the iron acquires a poor flowing power.

In the aluminium foundry, it is advisable to limit the temperature as much as possible, and in steel melting, the opinion of the advantage of a light ladle skull, indicating a temperature that is not too high, appears to be accepted.

The very praiseworthy British Exchange Paper presented by H. H. Shepherd at Paris states that for obtaining good results when employing steel in charges for malleable iron, the melting conditions should be well controlled to produce a superheated metal without excessive oxidation. This leads to the belief that Mr. Shepherd agrees as to an increase of oxidation with increasing temperature. In the section dealing with the effects of superheating, however, he states that in general the solubility of gases diminishes when the temperature "rises." It would be interesting to have this point settled during the course of the London Congress.

The effects of superheating acting on the refinement of the structure have been investigated by the various authors cited by Shepherd. This superheating, however, is carried out beneath a slag in rotary and electric furnaces which, as stated by this author, afford protection from oxidation much more easily than does the cupola. The foregoing emphasises sufficiently the fact that the foundryman should have a clear opinion of the melting temperature, which he must not confuse with the pouring temperature, since there may be a certain difference between the two.

Pouring Temperatures

This is the opinion recapitulated by Lee in "The Foundry" for December, 1938. "Pouring temperatures are being studied and some shops have arrived at what they consider the proper temperature for special jobs. There should be every reason to consider this factor, as it is quite important in other fields, such as casting and rolling of steel, brass and other non-ferrous alloys."

The problem may become complicated on account of the fortunate influence of a high temperature in giving rise to occurrences of a different nature from that referred to in the foregoing. There is no need to point out to grey-iron founders the influence of superheating in refining the graphite. Among others, British metallurgists have contributed largely and very effectively to the study of this question, which cannot be developed in the scope of this rapid summary. It would be impossible to give anything like a concise idea in a few lines.

Finishing Additions

Reference has been made to the more or less considerable degree of purity of the materials employed and also the different causes of contamination and transformation, which are rarely favourable and are unfavourable in most cases, during melting. At the end of the operation, the foundryman is still able to effect the protection and cleaning of the molten bath. He can consider the final purifying additions usually made in the case of steel and non-ferrous metals. He can make use of the influence of appropriate slags, which have long been employed in the case of steel, which are in the course of development in the case of cast iron and are employed in the form of flux in the case of non-ferrous metals. Here, again, the authors can only touch lightly upon and emphasise the essentially scientific character of this last aspect of the problem confronting the foundryman.

This modest contribution to the correlation of the ideas of the foundryman can best be concluded by the wish that efforts will be continued on the lines indicated at Warsaw, and that the science of the foundryman in general will be established on a common basis, regardless of the metal or alloy under consideration. The authors believe that the principles are the same and that it is to the great advantage of everyone, in his own particular case, making mistakes through ignorance and only applying a part of such principles, to become acquainted with the results attained and the efforts made in branches of metallurgy other than his own.

DISCUSSION

The report was presented in abstract by Mr. J. Léonard (Past President of the International Committee of Foundry Technical Associations) who said that the Report resulted from a suggestion by his French colleagues at the Warsaw Congress, and constituted a modest addition to the study of alloys. There were certain general principles which must be regarded as applicable to all foundry work, and those principles might have to be adjusted in one direction or the other according to the peculiarities of a particular metal that was being dealt with. The Report did not pretend to present original experimental results; it was a work of collation of daily workshop practice, and its object was to bring some

sort of order into the inferences which might be drawn from that daily practice.

COMMUNICATION

Mr. H. H. Shepherd, in a written communication, observed that he had read the Paper with a great deal of interest, and very much valued the appreciative statements made in this Paper with regard to the British Exchange Paper which he had presented to the International Foundry Congress held in Paris during 1937.

The English translation of that part of the Belgian Paper which referred to the writer's review of malleable melting practice stated, "This leads to the belief that Mr. Shepherd agrees as to an increase of oxidation with increasing temperature." This was not quite his view.

Increasing temperature did not, in his experience, necessarily give rise to increased oxidation. The extent of oxidation depended largely on the type of melting medium, and more particularly on the possible and actual extent of control. When he was writing on the melting of steel scrap charges in connection with oxidation, he had in mind cupola practice, which was not subject to careful control, and in this case super-heating could easily result in excessive oxidation. On the other hand, it was the writer's view that super-heating could be achieved, and particularly with certain types of melting media such as the electric furnace, without excessive oxidation.

Table A.—*Gas Content of Superheated Grey Cast Iron as Determined by the Vacuum Fusion Method (from the Paper by Di Giulio and White).*

Heat No.	Super-heating temperature. Deg. F.	Oxygen. Per cent.	Hydrogen. Per cent.	Nitrogen. Per cent.
1	2,570	0.0097	0.00008	0.0033
2	2,730	0.0057	0.0001	0.0057
3	2,855	0.0076	0.0001	0.0073
4	3,035	0.0058	0.00003	0.0056
5	3,085	0.0041	0.00015	0.0011
6	3,110	0.0033	0.00008	0.0026

The translation of the Belgian Paper also gave the following: "He states that in general the solubility of gases diminishes when the temperature 'rises.' It would be interesting to have this point settled during the course of the London Congress."

In support of the view which the writer expressed as above, he would quote from a Paper by A. Di Giulio and A. E. White, "Factors affecting the Structure and Properties of Grey Cast Iron" (A.F.A. Preprint No. 35-9): "P. Bardenheuer believes with Piwowarsky that a further important effect of super-heating is the elimination of gases, which makes a denser structure possible." Later in the same Paper under the sub-heading "Investigation of the Gas Content of Superheated Cast Iron" it is stated:—

> "The results of this investigation are given in Table IV. Unfortunately, the results obtained do not show any possible correlation with the preceding findings. Close examination of Table IV [Table A] will show the following facts to be true:
>
> "(1) Hydrogen and nitrogen contents of the superheated irons do not seem to vary in accordance with any law.
>
> "(2) Oxygen content decreases with an increase in superheating temperature.
>
> "This latter fact is in agreement with expectations, since it has been proved that, in general, the solubility of gases in metals decreases as the temperature increases."

The writer would submit that the above information, which was claimed to be supported by E. Piwowarsky and P. Bardenheuer, corroborated the statements which he made in the Paper to which the Belgian Association had made reference, and it was hoped that this would clear up the points in question. At the same time, the writer would be pleased to have further observations.

Mr. Léonard's Reply

In a reply by Mr. J. Léonard, on behalf of the Technical Committee of the Belgian Association, it was stated that two questions were asked: (1) Did an increase in temperature bring about a stronger oxidation? and (2) did the volume of dissolved gas vary in the same sense as the melting temperature?

The first question was best answered by pointing out that this factor should only be determined if all other conditions were equal. To compare the results obtained in different furnaces did not appear to be desirable. The opinion was maintained that excessive oxidation was brought about by superheating, in the case of cupola melting. The reply, however, did not remain indecisive, and in any given furnace melting in an atmosphere of constant composition, one could without equivocation state that oxidation increased with the temperature, the atmosphere being obviously oxidising.

So far as the second question was concerned, it might be asked whether the figures tabulated by Di Giulio and A. E. White were convincing. The Belgian Association, like Mr. Shepherd, were sceptical of the reliability of the hydrogen and nitrogen figures, because the irregularities shown permitted of the supposition of analytical errors, due either to manipulation or method used. The close agreement of the oxygen con-

tents was impressive, in spite of the low figure of 0.0057 corresponding to a temperature of 1,500 deg. C. However, it should be noted that in the temperature interval of 258 deg. C. (from 1,410 to 1,668 deg. C.), it seemed permissible to speak of a lowering of the oxygen content. The two low contents gave the clear impression of a diminution when related to two adjacent temperatures (1,696 to 1,710 deg. C.).

The only conclusion it was thought possible to be drawn from these six results was that, at about 1,675 deg. C., the O_2 content remained practically constant, and that above this temperature there was a sharp drop. The results of Di Giulio and White should be considered as relating to an iron carried to a single superheating temperature but cast at different temperatures. It was thus not the influence of superheating but rather the effect of casting temperature that was thrown into relief.

On the other hand, so far as the O_2, H_2 and N_2, and the CO and CO_2 gases were concerned, it might be asked whether they were encountered in cast iron. The writer had noted with interest the evolution of their contents, for it was not impossible that, at very high temperatures, the affinity of oxygen for carbon might not be preponderating in relationship to that of O_2 for the other elements, Si, Mn, of the iron and that, in spite of the feeble mass of the O_2 being able to render this passive in a very large measure, a reaction of the C with the oxygen did not lower the volume occluded with the latter, but in replacing it by a volume of CO_2 or 2 volumes of CO.

The above was evidently not favourable to an increase of volume in which credence was placed; however, one could not ignore these opinions of pinholes and blowholes coming from the metal and placed against the action of superheating.

The writer was pleased with the decision of the International Committee of Foundry Technical Associations to place the question of gases dissolved in alloys on the programme for the Italian Congress in 1940. It now only remained for the writer to thank Mr. Shepherd for having started the discussion. It was well worthy of considerable expansion next year in Rome.

Paper No. 694

Defects in Electrically-Melted Chilled Rolls*

By Dr. Ing. FRANCO BONDI

For various reasons, the casting of chilled rolls melted in the electric furnace is certainly neither common nor widespread. The most obvious of these reasons is economic in character, in view of the appreciable cost of erection and operation which this excellent method of melting involves in most countries. At the Acciaierie e Ferriere Lombarde Falck of Milan, particularly favourable conditions have made it possible first to carry out experiments and then to cast normally chilled rolls melted in the electric furnace.

The advantages offered by this method of melting are very important and certainly superior to the previous methods. The outstanding advantage is the possibility of maintaining unvarying composition which is always controllable during the operation, either by chemical analysis or by testing the variations of the hardness of bath samples.

This control also ensures perfect homogeneity of the bath, a very important matter when a number of rolls of the same type have to be cast from the same melt. Carbon, manganese, silicon and phosphorus are constant and similar from roll to roll. There is also the advantage of rapid melting and rapid working-down, so that in a 3-ton furnace it is possible to prepare a melt in three or four hours, including the charging time.

It enables a considerable percentage of steel to be incorporated without giving rise to any difficulties during melting. Another important advantage is the control of the temperature in the various stages of melting, thus permitting rapid melting at high temperatures of the different sorts of scrap contained in the charge, whilst fresh pig, expensive and easily liquefied, may be melted in a bath already prepared by charging the pig at a second stage without subjecting it excessively to the severity of the high temperature of the arc.

Further advantages are the exceptional ease whereby samples can be taken at any stage of melting, and the facility whereby it is possible to make corrections, by reason of the structural nature of the electric furnace. A disadvantage —which, however, is not always confirmed—is certainly to be found in the pressure and high temperature attained in the vicinity of the electric arc. This appears to have the disadvantageous effect of destroying the particular qualities of the special irons which make up the charge, or "burning" them, as is said in foundry jargon.

This phenomenon, which is not always confirmed in practice, would explain certain cases of lack of homogeneity and certain defective rolls found in the machine shop and rolling mill, on account of brittle material. Occurrences of this kind can nearly always be avoided by cautious and prudent operation of the furnace, but it is certain that melts carried out in direct arc furnaces of the Héroult type, and in arc resistance furnaces of the Bassanese type, have shown that the latter type is more suitable and rational, also on account of the lower heat to which the essential constituent elements of the metal, particularly the silicon, are subjected. A type of furnace which the author has not tried for melts of this kind, but which ought to give good results, is the indirect arc or radiant type recently adopted in foundry practice.

The melting operation does not offer any appreciable difficulties, and the metallurgical operations succeed one another much more simply and smoothly with regard to the steel incorporated in the charge.

The charges, which are selected and prearranged, are made by first introducing the scrap and steel, if any, whilst the pig is charged later into the molten bath. It is thus possible to apply the maximum power initially, thus appreciably gaining time in melting. A lightly-carburised lime slag is maintained on the molten bath.

When the slag is formed, samples are taken, the current being reduced to about half the original amperage, so that the bath is maintained at a temperature between 1,250 and 1,300 deg. C. This very important control is effected by continuous observation of the temperature by means of an optical pyrometer. Any rise in temperature is corrected by switching off the current and spreading fluorspar on the slag. The hardness is then checked, any irregularities being corrected by the addition of ferro-silicon and special pig.

* Presented on behalf of Federazione Nazionale Fascista degli Industriali Metallurgici.

If the bath will not take the addition of ferro-silicon on account of the presence of a slag which is too basic, the slag is entirely renewed and the trouble will then disappear. As a rule, only two or three samples have to be taken for bringing the melt into condition, the laboratory ascertaining in the meantime the variations in the carbon, silicon and manganese. When these three elements and the chill test are in agreement and the temperature is satisfactory, the charge is ready for pouring. This is usually carried out by means of a bottom-pouring ladle, which has the great advantage of eliminating any danger of slag inclusions, the only precaution taken being to employ a very large nozzle of 50 to 60 mm. (2 to 2.4 in.), and sometimes even 70 mm. ($2\frac{3}{4}$ in.), according to the diameter of the roll, so that pouring will be very rapid.

The pouring temperature is accurately controlled either by means of optical instruments or by means of appropriate technical devices, and is maintained between the limits of 1,150 and 1,190 deg. C. The average power consumption per metric ton is about 750 kw.-hrs. The bath samples are 190 by 135 by 22 mm. (7.5 by 5.25 by 0.8 in.), cast in dry loam placed on an iron plate. The moulding of these rolls does not offer any special features, except that the greatest care is taken in designing the moulding boxes, so as to facilitate the accurate assembling of the pouring gates and chills and the rapid removal of the gases from the mould.

Having outlined the melting processes, it is now proposed to discuss the general defects which have been encountered in the course of several years of production. These defects, although not peculiar to electric-furnace melting, are those which have been more especially encountered when employing this method. Generally speaking, it must be said that rolls are never cast with a greater body-length than 1,400 mm. (4 ft. 7 in.) nor a diameter exceeding 560 mm. (22 in.) (see Figs. 1 and 2).

These defects may be set out as follow:—(1) Explosions during pouring; (2) cracking; (3) cavities and surface flaws; (4) brittle necks, and (5) eccentricity and variation in hardness.

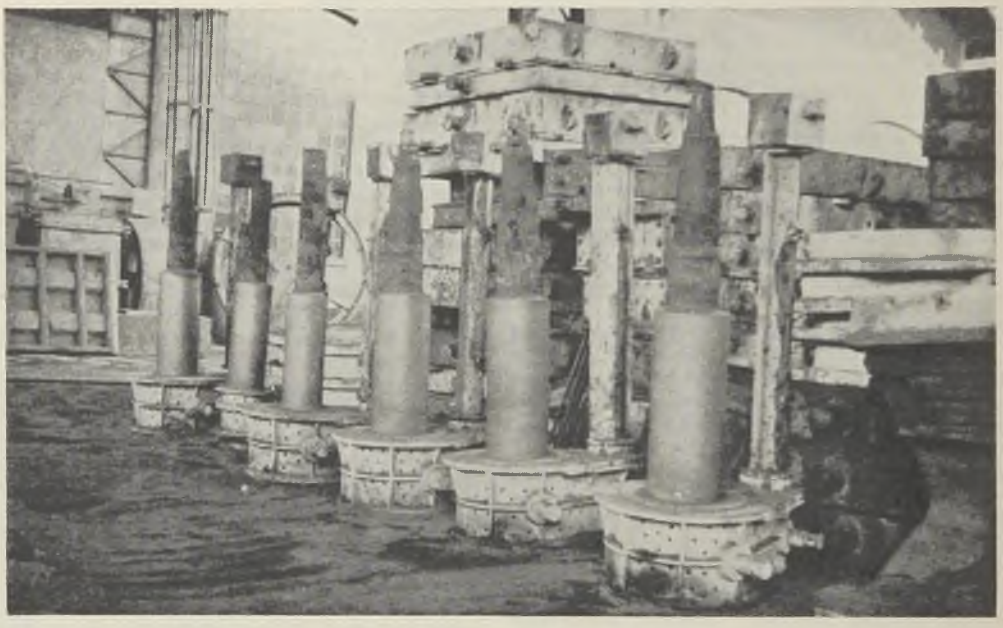

Fig. 1.

It is proposed to consider what are the real and probable causes of each of them and how it is possible to provide a remedy for ensuring the production of sound castings in this difficult branch of foundry practice—an endeavour which requires all the art of the foundryman, who is confronted with multiple and various factors which are not always clearly identifiable.

EXPLOSIONS DURING POURING

This occurrence, fortunately not very common in a well-conducted shop, is very harmful and dangerous, and always takes place at the com-

mencement of pouring, when the iron has filled only the lower neck of the roll or a little more. At this moment, one or more explosions project the molten iron from the pouring gate with such violence that the iron is thrown to a height of several yards. This phenomenon sometimes occurs when the mould is completely full, when it produces ferrostatic pressure in the metal. In this case it is less violent, and is accompanied simply by bubbling on the surface of the metal in the pouring gate and less violent spurting of the metal.

When this takes place, it is useless to continue pouring. In nine cases out of ten, it is certain that the roll will be defective. In fact, after stripping, the roll exhibits numerous blackened surface flaws to a depth of up to several millimetres which congregate more especially along the lower third part of the roll. Some of these flaws are situated at a considerable depth below the surface, so that even if the first blistered layer is removed by turning, the defect is not eliminated and the roll has to be rejected.

The defect is caused by the difficulty of rapidly eliminating the gas from the mould and sometimes from the coating of blacking on the chill, either through the loam by virtue of its natural perviousness and the means provided for promoting the latter, or through the surface of contact between the loam and the chill. The iron entering the loam mould of the neck, and rapidly filling it, may produce a violent liberation of gas. In the majority of cases it is water vapour, which not finding an easy exit through the mould, because the metal has already arrived at the chill, endeavours on account of its sudden increase in volume to seek a rapid exit through the molten iron, carrying the latter along and projecting it to the exterior.

Causes. (1) Insufficiently permeable loam; (2) insufficient venting, not exactly conforming with predetermined arrangements; (3) blacking contains too much volatile matter; (4) insufficient drying; (5) irrational cooling devices for the necks not permitting satisfactory ventilation of the lower boxes, and (6) chills not hot enough.

Remedies.—Accurate control of the moulding loam which should possess the optimum properties, failing which its use should not be permitted. Close consideration of the venting system for the removal of gas either through the mould, or through the box, in which numerous suitable holes should be provided, or through the joints between the mould and chill. Meticulous and careful consideration of this important part of the preparation of a roll can never be over-emphasised, and experience alone, in reference to the type of roll cast in each case, will indicate the correct steps to be taken.

With regard to blacking which contains an excessive amount of volatile matter, every foundryman will be familiar with the harm which this may cause. In this special case, therefore, the greatest attention should be paid to the quality of this material. Generally speaking, the amount of volatile matter should not exceed 1.5 per cent. of the principal ingredient employed, usually graphite.

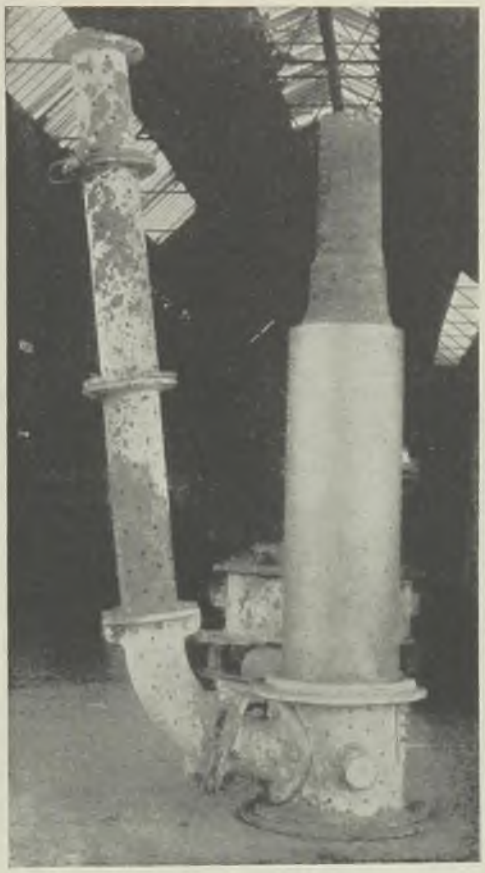

Fig. 2.

Passing to the question of insufficient drying, the author would emphasise the more important factor of these defects, since even if all the other precautions are taken, they are vitiated by the presence of even a very small amount of moisture in the mould. It is necessary not only to control the temperature of the drying stove and the time of drying, but the stove should also be rationally constructed to permit replenishing of the air for removing the vapour. The provision of forced draught effects a saving

in fuel and ensures uniform temperatures. It is preferable to remove the moulds just before pouring, so that they will still be warm at the time this operation is effected. Lastly, it is advisable to provide moulding boxes of such a character that the moisture evaporated when the metal enters the mould cannot collect in them.

Sometimes, because of design and working conditions, the necks have to be particularly dense and compact, and in such a case, apart from special blending and composition of the iron, it is possible to employ chills placed in the mould so that they are covered to a depth of a few millimetres with loam, sufficient to prevent them exerting a direct hardening effect. Of course, this mass of metal is an obstacle to the removal of the gases, and the disadvantage may be lessened by providing numerous vents. If the chills be not sufficiently hot, particularly in winter, moisture may condense on them, and, if not noticed and removed in time, this may have disastrous consequences.

CRACKING

This defect is one of the commonest and most feared in the production of rolls. The cracks appear in a wide variety of forms, longitudinal and transverse, and may extend over the entire length of the body of the roll or only over a part, on the edges and centre and finally on the necks (Figs. 3 and 4).

The causes are numerous and often not very clear, but, generally speaking, they may be classified as follow:—(1) Moulding defects; (2) defective pouring; and (3) metal of unsuitable composition.

Moulding Defects

A common cause is the joints between boxes and chills being inadequately sealed. The iron enters the interstices formed and produces a small fin sufficient to cause horizontal cracks due to irregular shrinkage (Fig. 4). Cracks may also be formed along the joint between two chills, due to the joint being insufficiently tight, and to the more intense cooling along this line, or else because of the temperature of the two parts not being the same, and resulting in different rates of cooling in the two sections of the roll.

These defects may be obviated by sealing well all the joints either between the chills and the loam or between the chills, and by taking care to see that the latter are at the same temperature prior to pouring.

Blacking may not be correlated with the cooling effect required from the chills, or be properly applied. With reference to the first case, blacking should have an insulating effect, *i.e.*, in addition to preventing the iron from sticking to the face of the chill, and to providing the casting with a fine surface, the blacking should principally also regulate the rate of formation of the hardened layer, so that the latter is not completely solidified at the moment

Fig. 3.

shrinkage commences, and the inner grey iron sets, producing very high pressures on its expansion. If the chilled layer is still in a condition of relative plasticity, it will "give" to some extent without rupturing, and the surface will remain sound, but if on the contrary it is already solid, it cannot yield and will crack, as is often the case.

The observation and study of this delicate and important factor has led the author to turn his attention to this last circumstance in an attempt to impart to the blacking the quality which will combine its insulating property with that of producing a good surface. Normally, in fact, it is usual to provide the previously-heated chills with one or more coatings of a mixture composed mainly of graphite and bonding materials. Experience has resulted in the creation of a mixture of insulating material, which is highly refractory (above 1,700 deg. C.), made up of best plastic clay mixed with graphite in definite proportions.

This mixture is applied to the chills with the maximum uniformity and with the desired thickness by means of compressed-air spray guns, the chills being maintained at an elevated temperature (300 deg. C.), so that the sprayed mixture dries instantly. The thickness of the coating produced may be so regulated as to insulate more the parts which are longer in contact with the cast metal, thus attaining the desired uniformity of cooling. In this way, the formation of cracks on the body of the rolls is almost completely avoided, and rolls of very fine appearance are produced (Figs. 1 and 2).

Cracks on the necks, generally the upper one, are attributable more to defective design than to moulding defects Such cracks, in fact, occur if definite conditions of proportion in the junction with the body are not observed, in accordance with the requirement that this junction should be very gradual. Insufficiently rammed zones in the mould may also produce swellings on the neck, which has shrunk differently from the body of the roll, giving rise to cracks.

Improper Pouring Conditions

A contributory factor in this case is badly-designed pouring gates, that is to say, too small to fill the mould at the desired rate. In this case, as the formation of the chilled layer is not homogeneous, vertical fissures are formed on account of the different effect which the pressure of the iron produces in the interior of the first chill, due to the weight of the iron, and also due to the increase in volume caused by the precipitation of graphite.

In this case, it is necessary to increase the diameter of the gates, so that the layer skin is formed practically at the same time throughout the entire height of the body of the roll and thus reacts uniformly to the internal stresses. This disadvantage occurs solely in rolls of small dimensions.

Moulds not Perfectly Vertical.—In this case, it is likely that vertical cracks will be formed in the lower part of the roll, along the generatrix which is most out of the vertical.

Excessively Slow Pouring.—An essential principle of the production of these castings is that they should always be poured rather quickly, because this ensures the ideal conditions for uniform cooling.

Fig. 4.

Excessively Hot Pouring.—It is necessary to pour rather cold at a temperature between 1,150 and 1,190 deg. C. The accurate control of this is indispensable, whatever be the method adopted. Pouring as cold and as rapidly as possible is the best guarantee of a good result.

Composition of the Metal

In the electric furnace, the composition of the charge is not of essential importance in regard to cracking, provided certain precautions con-

cerning the rise in temperature are observed, as emphasised at the commencement of this Paper. The only really dangerous element is the manganese, of which it is preferable to maintain a content of not greater than 0.40 per cent. Practical observations in numerous cases have shown that if this figure be exceeded, the increase in rigidity which this element imparts to the iron, especially in the chilled zone, may cause cracking.

CAVITIES AND SURFACE FLAWS

The name describes these flaws. They are generally small cavities with an oxidised surface, having a diameter not exceeding several millimetres and a depth which may attain as much as several centimetres. The most dangerous are those designated "pinholing," which, although they may be of small diameter, extend to a considerable depth, so that when the roll is turned on the lathe, the cavities do not disappear, leaving to some extent a trace which, however small, causes the rejection of the roll.

The causes are almost always attributable to defective moulds and rarely to defects of the metal, since in the electric furnace the phosphorus content is always certain to be below 0.10 per cent., thus safeguarding against any liquation of phosphide eutectic.

They may be:—Impermeable loam; insufficient or badly arranged venting; insufficient drying; badly distributed blacking; insufficient blacking; pouring gates too small; pouring temperature too high; chills too cold, in poor condition and insufficiently polished or cleaned.

The remedies are immediately suggested by these causes. Impermeable loam, by retarding the escape of gas at the moment of pouring, causes the formation of bubbles which sometimes merely settle on the lower surfaces of the chills, while at other times, as has been noted, they produce explosions with much more serious consequences. Inadequate venting may also have the same result. In both cases, close control in the preparation of the loam and moulding obviates all these disadvantages.

Insufficient drying, as is natural, produces conditions which favour defects. This has been emphasised and its more serious consequences discussed when referring to the explosions which occur during pouring.

Badly distributed blacking, especially on the lower portion of the chills, where the incoming hot metal impinges most strongly, may give rise to this defect. If there is insufficient blacking, the latter does not afford enough protection, the metal is partly attacked and there is erosion with the formation of characteristic pinhole defect. If the blacking is too abundant, it is carried by the flow of metal towards the upper part of the roll body, leaving a characteristic spiral trace following the gyratory movement of the iron in the form of striations, along which the excess of graphite is deposited, and numerous small blisters which, however, are generally of little importance (Fig. 4). The correct thickness will be determined by experiment in each particular case, in accordance with the mass and dimensions of the rolls.

The importance of the composition of the blacking should not be overlooked. Excess of graphite, inadequate organic binder or too much clay are also causes of defects. In point of fact, much graphite, especially if not of good quality, causes an evolution of gas which cannot always be eliminated and is the principal cause of pitting. The same applies to organic binders.

In the case of rolls having a rather high silicon content, when there is an excess of clay in the blacking, silicates are formed during pouring with the evolution of gas which remains imprisoned in the skin of the roll. It is possible to produce the best blacking while dispensing completely with organic binders, such as dextrin, molasses, starch, etc. Organic binders may be replaced by inorganic binders, such as refractory clay or bentonites suspended in Na_2SiO_4, without diminishing the adhesive and insulating properties, but on the contrary improving them in some respects. Everything depends upon the correct proportion between clay and graphite and upon the correct preparation. The best practice is to allow the mixture to stand for some days before it is filtered and used.

Gates of excessively small diameter, resulting in the lower parts being heated to a greater extent, may produce erosion and cavities. The same applies to a greater extent when the pouring temperature is too high. The effect of the above two causes is still greater when the chill, through long use, has in part peeled or become otherwise defective, because at these points erosion will be more marked and the iron will attack the walls.

It is advisable, therefore, to insist that the chill is in a perfect condition before applying the blacking. Any defects which are not serious may be repaired with cements, or if they are more extensive by means of electric welding, the surface being afterwards smoothed with a portable grinding wheel. It is thus possible to extend the life of a chill by several castings.

Another rather important factor to be observed is that the inner surface of the chill should be completely free from oxide which, even if covered with blacking, will generate gas in some form. For this purpose, thorough treatment with a portable grinding wheel and a rotary steel brush will afford the maximum guarantee, at the same time dispensing with the tedious method formerly employed, in which the

whole of the inner surface was treated manually with a piece of an old emery grinding wheel.

BRITTLE NECKS

This condition arises when the iron is not compact, but includes graphitic patches—a condition ill-adapted to resist wear during rolling and liable to break under load. The cause of this defect may almost always be attributed to an excessively high carbon content. The defect tends to disappear when the carbon content is 3.2 to 3.4 per cent. and appears upon an increase in these values. Sometimes, owing to particular requirements dependent upon the dimensions of the roll, that is to say the ratio of the diameter of the body to the diameter of the neck, it is necessary to have a carbon content higher than 3.6 per cent. in order that the passage from the chilled zone to the grey zone will be more pronounced.

The danger of brittle necks is then obviated by placing in the mould, as previously mentioned, iron chills of suitable thickness for densening the surface of the necks. Of course, in order to prevent the latter from being chilled, the chills should be covered with an adequate layer of loam.

Another means which is readily available when the electric furnace is used would be that of superheating the iron (1,550 deg. C.), so that the graphite would tend to dissolve completely, thereby increasing the compactness and improving the mechanical properties. There are not yet sufficient data, however, for recommending this method, which is in the experimental stage, especially as there is reason to believe that if the temperature is increased, the arc tends to graphitise the carbon, rendering it less suitable for combining with the iron.

ECCENTRICITY AND VARIATION IN HARDNESS

In this case, the depth of the chill varies from one point to another, or from one end of the body of the roll to the other, the difference being more marked, the greater the length of the roll. The defect is particularly troublesome because during the turning of rolls intended to be grooved, there is a possibility of the rolls being rejected owing to lack of homogeneity of the chill layer. The causes may be the following:—

Excessively slow pouring which, especially in the case of rolls having a long body, causes the lower part of the chill to be hotter than the upper part, the hardening effect varying between the two ends causing differences in the depth of hardness.

A chill (densener) which is not homogeneous in density, that is to say which, owing to melting defects, such as cavities, porosity or the like, has discontinuities in its mass, will not act uniformly in chilling the molten metal, the latter being hardened more where the chill is more compact than where it is less compact.

Badly distributed blacking with excessive thickness varying from point to point is another cause. In this case the remedies are obvious:—Rapid pouring, employing two pouring gates where necessary. Any defective chills should be removed at once and repaired by building up, or, if this be impossible, they should be scrapped.

At this point it will be appropriate to interpose that the maximum importance should be given to iron from which the chills are cast, which should be very dense and as low as possible in silicon and phosphorus.

The greatest attention should be paid to the distribution of the insulating blacking, a matter which cannot be over-emphasised, since it has been noted that this is the cause not only of the defect at present under discussion, but of numerous other defects.

With this brief, unpretentious account, dictated solely by practice and observations in the foundry, the author has rapidly reviewed the principal defects which confront the foundryman producing chilled rolls, with special reference to rolls produced from iron melted in the electric furnace.

DISCUSSION

The Chairman (Major Miles) remarked that, due to the fuel position, and for other reasons, the electric furnace was more extensively used in Italy than was the case in this country, for what one would regard as a cheaper range of products.

The Explosion Mystery

Mr. F. J. Cook (Past-President of the Institute of British Foundrymen) said one of the outstanding points of the Paper for the ordinary foundryman was the prominence given to explosions during pourings. Although explosions did happen, they were not of such frequency as to be mentioned in a Paper. Was it to be understood that for some reason, electrically-melted iron was more prone to explosions than ordinary furnace-melted iron? If so, to what was it attributed, because in a properly poured mould one would not expect to have a greater amount of explosions than under ordinary furnace conditions?

Was there some quality of electrically-melted iron that caused those explosions?

Dr. Bondi replied there was no particular condition, but it was dependent on the proper preparation of the mould. Iron melted in an electric furnace could be melted at the exact temperature required. One could get superheated iron, but for pouring one had to wait until it was in proper condition.

Pouring Temperatures

Mr. J. Roxburgh (Sheffield) complimented Dr. Bondi on his Paper and thanked him for bringing the subject before them. He had given a temperature of from 1,150 to 1,190 deg. C. for casting the rolls described. That was quite different from English temperatures, which ranged from about 1,230 to 1,270 deg. C. The former range seemed to be a very low casting temperature. Another point of interest was the question of running, and he would like to know the relation of the cross-sectional area of the ingate to that of the downgate, which of course really governed the speed of running.

Another important point was the blacking used, which Dr. Bondi said should be applied to the chills with the maximum uniformity. Could he indicate the actual thickness of the blacking which was applied? On that subject, too, there was a further point. Dr. Bondi said that when applying the blacking the chills were at a temperature of 300 deg. C. That seemed rather a high temperature at which to apply the blacking, as he personally would be afraid of boiling, and difficulty in making the blacking adhere to the chill.

With regard to the composition of the chills, what material was used? Dr. Bondi had said it should be very dense and as low as possible in silicon and phosphorus. Could he say what material was actually used? Could he tell them the sulphur content of the iron from the electric furnace used for the chilled rolls?

Finally, what control was imposed to ascertain the depth of chill shown by the chill test? Did he get much loss from the chill test to the actual casting?

Low Casting Temperatures

Dr. Bondi, in reply, said the temperature of pouring with an electric furnace was a matter of practice. The temperature of 1,190 deg. C. or a maximum of 1,200 deg. C. was what they used for their chilled rolls because they found that pouring at higher temperatures caused many difficulties through the rolls cracking and from pinholes.

As to blacking thickness, they applied it with a spray gun. They used not only a trade blacking with sodium silicate, but mixed with it a good quality of high-refractory (about one-third) blacking. They heated the chills up to 300 deg. C. for applying the blacking, because at that temperature it was instantly dried and they could get the right thickness. The layer was about the thickness of an eggshell, and on the underside of the chills about double that thickness. That was to prevent the hot iron running on the chills from attacking it and causing surface trouble.

When melting in an electric furnace, sulphur was of no importance because it could be as low as they wanted. The figures were about 0.012 per cent. or lower if necessary.

As to the differences of the chill test, they allowed for 10 mm. on the chill, which checked up with 5 mm. of contraction and 5 mm. for the cutting of the chill.

Composition and Making of Chills

The chills were made by charging up equal quantities of the chill and a good hematite iron. There was a minimum of manganese (about 0.5 per cent.) and sulphur, whilst the phosphorus was very low; the carbon was about 3 per cent. and the whole was melted by cupola with a silicon content of about 2.5 per cent.

As to the size of runners and gate, these were adjusted in relation to the diameter of the roll. For the little rolls of about 300 to 350 mm. diameter, they used a runner of about 50-mm. section so as to cast rapidly. For a roll of about 500 to 550 mm. diameter and 1,400 mm. they used a runner of about 60 mm. and the nozzle of the ladle was about 50 mm. Such rolls were poured in from 30 to 35 secs. The relation between the runner and the intake and the runner and the neck was about one to three. The runner was circular and the intake was rectangular because it was tangential to the roll.

Influence of Melting Process on Chill

Mr. R. Chavy (Paris) asked if any preparatory experiments were made to see if the depth of the chill was the same for an iron made in the cupola and an iron made in the electric furnace. From his experience it appeared that the chill was deeper when cast iron was melted in the electric furnace.

Dr. Bondi agreed that it was so. With the same compositions they had a chill of about 4 or 5 mm. higher with the electric furnace than with the cupola, and the metal was denser in the chill section than in the core section.

The Chairman (Major Miles) thanked Dr. Bondi for his very interesting Paper which had prompted so full a discussion, and Dr. Vanzetti and the Federazione Nazionale for allowing the Paper to be presented.

Paper No. 695

Laws Governing the Operation of the Cupola*

By Dr.-Ing. MASSIMO BARIGOZZI

The general equation for the cupola, which is attributed to Falk, according to what has been recently stated by Jungbluth,[1 2 3 4] is expressed as follows in the author's notation:

$$\frac{Q\alpha K}{3{,}600} = \frac{V}{M} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where Q is the hourly output of the furnace in quintals (100 kg.) of iron,

K the percentage of coke relative to the iron,

α the carbon content of the coke,

V the blast volume in cubic metres per second.

As a percentage K is to be taken as meaning the *total quantity of coke in kilograms which is burnt in melting 100 kilograms of iron*, of which quantity the *charge percentage* is only a part, even if the greater part.

In fact, there is burnt with the charge coke a part of the "bed" coke, which may or may not be replenished during the melting operation by extra charges of coke, so that in order to determine K it is necessary to obtain the difference between the total coke introduced (charge coke, extra coke, bed coke) and that recovered in dropping the bottom (a deduction being made for the ignition coke, *i.e.*, the coke burnt in front of the tuyeres), or what amounts to the same thing, it is necessary to add to the charge percentage the amount of bed coke and total extra coke corresponding to each 100 kilograms of iron.

Since, as a rough average, this increase in the charge percentage is approximately 15 per cent. it follows that when K is put equal to 10, a charge percentage of 8.5 ÷ 8.7 per cent. is actually considered; a charge percentage of 10 per cent. produces a total percentage of 11.5, and so forth.

This being clear, it may be added that when in what follows the height of the *combustion layer* is calculated, this will not be limited to that of the charge coke, but will also include the portion of the bed coke participating in the combustion.

The significance of M is clear if it is borne in mind that the first member $\frac{Q\,\alpha\,K}{3{,}600}$ is none other than the quantity of carbon burnt per second, and if X″ is the corresponding quantity of coke, it is equal to $\alpha X''$. Hence $M = \frac{V}{\alpha X''}$ that is, M is the specific blast volume per kilogram of carbon burnt.

M is not constant, but varies according to a law which is to be determined. Its value is obviously strictly connected with the performance index i expressed as the ratio between the quantity of CO_2 contained in 1 cub. m. of the waste gases and the sum of $CO_2 + CO$.

This is the general position of the problem of the cupola which leads to equations and diagrams where the variables M or i and the comparisons in general between the various magnitudes are established as functions of $\alpha X''$, that is of the quantity of carbon burnt in unit time, or of αK, that is the quantity of carbon burnt per 100 kilograms of iron.

It is true that this is the only method of attaining results which are strictly scientific and of general application.

Here, however, reference is made to the coke employed in cupolas in Italy where, *on an average*, $\alpha = 0.86$, and the calculations are given on the basis of this *mean value*, that is referring to coke rather than to carbon, so that the diagrams obtained are not strictly accurate, but are a sufficient guide for the operation or design of cupolas.

The series of diagrams to be considered as general, that is referred to the carbon burnt, will be established after completion of the series of tests of really scientific character on cupolas actually in operation, which was decided on by the Federazione Meccanici—Foundry Group, and for which a sum of 100,000 lire has been provided. Referring, therefore, to coke having 0.86 carbon and not to pure carbon, equation (1) becomes:—

$$\frac{QK}{3{,}600} = \frac{V}{m} \quad \text{and} \quad \frac{QK}{3{,}600} = X''$$

where m is the specific blast volume per kilogram *of coke*.

* Presented on behalf of the Federazione Nazionale Fascista degli Industriali Meccanici.

If the theoretical amount of air suffices for combustion, then for a coke containing 0.86 of carbon, like the ordinary metallurgical coke employed in Italian foundry practice, the theoretical blast volume at 18 deg. C. would be $V_t = 4.08\ (1 + i)\ X''$. . . (2). Thus, in an X″, V diagram showing the relationship between the coke burnt and the blast, there would be for each performance index i a straight line starting from the origin:—

$$X'' = \frac{1}{4.08\,(1 + i)}\,V \quad .. \quad .. \quad (3)$$

The blast, however, is always in excess and it is found that up to a certain limit at least, the excess must be increased in order to obtain better performance indices.

Tests carried out in Italy on cupolas with a coke having $\alpha = 0.86$ and normal reactivity show the following:—Referring to the square metre of furnace, for each value of X″ or V, the performance index is 0.4 when m is equal to about 6.50, a figure higher than the theoretical blast, which would be 5.71. For $i = 0.7$, $m = 10$ and for $i = 0.8$, $m = 12$.

The values are recorded in Table I.

In a Paper read at the Warsaw Congress[5] last year, the present writer, in the absence of analyses of the gases, made use of a hypothesis in order to establish graphically in a tentative manner the position of the straight line $X'' = \frac{1}{m}\,V$ in the X″, V diagram. A certain number of analyses have now shown that the positions are sufficiently near the true ones.

Further critical study of the measurements of the blast will presumably shift them towards the left, that is to say, towards lower values.

Accepting the determinations as they stand for the present, the X″, V diagram given in Fig. 1 shows the straight lines of the *performance indices*, the general equation of which would be $X'' = \frac{1}{m}V$. Fig. 2 shows the relationship between m and i; employing the analytical form, it will be seen that it can be written:—

$$m = \frac{4.08}{1 - i^{1.47}} \quad .. \quad .. \quad (4)$$

or

$$m = 2.34\,\frac{2 - i}{1 - i} - 0.1 \quad .. \quad .. \quad (5)$$

which is a more convenient formula, sufficiently approximate in the only range under consideration, *viz.*, between $i = 0.4$ and 1, since for values below 0.4 it is defective.

The relationship between the variables X″, V and i with m would then be known, that is to say: Given X″ (the coke consumed) and the blast, the value of i is ascertained without the necessity of analysing the gases.

TABLE I.—*Data Obtained and Calculated for Thirteen Cupolas.*

No.	D. Mm.	A. Min.″	X″. Kg.-min.″	V. m³.-min.″	m.	i.	Γ.	Q.	S.	K.
86	1,300	1.327	0.195	1.81	8.26	0.61	753	67.82	0.175	10.4
81	1,000	0.785	0.222	1.71	7.71	0.66	636	57.32	0.198	14.0
20	600	0.285	0.188	2.03	7.91	0.57	880	68.42	0.195	9.9
9	500	0.198	0.206	2.92	10.05	0.63	757	75.75	0.168	9.9
72	900	0.636	0.243	3.14	9.60	0.57	786	78.61	0.195	11.16
65	850	0.567	0.077	1.58	18.00	0.92	617	35.27	0.109	7.94
8	500	0.198	0.166	2.07	12.31	0.78	757	75.75	0.134	7.9
66	850	0.567	0.169	2.20	12.85	0.92	705	88.18	0.109	6.9
23	600	0.285	0.169	2.45	12.72	0.68	880	77.19	0.156	7.9
83	1,200	1.131	0.194	2.21	11.25	0.67	885	88.41	0.157	7.9
37	700	0.390	0.176	2.35	12.10	0.75	615	58.97	0.148	10.8
71	900	0.636	0.233	3.14	10.74	0.67	786	94.33	0.157	8.9
56	800	0.503	0.152	2.48	16.08	0.84	796	79.50	0.123	6.9

Given X″ and the analysis of the gases, the blast is obtained. The knowledge of the laws governing the cupola operation cannot be said to be complete, however, without a knowledge of the manner in which m (or i) depends upon the operation variables.

Jungbluth has given a formula for determining the index which he calls η_v and which is a hundred times greater than our i ($\eta_v = 100\ i$), as a function of K, after having expressed m as a function of η_v, on the basis, however, of the theoretical blast, which is not in accordance with reality.

Although the blast, as measured by the apparatus, and eliminating the leakage from the mains and making the corrections due to the atmospheric conditions, particularly the temperature, is greater than reality, and Leopold Schmid[6] records having frequently found that the real blast is only 0.80 of that given by the reading, yet by making such corrections, it is always

found to be considerably in excess of the theoretical blast of each particular combustion, such excess being from 20 to 50 per cent. or more, and which commands acceptance, despite the very low values for the free oxygen in the analysis of the waste gases.[1]

The law according to which m varies with i is therefore not that of the theoretical blast, as

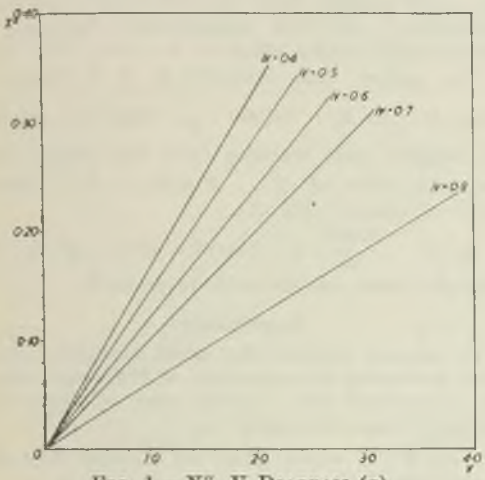

Fig. 1.—X″, V Diagram (a).

stated above, but another, namely equation (4) or for practical purposes equation (5).

Furthermore, it should be observed that the formula proposed by Jungbluth

$$\eta_v = \frac{386.5}{\frac{K \cdot k}{100}} + 15 \quad \text{where } \eta_v = \frac{CO_2}{CO_2 + CO} \cdot 100$$

and which rendered in the author's notation for $k = 0.86$ would become:—

$$i = \frac{4.49}{K} + 0.15$$

is in each case applicable only to the cupola operation in which the charge of iron is always full (on the basis of 900 kg. of iron per square metre and coke 72 kilograms, if K = 8, that is, m is 0.160 of the layer) and K varies with the increase in the charge of coke.

The influence of the size of the pieces, recently studied by J. Buzek and N. Czyzewski,[2] will be disregarded.

The author has found, however, by examining more than 100 furnaces in Italy, that very frequently the charge per square metre of furnace drops to 800, 700, 600 and even 400 kgs. Under such conditions even a moderate charge of coke corresponds to a high percentage. If in the example given, against 72 kgs. of coke, there are not 900 but 600 kgs. of iron, the percentage of 8 becomes 12, and if the charge was reduced to 450, it would attain 16 per cent.

Under such conditions it can no longer be said that i will be a function of K. This, however, will be discussed further below.

Thus it will be seen for the above working conditions, with variable K and with a constant charge of iron, up to what point the laws recently enumerated by Jungbluth are not in contradiction with the indications of the X″, V diagram, and at what point the divergence commences. In the first place

$$m = \frac{4.45\,(100 + \eta_v)}{100}$$

which interpreted is expressed as

$$m = 4.45\,(1 + i)$$

Therefore, whereas according to Jungbluth

$$m = 4.45\left(1.15 + \frac{4.49}{K}\right)$$

according to the author's investigations

$$m = 2.34\,\frac{2 - \left(\frac{4.49}{K} + 0.15\right)}{1 - \left(\frac{4.49}{K} + 0.15\right)} - 0.1$$

According to Jungbluth, the difference between the values of m for varying values of K are less than those personally calculated. For example, for K = 10, m according to Jungbluth is 7.14, as against the author's 8.09. For K = 8, m according to Jungbluth is 7.65, whilst in the author's case it becomes equal to 10.

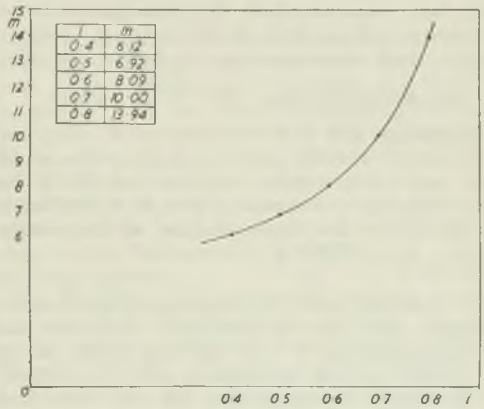

Fig. 2.—m, i Diagram.

Jungbluth's diagram, however, is perfectly compatible with the author's. Thus, according to the former, in the X″, V diagram, the straight lines starting from the origin each represent one i and hence one K, and merely the slope of these straight lines differs in the representations given by him and the author (Fig. 1).

The same also applies to Jungbluth's Q, V diagram (charge, blast).

As $Q = \frac{X''}{K}$ 3,600, there is at all events $Q = f$ (K, V), namely, an infinite number of straight lines, starting from the origin, one for each value of K. In this method of considering the subject, only the diagrams relating to Q K V T, showing the increase of T with K are compatible.

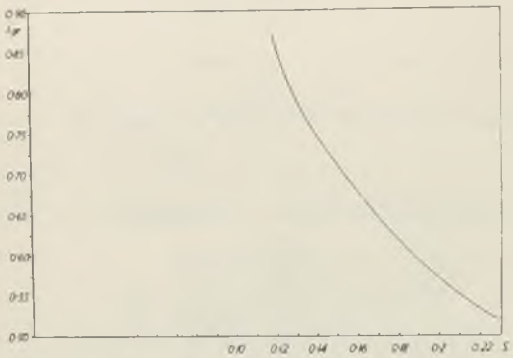

FIG. 3.—i_g S DIAGRAM (*b*).

For the general case in which K varies in any manner, either on account of variation in the charge of iron or variation in that of coke, it can no longer be said that $i = f(K)$.

Various considerations regarding the combustion lead one to believe that the preponderant influence will be that of the layer S, and another, much less important, is due to the whole of the charge of iron. $K = \frac{C.100,}{\Gamma}$ where Γ is this charge and C is the charge of coke, and assuming a specific gravity of the coke of 450 kgs. per cubic metre, it gives C = 450 S per square metre of furnace, where S is the height in metres of the layer of coke of the charge, whence $K = \frac{45{,}000\ S.}{\Gamma}$

If, however, an i, S diagram (Fig. 3) is examined, there are no distinct i, S curves each corresponding to a Γ, as one would be led to believe on the assumption of $i = f$ (S. Γ.) It is found, however, that for Γ less than 600 kgs., there will probably be such curves, while for Γ between 600 and 900 kgs., the points lie in such a manner that it is possible to regard a single i, S curve (diagram of Fig. 3) as a plausible representation.

However, this curve (diagram *b* of Fig. 3) has an equation sufficiently close to $i = \frac{0.085}{S} + 0.15$.

It is possible to see in Jungbluth's curve $i = \frac{4.49}{K} + 0.15$ a special case of the former, namely the case relative to $\Gamma = 900$.

In fact, in such a case $K = 45{,}000 \frac{S}{900} = 50$ S and by substituting this value in Jungbluth's equation that of the author is obtained. He therefore assumes this curve to be a general expression, with the remark that Jungbluth's observations permit this.

The author thus conceives a K, S diagram (Fig. 4). As $K = 45{,}000 \frac{S}{\Gamma}$, there is a group of straight lines starting from the origin, one for each value of Γ. Finally, a Q, X″ diagram is formed (Fig. 5).

As $Q = \frac{3{,}600}{K} X''$, there is also a group of straight lines, one for each value of K.

Conclusions

In general, between the limits considered, the laws governing the operation of the cupola may be represented for a given coke by four extremely simple diagrams:—

(*a*) X″, V which gives the straight lines of the *indices* i.

(*b*) i, S representing the curve of the variations of the index in general. That of Jungbluth is for a particular case.

(*c*) K, S representing the variation of K with S and with Γ.

(*d*) Q, X″ finally representing the variations of Q with X″ and with K.

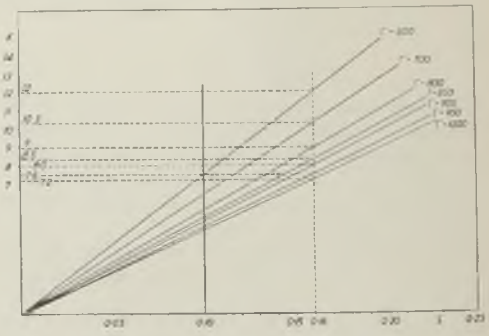

FIG. 4.—K, S DIAGRAM (*c*).

Taking the coke of $a = 0.86$, these diagrams assume a mean value for Italian cupolas and thus lend themselves to the solution of the various problems of the cupola with a sufficiently close degree of approximation. These are problems concerning the rate of working of a

furnace or affecting the design of a furnace yet to be constructed.

For example, if a furnace is to be taken over, X″, S, K and Q are known. From (*b*) knowing S there is available *i*, and hence V is found in (*a*). Diagrams (*c*) and (*d*) are not required as their data are known. Thus, without measuring the blast or analysing the gases, the performance index and the blast are known.

If it is a matter of designing a furnace, the data taken as basis are more often Q and

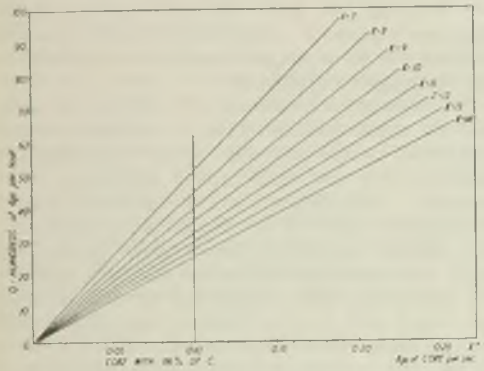

Fig. 5.—Q, X″ Diagram per Square Metre of Furnace (*d*).

K, it being necessary to find the other variables. It will be expedient to determine X″ from (*d*) and (*c*) and then to fix the value of S (and hence a value of Γ or *vice versa*). S being fixed, one obtains *i* from (*b*) and hence V is found in (*a*).

It is considered that when the figures and the positions of the lines have been confirmed, it will be very useful for the foundryman to be acquainted with these diagrams and to endeavour to make use of them for bringing into play the variables of the cupola in a manner more in agreement with industrial requirements.

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DISCUSSION

Mr. M. Olivo said the theory laid down by the author appeared to him to be very complicated. He had tried to put the laws into practice, because he had been working with cupolas for 30 years and desired to see if the theory was practical. In Italy they were going to make some official trials in a large foundry to ascertain its worth.

His own experiments had to a certain extent agreed with the theory, but his general experience was that each cupola had its own peculiarities—and he had tried more than a thousand—even when it was built to the same design and was installed in the same shop as others.

Then there was the question of coke. If one charged more coke, would it give hotter iron? One would naturally think the answer would be "yes," but he did not hold that view. With each cupola one had first to find the optimum depth of coke bed (it might be 15 or 20 cms.), and then adhere to it. To increase the temperature of the iron they had only to diminish the weight of the charge. On the contrary, if one had a large casting to make which did not demand a high temperature, the charge of iron could be increased, but the coke must always be left at the same height.

The fundamental ideas of the author were correct, he thought, and if they could be presented in tabular form they would be useful for anyone working with cupolas.

Difficulties in Gas Sampling

Mr. A. Campion (Glasgow) thought it was all to the good that attempts should be made to get down to the fundamental reactions and laws of the cupola. As the previous speaker had mentioned, it often happened that different cupolas appeared to possess peculiar characteristics. This had led to the idea that every cupola was a law to itself, but he was inclined to think that this belief was due to the fact that available knowledge of the fundamental laws of cupola operation was at fault.

The Paper was of considerable interest, but he had not been able to make out how far the figures had been obtained from actual working. Theoretically the composition of the waste gases should indicate the efficiency of the combustion of the coke and of the cupola performance. There was, however, a difficulty in obtaining representative samples of gas, and if the author had examined the gases he (Mr. Campion) would be interested to learn how the samples were taken and the position in the cupola from which they were drawn. He had never been quite satisfied that any sample of gas gave a true representation of what was taking place within the furnace. There were so many complex reactions going on

at different temperatures as well as polymerisation and dissociation of the gases that a sample drawn from any part of the high-temperature zone might when cooled to normal temperature be entirely unlike the gas within the cupola. This was a field which could usefully be explored.

Importance of Air Distribution

In regard to the air supply, the actual coke to air ratio was not the only factor and he doubted if it was even the main factor in determining the correct operation of a cupola. The structure of the coke and the manner in which the air was applied were very important factors which must be very closely controlled. He had come to the conclusion that quite a wide latitude in the air volume admitted was permissible and that the most important thing was the distribution of the air within the combustion zone. Recent investigations had shown that very few cupolas of normal construction permitted of an even and regular distribution of the air throughout the cupola area in the vicinity of the tuyeres. The results obtained from the examination of a large number of cupolas of various sizes and designs had been most surprising, and seemed to indicate that radical changes in design were called for if the best results, especially in the case of high-duty iron, were to be obtained. Regular distribution of the air and its proper application to the coke led to coke economy, increased metal temperature, improvement in the quality of the metal and improvement in the general performance of the cupola.

An Important Variable

Mr. J. E. O. Little emphasised Mr. Campion's remarks, and said the results Mr. Campion had obtained on that particular work had been so phenomenally successful that the figures, when published, would, he believed, clear up much of the mystery as to why one cupola was different from another. The question of how the coke burned was also of considerable importance. In some parts of the cupola, the coke might be hardly burning at all, and in another place it might be burning fully to CO_2. Ultimately they got a mixture of gases farther up the cupola stack that had no true relation to the actual burning conditions down in the hot part of the cupola.

Carburising Steel-Mix Charges

Mr. W. R. Bean (Past-President, American Foundrymen's Association, Chicago) referred to the problem of getting accurate samples of gas from cupolas. That was a problem in the study of cupola operation. In the United States at the present there were cupolas in which the air volume was being automatically controlled by the CO_2 content of the gases. The gas was drawn off from the cupola stack below the charging door. That application was one of the most interesting developments in cupola operation in recent years, and in America was recognised as a unique application.

The control was worked in conjunction with hot blast, for the sampling was more accurately done in a cupola of that type than in the standard cupola, due to the fact that the gases were automatically removed through a circular gas-duct located approximately 6 ft. below the charge door. A constant volume of probably 80 per cent. of the total volume of gas was drawn off for burning to heat up the supply of air. That was a point in connection with the measurement of the air or oxygen used in a cupola which was sometimes overlooked.

The industrial importance of this development was at once recognised in a contest recently sponsored by the scientific apparatus makers of America, for the most novel adaptation of a scientific instrument to industrial control. Although a total of 67 Papers were entered in this contest, including three from Europe, this entry was unanimously chosen for first prize.

A condition which might not exist in Europe, but which did in the States, was that cupola charges were often made up of as much as 50 to 60 per cent. of steel scrap. In a charge made up of equal parts of steel scrap and high-carbon material, about 30 lbs. of coke per ton was used to carburise the low-carbon materials in the charge. The coke used in carburising did no work in melting, and required no oxygen, since it was not burnt. That made a difference in the calculation of the volume of air which was delivered to the melting zone of the cupola.

Maintenance of Control Instruments

Mr. J. H. Cooper (Darlington) said he was very interested in the formula given for calculating the amount of air used in the cupola, but felt it would be better if it could be simplified. At present, measurements were made by Pitot tube, improved or modified for the purpose, but his experience had been that it was often fitted in quite unsuitable positions in the pipe line, and promptly forgotten. Also the air in a cupola blast line might be laden with dust or moisture. Recently he had examined a number of Pitot tubes, and in one case had found the orifices larger than they should be, while in others dust and dirt had practically closed them up. In one such case recently, he found a cupola that was being given twice the blast it could pass, and investigation showed the orifice of the Pitot tube was nearly blocked up. Users, when installing cupolas, often gave no indication to the designer of the purpose for which the furnace was intended, and the consequence was that the conduct and type of tuyere were quite unsuited for the use to which it was put.

With regard to Mr. Campion's difficulty of taking samples of gas, his practice had been to insert a sloping tube about 4 ft. above the tuyeres. The tube was put in at an angle so as to prevent it becoming blocked by dust falling into it, and with it gas could be taken continuously.

Dr. Barigozzi's Reply

Dr. Barigozzi, in reply, wrote that as he had no time available to reply in detail to the various speakers, he therefore would explain a fundamental feature of his Paper which had, perhaps, not been sufficiently developed in the text. It was as follows:—

Reference was only being made to the melting conditions when making engineering castings, using no steel, in an ordinary cupola, with charges made up of pig-iron and scrap, such as was used in Italy and elsewhere for current production. Under such conditions, there was no noteworthy carburisation of the iron.

It was certainly quite difficult correctly to carry out analyses of gases from the stack of a cupola. Most of the compositions, even those cited in the text, did not check up with the law

$$4.76\ (CO_2 + O_2) + 2.88\ CO = 100.$$

The analyses on which the basis of the theory he had envisaged rested did, on the contrary, agree with this formula. Samples of the gas had been taken by means of suction through a by-pass tube of decreasing section with the object of obtaining the best mixture. This method was to be used in the experiments which were to take place at the Terni steelworks, and thereby it was hoped to illuminate more clearly the laws governing cupola operation.

So far as his diagrams were concerned, he pointed out that the linear form of all those which related to the variables of the equation

$$X'' = \frac{QK}{3\,600} = \frac{V}{m}$$

(which is only the statement of a very elementary truth, then QX″ and X″,V) was obvious. It was also obvious that a linearity of the relationship existed between K and S. That there would be a relationship between m and i (performance index) was also evident.

According to Jungbluth, i was solely a function of K. His own observation was that, in Italy as elsewhere, K could be very high due to having reduced the metallic charge, whilst maintaining the coke constant; K could not be regarded, generally speaking, as the constant. Yet this rôle was especially played by S, which was the depth of the coke layer which formed the charge. The equation which the author had given of $i = f$ (S) (and of which that of Jungbluth was a special case) was provisional, and awaited the confirmation of the Terni experiments.

It was, however, at the first approximation, applicable. It was true that the nature of the metal charge also had an influence on the performance index, but his personal opinion was that this effect was only secondary. Another secondary influence was that of the blast pressure.

In conclusion, the author believed that the form of the diagrams he had submitted would remain unchanged. Only the right-hand cluster X″,V might be subjected to a rotation, when the blast determinations and the coke consumption had been established accurately.

Being given the linearity of the diagrams (except the curve i, S) they could be fused into one single diagram, interpretable according to diverse scales, and this could be useful for informing foundrymen as to the operation of their furnaces or for designing new ones. The diagrams in general scientific form ought to be related not only to 86 per cent. carbon coke, as the author had done, but to the combustible carbon contained in the coke.

Scottish Branch

Paper No. 696

Effect of Moisture on the Principal Properties of Moulding Sands*

By J. DEARDEN, B.Sc. (Associate Member)

In presenting this Paper, the writer feels it his duty to open it with an apology for adding to the large and possibly confusing volume of information already existing on the subject of moulding sands. It was this confusion of testing methods and results which led him to make his own experiments, and he hopes that the results will be of the same practical assistance to others.

This work was undertaken because it was thought that moisture is probably the most important variable in moulding sand, and certainly the easiest to control. The working moulder usually has no say in the choice of his sand, not even its grain size or its clay content, and he has to make the best use of whatever sand is provided. There are, however, two matters in which he can, and does, exercise his discretion; these are the moisture content of his sand, and the amount of ramming given to the sand when making the mould.

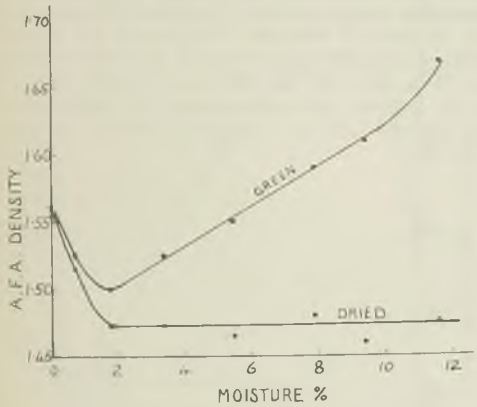


FIG. 1.—EFFECT OF MOISTURE ON DENSITY OF SOUTHPORT SAND.

The Paper is chiefly confined to the effect of moisture on sand, especially from a moulding point of view. This is not because the effects of hard or soft ramming were considered of lesser importance, but rather because moisture content is more easily defined and measured. Determinations of moisture content were made with the "Speedy" moisture tester, the readings of which were occasionally checked by weighing samples of sand before and after drying.

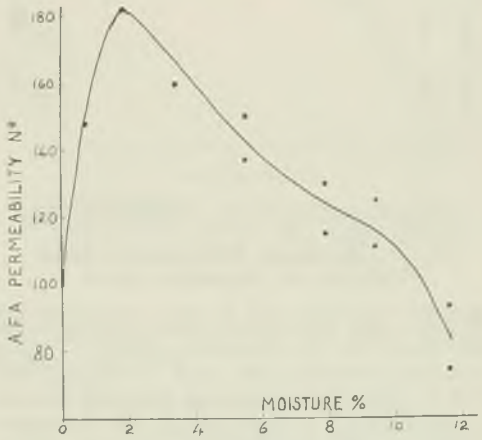


FIG. 2.—EFFECT OF MOISTURE ON PERMEABILITY OF SOUTHPORT SAND.

The properties of moulding sands are influenced by a rather formidable list of variables, which include the size, shape, surface condition and distribution of the sand grains, the quantity and quality of the clay and its distribution by milling, the moisture content, and the degree of ramming applied to the sand whether in the form of a mould or a standard test-piece. The present Paper records the effect of moisture on samples of various sands, as measured under standard ramming conditions, irrespective of sand composition. Standard ramming conditions were ob-

* The author was awarded a Diploma for this Paper.

tained by use of the well-known A.F.A. drop-weight rammer, in which the ramming of the sand is independent of its composition.

Tests on Sea Sand

The first series of tests was made on Southport sea sand. Being completely devoid of clay and silt, such a sand is free from the erratic effects due to variations in the quantity, quality and distribution of clay among the grains of ordinary moulding sand. It is thus possible to study the effect of moisture on the sand grains alone.

Fig. 1 shows the effect of increasing moisture on the A.F.A. density (*i.e.*, the apparent density of the sand test-piece when rammed by the three standard blows in the A.F.A. apparatus). The upper curve gives the density as rammed, and

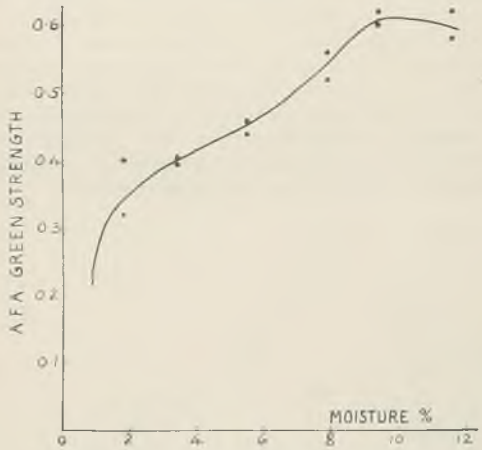


FIG. 3.—EFFECT OF MOISTURE ON GREEN STRENGTH OF SOUTHPORT SAND.

the lower one the density after allowance has been made for the moisture content. Above 2 per cent. moisture, the latter is virtually constant at 1.47, thus indicating that the increase in green density is due only to the increasing presence of moisture between the sand grains, and not to any closer packing of the grains themselves. There is a curious reduction in density as moisture increases from zero to 2 per cent.

Figs. 2 and 3 show the effect of moisture on the permeability and green strength of Southport sand. Increasing moisture above 2 per cent. gradually reduces the permeability by filling up the pore spaces between the grains. Sea sand is, of course, useless for moulding without a bond, but it is interesting to observe the gradual rise in green strength in Fig. 3, showing the slight bond afforded by the surface tension of the moisture between the sand grains.

At a later date these tests were repeated, using Irvine sea sand, which is coarser than Southport. The results are shown in Figs. 4, 5 and 6, from which it will be seen that the sand

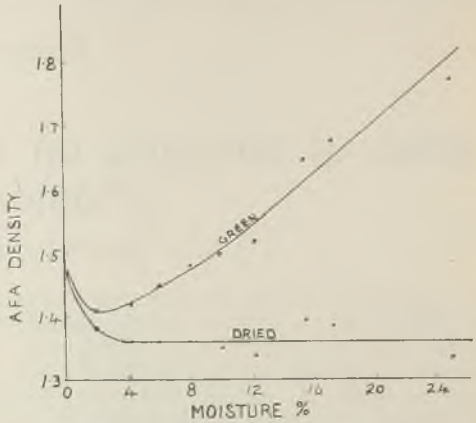


FIG. 4.—EFFECT OF MOISTURE ON DENSITY OF IRVINE SEA SAND.

exhibits similar characteristics to Southport, although to a different degree. Here, again, there is a reduction in density as moisture is increased from zero to 2 per cent.; the author

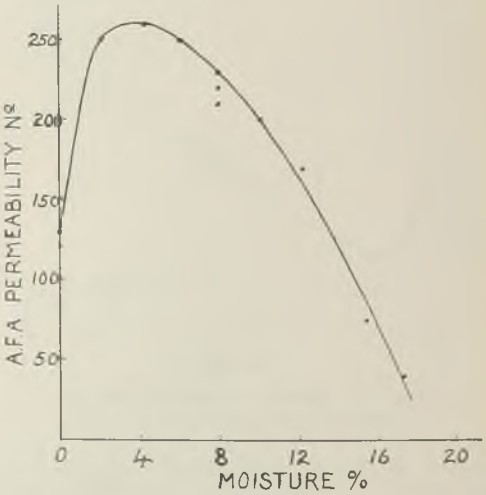


FIG. 5.—EFFECT OF MOISTURE ON PERMEABILITY OF IRVINE SEA SAND.

is unable to offer any explanation and would welcome discussion on this point.

Tests on Sea Sand with Clay

Having established the effects of moisture on pure sand, the next step was to study the same

sand when bonded with a known amount of clay of known quality. This was done by milling Irvine sand with sufficient bentonite to form a good working bond.

The amount of bentonite added was 2.2 per cent., and it is interesting to compare the re-

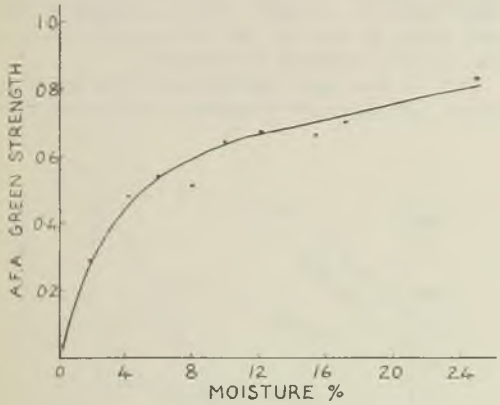


Fig. 6.—Effect of Moisture on Green Strength of Irvine Sea Sand.

sults with those obtained with Irvine sand alone, at 4 per cent. moisture in each case. Although there is no appreciable increase in density due to the presence of the bentonite, the permeability has come down from 260 to 165, owing to the fine particles of bentonite having swelled in the presence of the moisture. If this change had

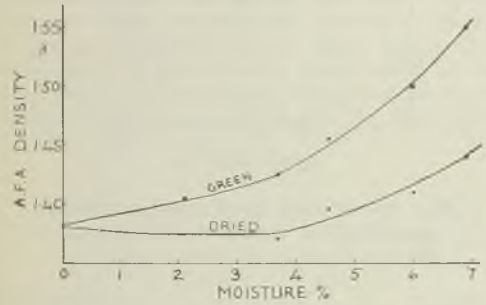


Fig. 7.—Effect of Moisture on Density of Irvine Sea Sand milled with 2.2 per cent. Bentonite.

been brought about by the crushing of the sand grains during milling, a marked increase in density would have been recorded. While sea sand has virtually no strength, the bentonite addition and the milling action have given it a green strength of 5.5 lbs. per sq. in. and a dried strength of 118 lbs. per sq. in. at 4 per cent. moisture.

The effects of increasing moisture on this mixture are shown in Figs. 7, 8, 9 and 10. Compared with Fig. 4, the lower curve of Fig. 7 now shows an upward tendency above 4 per cent. moisture, thus indicating that the increased green density is now no longer due to moisture alone, but also to a closer packing of the sand grains. This effect is considered to be due to the moist bentonite acting as a lubricant between the sand grains, as moisture alone is insufficient to cause it. Permeability rises to a maximum at about 4 per cent. moisture and then falls. The maximum green strength was found at about 2 per cent. moisture, but in this condition the sand was too dry for moulding purposes, and a moisture content of 3 to 4 per cent. would be more desirable.

The most remarkable effect of moisture in this case is on the dried strength, and Fig. 10 shows

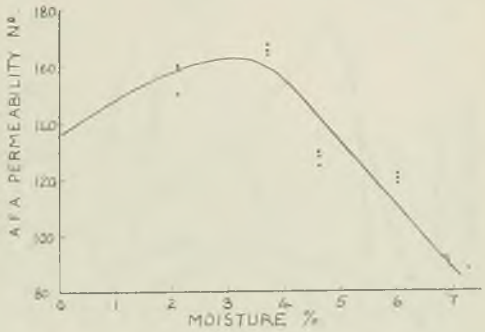


Fig. 8.—Effect of Moisture on Permeability of Irvine Sea Sand milled with 2.2 per cent. Bentonite.

the phenomenal rise of this property with moisture; the dotted line shows the green strength on the same scale.

Tests on Raw Moulding Sands

Figs. 11, 12 and 13 show a similar series of tests on four raw moulding sands. These sands were tested as received, and without further milling. The results are representative only of the particular consignments of sand under test, but are roughly typical of their class. Their maximum green strengths are in the same order as their clay contents, and it appears that the higher the clay content, the greater is the variation in green strength due to moisture. It does not follow that the moisture content producing maximum green strength is also the best for moulding purposes, as the sand is then rather brittle and difficult to patch; a higher moisture is therefore to be preferred. Each sand has a maximum permeability, but not necessarily at

the same moisture which gives maximum green strength.

The dried strengths plotted on Fig. 13 were determined on B.C.I.R.A. specimens rammed to the same green density as the corresponding A.F.A. green compression test-piece. This is because the only compression-test machine available at the time had a maximum capacity of 50 lbs., and that is much too low for breaking dried A.F.A. test-pieces. The dried strength is again acutely sensitive to moisture content, except in the case of Belfast sand, which was a red sand containing only 4 per cent. clay.

Tests on Facing Sands

This series of tests was made on the uniform sand circulating in a mechanised plant, and maintained at facing-sand quality for green-sand moulds. The quality was maintained by a 2 per

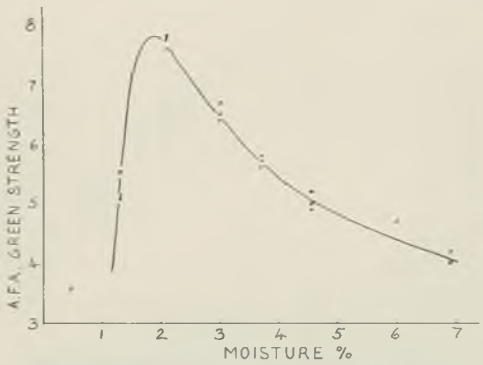


Fig. 9.—Effect of Moisture on Green Strength of Irvine Sea Sand milled with 2.2 per cent. Bentonite.

cent. daily addition of raw sand, and sufficient coal-dust to maintain an 8 per cent. loss on ignition. The raw sand was of synthetic origin, the bond being a mixture of fireclay and ball clay. The results are plotted in Figs. 14 to 18, and exhibit features similar to those already noted in other sands, but differing in degree. The more important features are the rapid drop in green strength and permeability above 6 per cent. moisture, and the continuous rise in dried strength, although the latter is not so marked as with the bentonite sand of Fig. 10.

Packing of Sand Grains

This question of increased packing of the sand grains when the moisture is raised above a critical value was investigated in several different sands, and the following conclusions drawn. Clay-free sands, such as sea sands and silica sands, do not pack closer with higher moisture. Red sands, such as Belfast, Stranraer, Moulds-worth and Mansfield, do so slightly or not at all, according to their clay contents. Sands high in clay content, such as Belgian red, Scottish rotten rock, and synthetic sands, especially if the last-named contain Colbond or bentonite, exhibit a closer packing of the grains above certain moisture contents. The inference is that this effect is due to the lubricating action of clay in the presence of moisture.

Fig. 18 has been included as a matter of interest. It shows the increase in green and dried

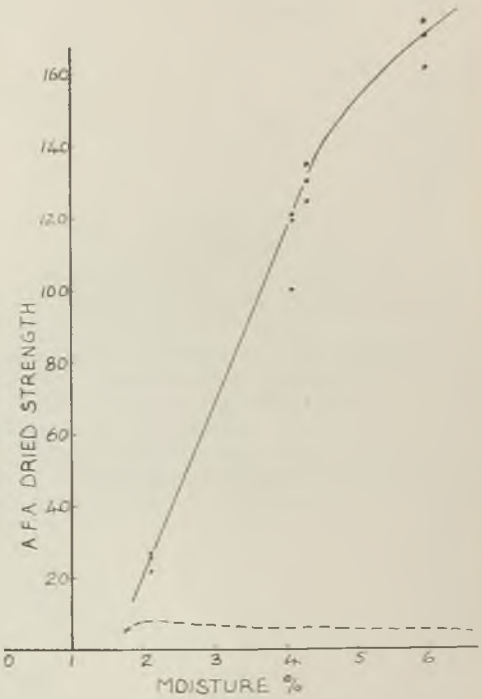


Fig. 10.—Effect of Moisture on Dried Strength of Irvine Sea Sand milled with 2.2 per cent. Bentonite.

strength of the plant sand obtained by harder ramming, the moisture being kept constant. It shows that one blow with an A.F.A. rammer is sufficient to give a dried strength of 30 lbs. per sq. in. in this sand, whereas 27 blows are required to attain this strength in the green state.

A comparison of the relative effects of moisture and ramming on dried strength can be drawn from Figs. 17 and 18. At 6.3 per cent. moisture, the dried strength of the plant sand is 54 lbs. per sq. in. To double the dried strength by extra ramming, it is necessary to give 11 blows instead of the customary 3 blows. The

same increase in dried strength can be obtained with 3 blows if the moisture is raised from 6.3 per cent. to 9.3 per cent.

Moisture Added After Ramming

As moisture has such a marked effect on the dried strength, it was decided to investigate

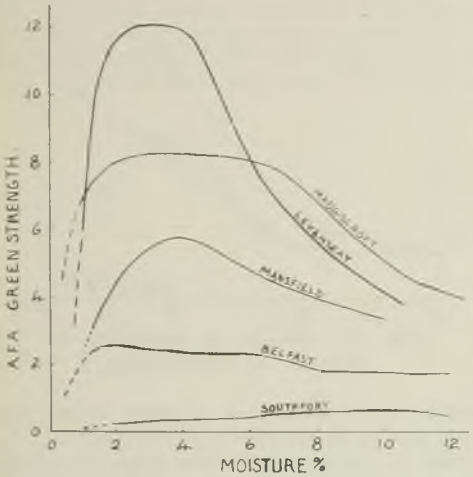


Fig. 11.—Effect of Moisture on Green Strength of Raw Moulding Sands.

the effect of its addition to rammed sand, as this is sometimes done during moulding. A.F.A. test-pieces were prepared and allowed to absorb increasing amounts of water, after which they were dried and tested under compression in the usual way. The samples of sand used were not identical with those quoted earlier in the Paper,

Table I.

	Moisture added after ramming.	Total moisture.	A.F.A. dried strength.
	Per cent.	Per cent.	
Plant sand.	—	9	109
	3	12	99
	6	15	108
	9	18	108
Madgiscroft rock sand.	—	8.5	118
	3.5	12.0	114
	7.5	16.0	117

but were adequate for the purpose. The results are given in Table I.

These results show that if moisture is added to raise the dried strength of a sand, it must be added to the sand before and not after ramming.

Control of Moisture Content

There are several reliable moisture testers available, but they do not indicate whether a sand is too wet or too dry for moulding purposes. This important question can only be settled by feeling the sand with an experienced hand. The case of Irvine sea sand bonded with bentonite is an illustration of this point. This sand was suitable for moulding when the moisture was about 3 to 4 per cent., but when it was in regular use in a mechanised plant, with suffi-

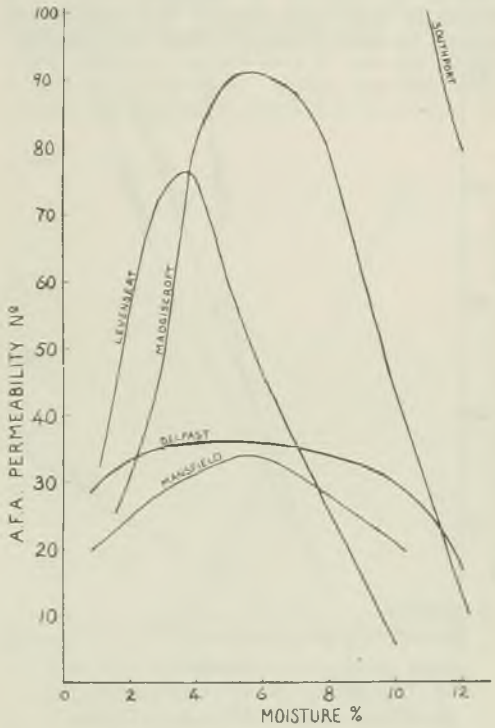


Fig. 12.—Effect of Moisture on Permeability of Raw Moulding Sands.

cient coal-dust to maintain an 8 per cent. loss on ignition, the sand felt dry at 4 per cent. moisture, and it became necessary to raise the latter to 5 to 6 per cent. to develop sufficient plasticity in the sand. A possible explanation of this is that much of the coal-dust in the sand had become coked under the influence of the hot metal, and the extra moisture was absorbed by the pores of this coke, and by the fine particles of coal-dust.

In addition to the effect of coke, the working moisture content of a sand is affected by the grain size and the clay content; the finer the grain and the higher the clay content, the

greater is the amount of moisture necessary. Hence, it is impossible to specify one moisture content for all sands, and each must be taken on its merits. Experience, coupled with a moisture tester, will decide what is the best moisture content for any particular sand. Then, provided the sand is controlled at a constant quality, the moisture tester can be used to ensure that this figure is being adhered to. Accurate determinations of moisture are necessary in order to decide whether variations in strength and permeability are due to moisture only, or to changes in sand composition. This applies particularly to dried strength, which is so sensitive

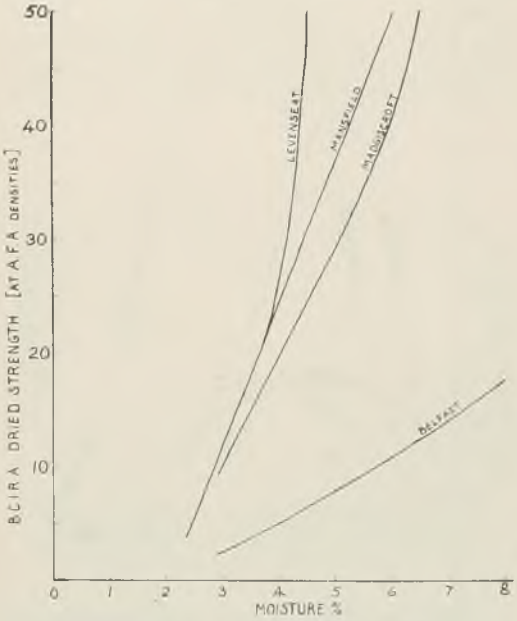


Fig. 13.—Effect of Moisture on Dried Strength of Raw Moulding Sands.

to moisture that it is almost a measure of moisture content in itself.

Conclusion

The experiments described in the Paper show that each sand is a law unto itself so far as the effects of moisture are concerned, and test results should always be referred to the moisture content, as variations in the latter do have considerable influence on the properties of sands. Before it is possible to express an opinion on any sand, it is desirable that its characteristics should be tested over a range of moisture contents.

From the moulding point of view, it may be stated that, within the usual range of moisture, increasing moisture gives a reduced permeability and green strength, but a much higher dried strength; it also makes the sand easier to ram, in which case there is a danger of the permeability being reduced even lower. Red sands are

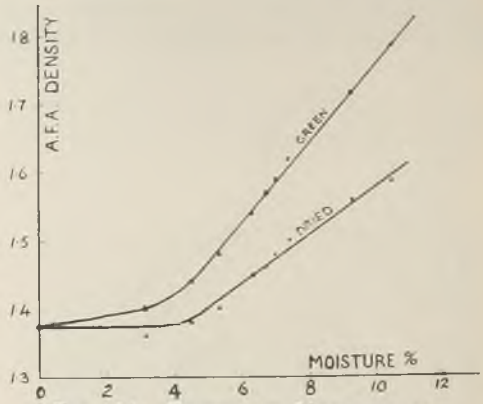


Fig. 14.—Effect of Moisture on Density of Plant Sand.

affected by moisture to a lesser extent than other and more heavily-bonded sands.

Some of the tests have been made at moisture contents which may appear absurdly low or high. This has been done solely with the intention of exploring the effects of moisture over as wide a

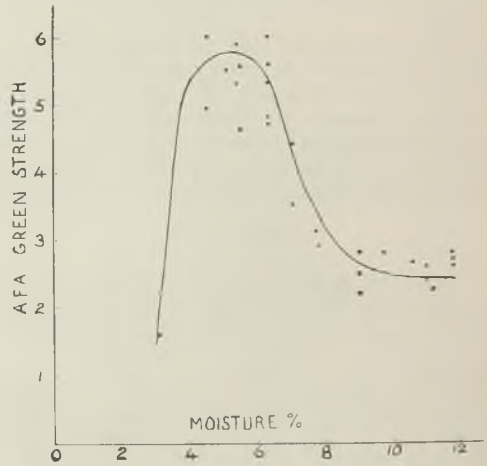


Fig. 15.—Effect of Moisture on Green Strength of Plant Sand.

range as possible. It is not suggested that these extreme values are of any use in moulding, but they have a scientific value in so far as they lead to a fuller understanding of the effects of moisture on sand.

It has been noticed that the maximum green strength of raw moulding sands is developed at a

lower moisture content than is required for facing sands which contain both used and unused coal-dust. This is probably due to a portion of the moisture being absorbed by the pores of the coke and the surface of the fine coal-dust, so that more is required to develop the maximum strength of the sand. This may provide an explanation for the statement that the use of coal-dust with a moulding sand raises the green strength. The working range of moisture is above that needed for maximum green strength, so that if coal-dust is used and the percentage

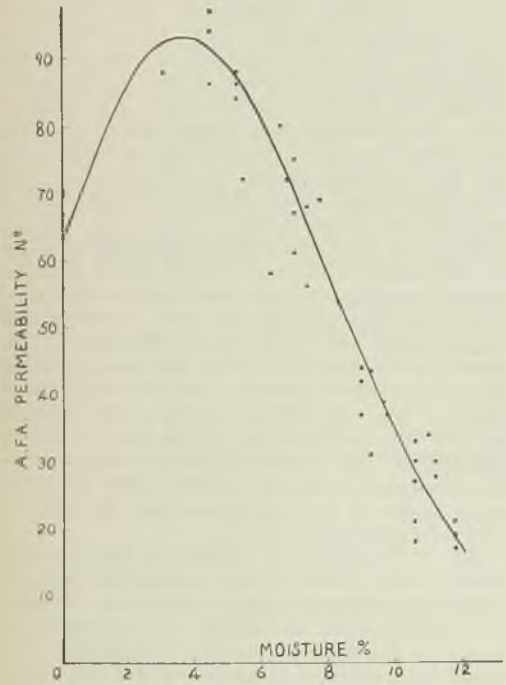


Fig. 16.—Effect of Moisture on Permeability of Plant Sand.

of moisture kept constant, some of the moisture will be transferred from the clay to the coal-dust, and the green strength will rise.

If the moisture in the sand be controlled by the feel of the hand, this effect will not occur, as the moisture will be unconsciously raised to maintain the required degree of plasticity in the sand, as already explained.

The author wishes to thank the London Midland & Scottish Railway Company for permission to publish the information contained in this Paper.

DISCUSSION

The Branch-President (Mr. R. Ballantine) said he thought that the Madgiscroft sand, with 6 per cent. moisture, gave the best results. He did not agree with Mr. Dearden as to the use of bentonite; he preferred to use 6 per cent. rock sand, which gave a better result because it made for easy compression when the contraction of the metal took place.

Mr. A. L. Mortimer asked for information about the two rock sands which had been dealt with. He would like to know whether a difference in the type of sand affected the green strength, etc. The dry and green strengths of those sands had been given, but had the author any information about the sea sands after drying? If the sea sand had been bonded, would the permeability be affected?

Mr. Dearden replied that it was not possible to test sea sand after drying out the water, because the test-pieces would fall to pieces. The

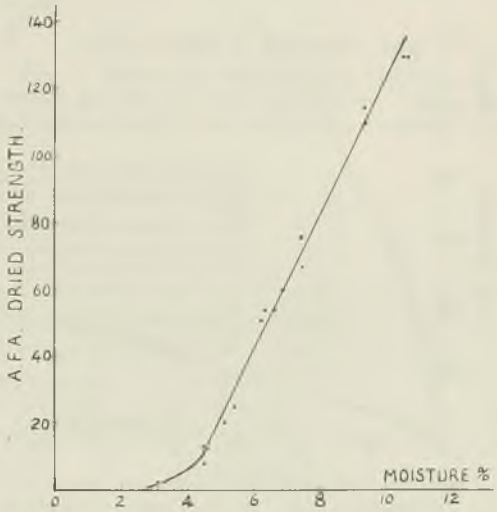


Fig. 17.—Effect of Moisture on Dried Strength of Plant Sand.

permeability of dried sea sand should not change with moisture because the dried density was constant.

Mr. W. Buchanan said, amid laughter, that he had already said and written so much on the subject that he was afraid that, without looking up his notes, he might contradict himself instead of the speaker.

The effect of putting water into sea sand had been dealt with, but he thought this served no useful purpose. The same applied to the very high and low moisture contents used. The normal range provided enough field for research. Water should be put into the clay where it would stay, and not separate round the grains or fill up the pores. The question of loam did not make any difference, as it was always dried.

He thought it would have been better to have taken a known volume of sand and then to have found out what happened on adding a known volume of water; but, as already stated, this would have no useful purpose. He had already shown that the A.F.A. test results were subject to a change of ramming as well as any change due to the water itself, and the conclusions could only be said to be "the effect of water on the A.F.A. test-piece" rather than its effect on moulding sands.

Mr. W. W. Braidwood thought it hardly fair to say that Mr. Dearden's work served no useful purpose. Mr. Dearden had asked for a possible

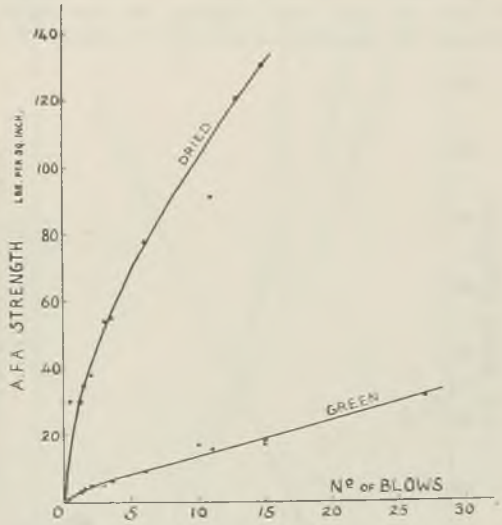


Fig. 18.—Increase in Dried and Green Strength of Plant Sand with Harder Ramming. Moisture Constant at 6.3 per cent.

explanation of the drop in density up to 2 per cent. water addition. He suggested that in the dry condition the sand was most able to flow, and a small water addition, by increasing the surface tension, prevented complete packing of the grains. After that amount had been added the water was in excess and the resistance to compaction was not further increased.

Mr. J. E. O. Little agreed with the idea of starting from pure sea sand, as it was always advisable, he said, to start at the base and go through the full range. He was pleased that Mr. Dearden had extended the water contents to the stage where the sands became extra wet, because that was important from the angle of loam moulding. Using wet loam was usually regarded as a safe method, but it could provide trouble, the same as other sands. He was of the opinion that facings deserved more attention, especially in regard to scabbing and buckling. In some work which Mr. Hudson had published it was shown that expansion at elevated temperatures was associated with buckling.

In this connection, Mr. Little said he had recently carried out some experiments which showed the clay content to be a very critical factor in scabbing. Also, the type of clay was important from the point of view of refractoriness in reducing atmospheres. He had made two green-sand moulds with loam cores; the cores were as nearly identical as possible, being made from the same batch of loam. One of the moulds was sleeked with plumbago, and with the other the plumbago was merely dusted on. The core loam was known to be prone to buckle, and the two castings showed a difference, in that with the sleeked mould the core did not buckle, but with the other it did.

The gases from the mould cavity were collected as the mould filled, and it was found that the sleeked mould gave 8 per cent. carbon monoxide, whilst the other gave 10 per cent. It would thus appear that even the small difference in the mould atmosphere, caused by the metal running on to a smoothed plumbago surface and a rough more or less unprotected surface, was sufficient to alter the performance of the loam of a core exposed to that atmosphere. In other words, the condition of the mould face could affect the performance of the core face from the point of view of buckling.

Mr. T. Tyrie said it appeared that, in clay-bonded sand, there was a maximum point at which the maximum green compression strength was reached, but apparently no maximum was shown in the case of the dry compression. He would be interested to know whether the author had found any maximum point after drying the bonded sand.

Mr. Dearden replied that he had found no maximum in the dried-strength curve, but the green strength did definitely exhibit such a maximum. It might have been found if the moisture had been taken even higher, but very wet sand was not easy to ram because of its sticky condition. Mr. Braidwood's suggestion as to why the density of sea sand fell with moisture content up to 2 per cent. was welcomed. But was Mr. Braidwood right in thinking that it was entirely due to surface tension, or was it partly due to some other cause? The suggestion solved one problem, but set another, namely, why did the green strength of sea sand increase continually with increasing moisture if the surface-tension effect was at a maximum with 2 per cent. moisture?

Paper No. 697

Examples of Loam Moulding*

By R. D. LAWRIE (Member)

The use of loam has many advantages in the foundry, more particularly in the jobbing foundry. By its use the cost of patternmaking can in many instances be considerably reduced, and although it cannot be employed profitably in every case, there are certain classes of work for which it is eminently suited. Its primary value lies in the ease with which it can be swept to a given shape; in cylindrical work, for example, its use is both cheap and effective, a profiled edge board being all that is required in the way of a pattern. Such shapes may be swept either about a vertical or a horizontal spindle.

For castings of large diameter and short length, vertical sweeping is the method generally employed, whilst castings of which the diameter is small in comparison with the length are easier swept by the second method, *i.e.*, horizontal sweeping. Loam moulding is not necessarily confined to castings of a cylindrical shape, or those which can be shaped by sweeps or strickles; it is often necessary to employ a part-pattern in conjunction with sweeps, where the shape of the mould deviates from the circular. Loam is also the method usually employed when the pattern is too large for the moulding tackle available, or when the size and shape of the pattern are such that the mould has to be split into irregular shapes to facilitate either handling, drying, pattern removal, or the placing of cores during closing.

MOULDING A BORING BAR

Fig. 1 shows an arrangement drawing of a boring bar 36 in. dia. and 56 ft. long. The bar was made up from two separate castings, one 31 ft. and the other 25 ft. long, and weighing as cast 25 and 20 tons respectively. The moulds for these castings were swept in loam, partly by horizontal sweeping and partly by horizontal strickling. The larger casting was made first, the mould being built inside a cast-iron casing 4 ft. square inside and 36 ft. long, split longitudinally and machined on the adjoining faces.

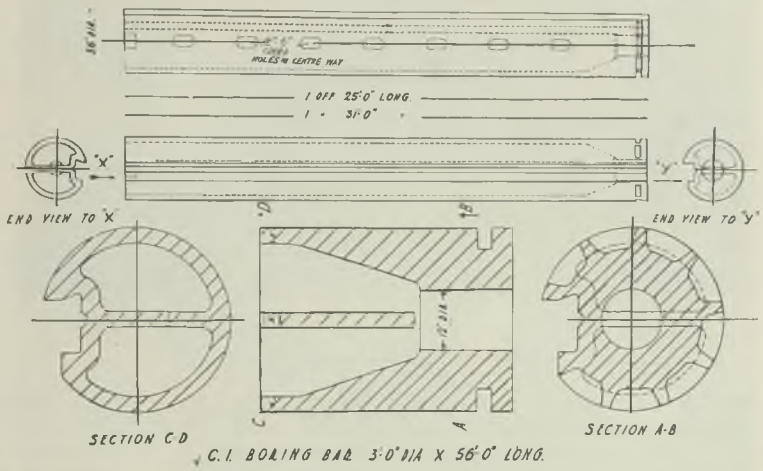


Fig. 1.—Arrangement Drawing of Boring Bar.

Strickling Tackle

The sweeping tackle employed consisted of a hollow steel spindle $3\frac{1}{2}$ in. outside diameter and 36 ft. long, supported in bearings at either end of the casing, also about the middle of its length in a bearing slung from the underside of a mild

* The author was awarded a Diploma for this Paper.

steel channel which straddles the casing. The end bearings, which are interchangeable, are dowelled and bolted to the ends of the casing. (See Figs. 2 and 3.)

The sweep or profile board is fastened to the spindle by six shear arms and revolves with the spindle, a cranked handle being attached to each end of the spindle for this purpose. The mould is built up with bricks to within an inch of the profile board and a coating of wet loam applied to the face of the bricks; the profile board is rotated and the loam is brought to the desired shape.

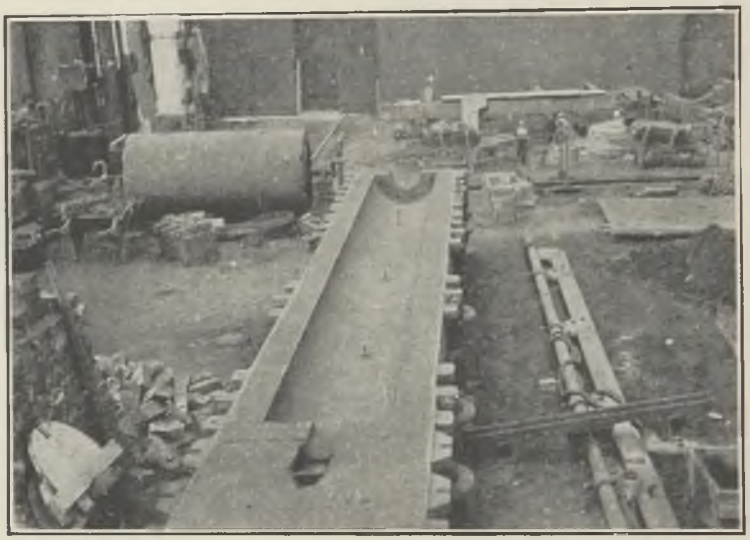


Fig. 2.—Mould for 31-ft. Casting for Boring Bar, with Sweeping Tackle on right.

Making the Joint

The joint is strickled off by means of a steel straight edge about 6 ft. long and 6 in. deep, having a recess 12 in. by $1\frac{3}{4}$ in. in the middle of its length, so that it rests on the spindle and the edges of the casing simultaneously. After the bottom half of the mould is swept up, the spindle and board are transferred to the other half of the casing and the top portion of the mould is made up in exactly the same manner as the bottom. The recess for the screw is formed in the top half-mould, and is shaped by a wooden frame which is placed inside the top half-mould and packed with loam and bricks, reinforced with gratings keyed through to the outside of the casing.

The spindle is next returned to the bottom half-mould, the original board removed and a new one substituted, which is cut to the profile of the inside of the casting. It will be appreciated that this latter board will be clear of the surface previously swept, by a distance equal to the desired thickness of the casting. This space is now packed with damp moulding sand and swept to the shape of the board, and forms what is known as the core box.

Moulding the Middle Rib

The middle rib—originally designed solid—was provided, at the request of the foundry, with a series of holes 12 in. by 6 in. spaced at 3-ft. centres, and is now placed in position in the core box. For the purpose of effecting its removal, the rib is split longitudinally through the centre of the holes. (See Fig. 4.) A parting wash is next applied to the surface of the core box which is now ready to receive the core-iron.

Preparing the Core-Iron

The core-iron consists of two $6\frac{1}{5}$-in. dia. perforated steel tubes carrying a series of cast-iron grids with dabbers or prods, which encircle both bars, and having cross-bars which pass through the 12-in. by 6-in. holes in the centre rib. The holes in these grids are made $\frac{1}{4}$ in. larger in diameter than the tubes which they encircle, and are wedged in position by small mild-steel wedges which are all placed with their points facing towards the bottom end of the casting, *i.e.*, the end with the small opening. Owing to the small diameter at the bottom end of the casting the tubes stop at a point where the metal thickens up, some 2 ft. 6 in. from the end of the casting.

Into the end of each tube is fitted a cast-iron block 12 in. long with a $2\frac{1}{4}$-in. square hole running lengthwise and a $4\frac{1}{8}$-in. long by $1\frac{1}{8}$-in. hole crosswise. These blocks are secured by six $\frac{3}{4}$-in. dia. countersunk screws and a hole through the tube connects with the hole in the block. Into the ends of these tubes are placed mild-steel connecting links 2 in. by 2 in. tapering to 4 in. by 1 in., with an offset so that they meet at a point some inches from their ends, terminating in a head with a cotter hole $4\frac{1}{8}$ in. by $2\frac{1}{8}$ in. Fig. 5 shows details of the twin core bars, cross grids and connecting links. The core-iron is now in one piece and perfectly rigid.

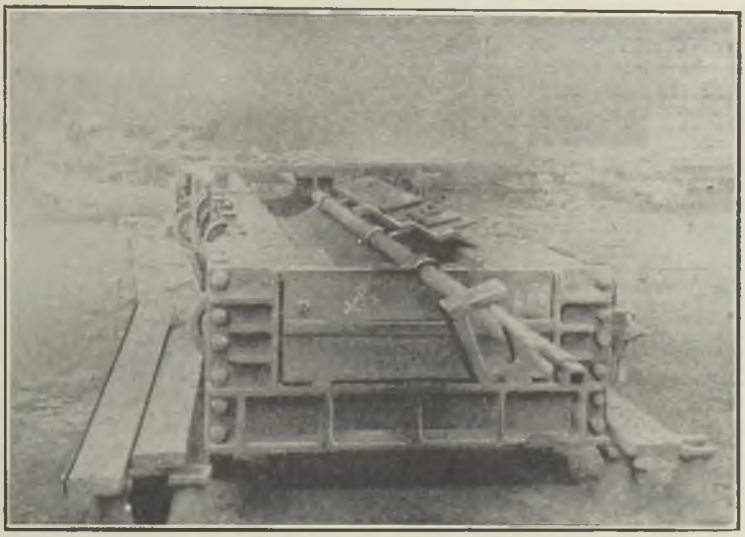


Fig. 3.—Mould with Sweeping Tackle in Place.

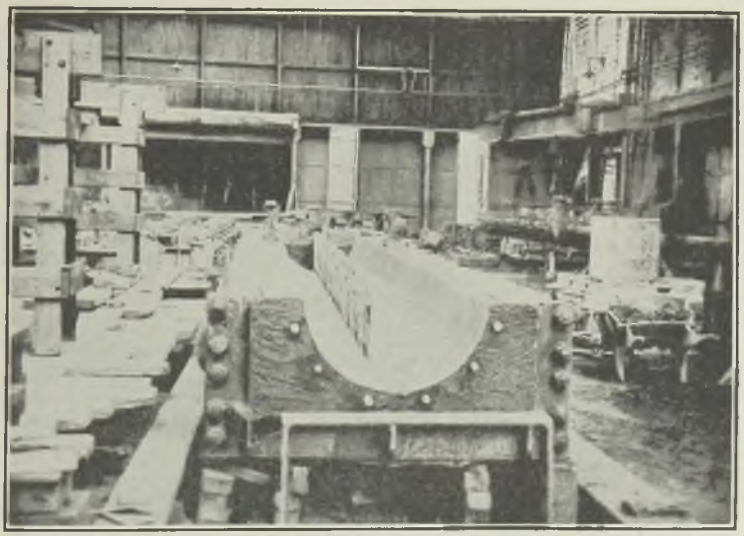


Fig. 4.—Arrangement for Middle Rib.

The offset links are bolted together just clear of the casting, and the ends which fit inside the

two tubes are secured by a 4-in. by 1-in. cotter pin. These cotter pins are an easy fit and are made to slide through from either side and project a matter of 1½ in. at each side of the tube. Fig. 6 shows the core bar completely assembled and ready to go into the core box. The body of the core is constructed of soft loam bricks and a good layer of ashes, about 4 in. behind the face of the core, connected to the perforations in the tubes by short lengths of straw rope to permit free escape of air and gases during casting. The top half of the core is shaped by strickles which run on steel straightedges laid along the joints of the mould.

Core-Handling

Fig. 7 shows the core at this stage with the strickle in position resting on the steel straightedges. The eye bolts seen projecting are for the purpose of slinging the core and are screwed into the twin core tubes. At this stage the bottom half-mould and core are placed in a stove and dried sufficiently to lift the core out of its box; then any breakages are repaired and the core

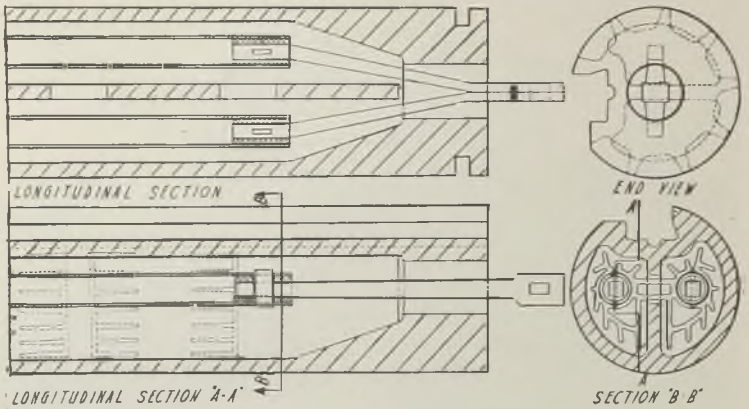


Fig. 5.—Details of Core Bars, Cross Grids and Connecting Links.

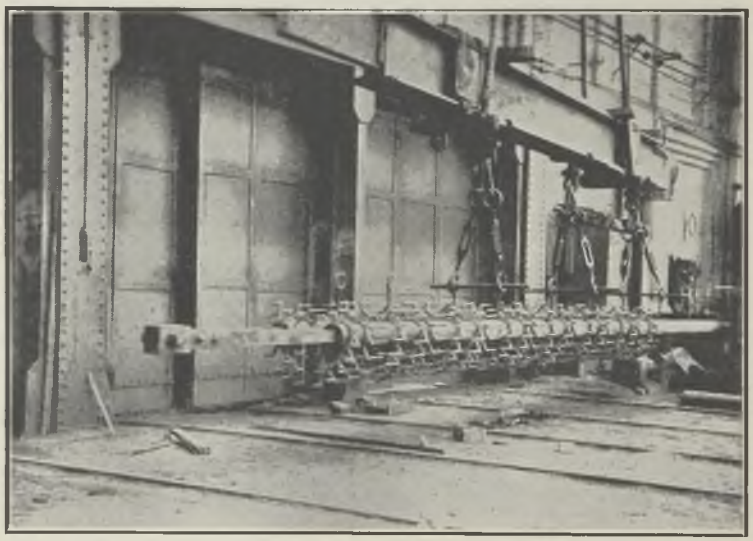


Fig. 6.—Core Bar Completely Assembled.

is given a coat of liquid blackwash and returned independently to the stove for complete drying. The sand thickness is removed from the core box, leaving the original swept surface, which is blackened in a like manner to the core; the top is treated also with blacking and the whole job dried off in the stove.

After drying, the core is placed in the bottom half of the mould, supported by prints at each end and at intervals along its length by mild-steel chaplets. Fig. 8 shows the mould at this stage with the core in position looking from the top end. Fig. 9 is a view from the opposite end. After the mould had been assembled it was lowered into a casting pit in a vertical position for casting.

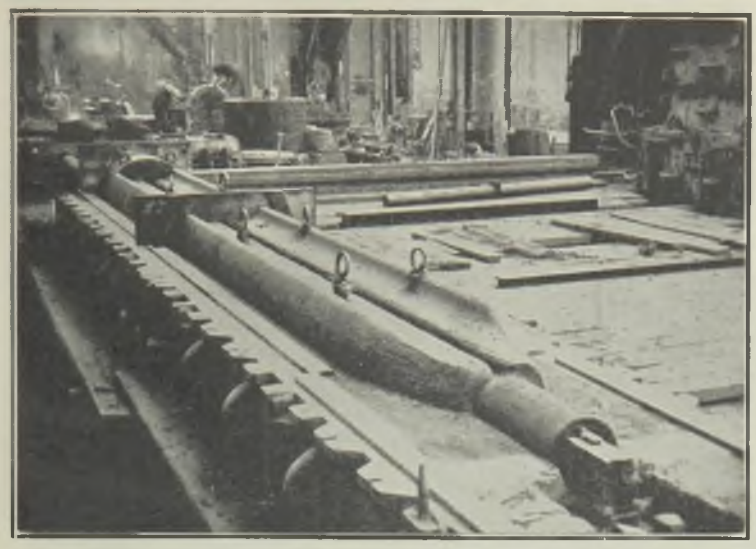


Fig. 7.—Top Half of Core in Process of Strickling.

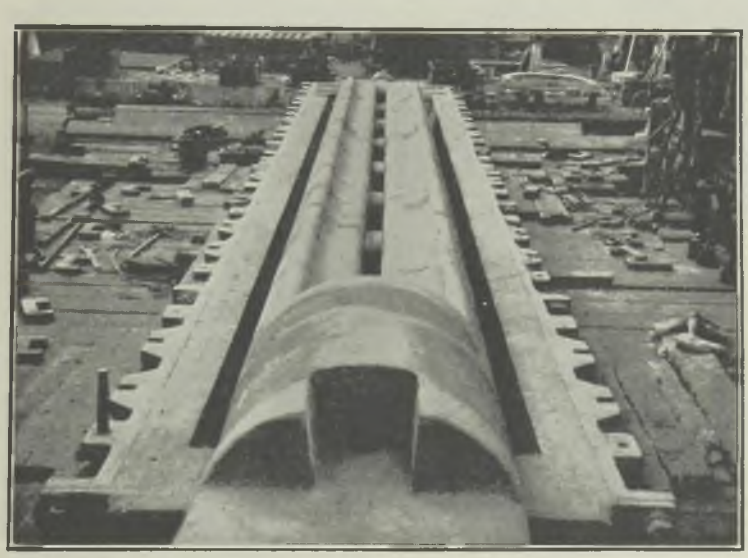


Fig. 8.—Mould with Core in Position, viewed from Top End.

Casting Arrangements

Fig. 10 shows the commencement of this operation; it will be observed that the mould is slung by one end from the overhead crane, whilst the opposite end rests on trunnions. Fig. 11 shows the mould ready for casting. Two ladles were used to fill the mould, one pouring direct into the rectangular pouring basin, while the second ladle poured into an auxiliary runner trough connected to the aforementioned main basin. The core itself protrudes through the top of the casing and can be seen clearly in the centre of the pouring basin.

Metal was introduced through nine $1\frac{1}{4}$-in. dia.

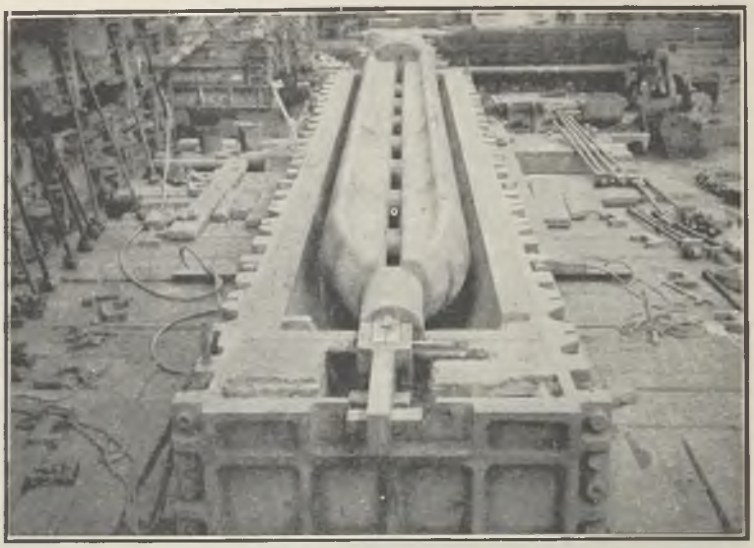


Fig. 9.—As Fig. 8, viewed from the Opposite End.

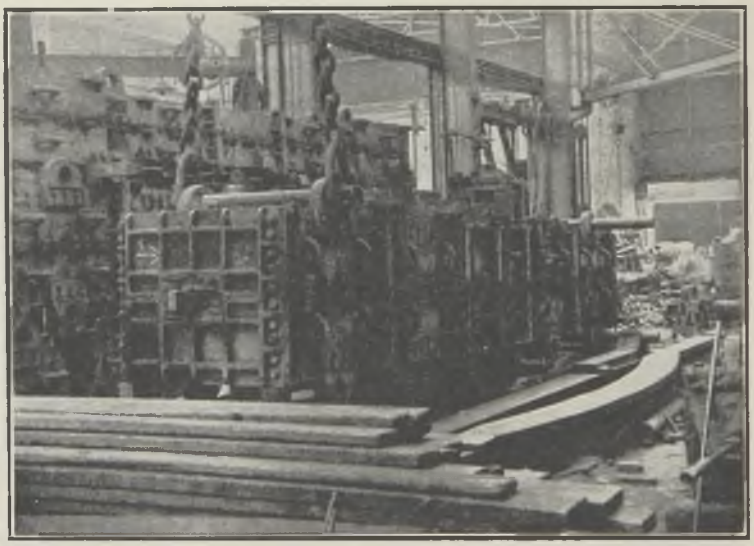


Fig. 10.—Arrangement for Lowering Mould into Casting Pit.

gates, spaced round the outer metal thickness (see Figs. 4 and 8). It will be noticed that Fig. 4 shows six gates formed in the bottom half of the mould, whilst Fig. 8 shows three gates formed in the core itself; this is due to the change of contour of the casting. Referring back to Fig. 1, it will be observed that there are eight recesses near the bottom end of the casting. As these recesses were cored out it will be obvious that to allow molten metal to fall on to these cores from a height of 36 ft. would be attended with disastrous results. To guard against this, during the actual casting operation metal was first introduced through a single gate located on the centre line of the rib, midway between the rib and the recess for the screw (Fig. 8). After sufficient metal had been allowed to enter the mould through this single gate, to cover the projecting cores to a safe depth, pouring was continued through the remainder of the gates until the mould was completely filled.

Stripping and Fettling

After an interval of a week had elapsed, to permit thorough cooling and normalising to take place, the casting was removed from its mould and fettled ready for machining. The removal of the offset links from the bottom end of the twin core-bars was a slow and arduous job, as the amount of space available was extremely small. The internal core was removed as far as the cotter pins which dropped down clear of the core bars, these being subsequently withdrawn from the top end.

Earlier in the Paper reference was made to the manner in which the grids were wedged to the twin bars. The object of having the wedges pointing towards the bottom end of the casting was that during the pulling out of the core bars the wedges cleared themselves. When once the bars had been removed from the casting, the remaining cast-iron grids were easily broken out and the inside cleaned out of all debris and the casting removed to the machine shop.

Analysis of Casting:—T.C., 3.19; Si, 1.08; Mn, 1.03; P, 0.28, and S, 0.04 per cent. The casting temperature was 1,240 deg. C., and the pouring time, 125 secs.

Fig. 11.—Mould Ready for Casting.

EXHAUST STEAM BEND

Fig. 12 shows a casting for a 90 deg. bend for exhaust steam, two of which were supplied to the order of a firm in the Midlands and installed in a Yorkshire city power station. The castings weighed 25 tons each and were moulded in loam from a skeleton pattern (Fig. 13). The foundry in which these castings were made has a river running alongside, and as there was no watertight pit available at the time it was decided to dry the mould in a stove. This necessitated the making of a bottom plate 20 ft. by 18 ft. by 6 ft., having provision for lifting and bolting.

Handling Arrangements

An examination of the pattern will show that the slinging of the mould demands more than the usual attention owing to the fact that the load is not uniformly distributed on the bottom plate. For this reason it was decided to make

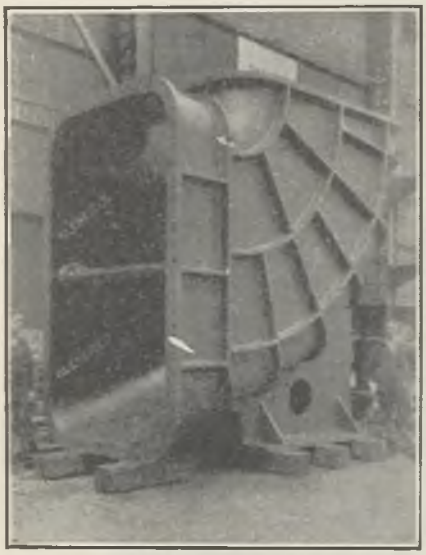


Fig. 12.—Casting for 90-deg. Bend for Exhaust Steam.

the bottom plate with lugs 12 in. square and at 12 in. centres all round the outside; by this means alternative lifts could be arranged, also provision for bolting prior to casting. The pattern being of the skeleton type of construction and therefore easily distorted, it was necessary to provide suitable bearings on which to rest the pattern.

Strickling Methods

Fig. 14 shows these bearings being swept up by a suitably-profiled board. The pattern was eventually laid on these various bearings, and on checking up was found to be perfectly level and free from distortion in any direction. Bricks and loam were built underneath the pattern to a height of three courses, the joints being packed with ashes to facilitate drying and venting; the top course in contact with the pattern was built solid, the open panels in the pattern simplifying this operation. At this stage six horizontal ingate patterns 4 in. by 1 in. were placed in position against the pattern so as to introduce metal at the cross ribs running underneath the pattern; 2-in. square downgates were placed to connect with these ingates, extending from the joint level down past the ingates for 3 in. or 4 in., so as to create a pool of metal.

From this point upwards it will be observed that the building assumes a new shape, consisting of two distinct sections, the larger section being of triangular shape having its outer walls at right angles to one another, whilst the inside assumes the curved contour of the pattern with the stool or base section projecting.

Pillar as Drawback

The smaller section is more or less an isolated pillar, and it was decided to build this in the form of a drawback for reasons which will be explained later. Building was carried up to the joint level, which was arranged where the pattern shape changes from the vertical to the circular. Building rings were placed at intervals of three courses, with reinforcing grids in all corners, soft loam bricks being built behind the flanges and at all points where contraction stresses were likely to be experienced. All joints over 4½ in. from the face of the pattern were filled with ashes, and in congested corners such as fillets straw ropes were introduced and led to the outside.

Making the Main Core

The building having reached this joint level, attention was turned to the main core. The main lifting iron for the core was of the box or girder type, 18 in. deep, and consisted of two parts so that they could be removed from the casting and used over again. Reference to

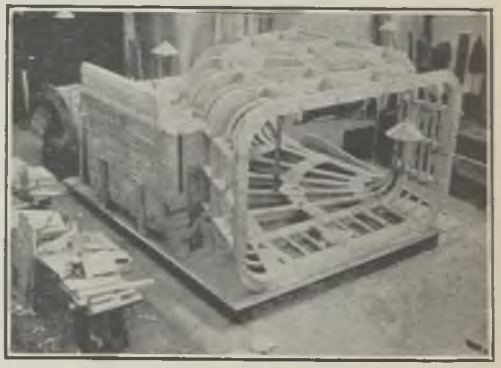


Fig. 13.—Skeleton Pattern for Bend Casting.

Fig. 15 shows the smaller portion of the iron to have four rectangular arms, which are threaded through suitably placed holes in the larger section, being afterwards securely wedged together, and making an extremely strong and rigid core-iron.

For purposes of slinging and holding down the core, three rectangular lugs were cast on each print end of the core-iron, the outside lug at each end being placed as far out as possible, so that the centre of gravity of the core should lie between a line joining these two outer lugs and the axis of the pattern. It was planned that the load would be carried by the two outer lugs at each end, and two additional slings carried up from lifting eyes in the heel of the main iron would look after the balancing or levelling of the load.

Fig. 16 shows the core slung in the manner already described. The core was built hollow, the main iron being packed with bricks and loam, side walls 12 in. thick, the top being covered by a grating with dabbers uppermost, 12 in. long. The top grating was supported at intervals on bricked pillars, 12 in. square. To assist in holding down the core during casting, a cast-iron bar, 8 in. square and 4 ft. long, was built in position on end, resting on the main core-iron and placed centrally with the 18-in. dia. hole in the top of the casting.

It was easily realised that the question of contraction in such a casting would require careful consideration, and that immediately the casting had set, steps would have to be taken to allow free and unhindered contraction to take place and prevent a possible fracture. To accelerate the easing of the core, slackening bars were built into the walls of the core near to the centre of their height. Along the longer radius this bar was in two parts, curved to suit the pattern and wedge shaped, 2 in. thick at the casting, tapering to 4 in. and 10 in. wide.

Along the shorter radius two similar tapered bars were built; these, however, were perfectly straight. In the centre of each supporting pillar a similar shaped wedge was built, 12 in. square, and provided with a mild-steel eye cast in the thicker side. Reference to Fig. 15 shows these slackening bars.

Making the Top Part

The core having been built, the joint was made and preparations for the top commenced. The top was actually in six sections, four of which carried the cope up level with the top ribs of the pattern, and bevelled down to the centre of the radius joining the top and sides of the pattern. The top-part proper was in two portions, two box-parts, 14 ft. by 9 ft. by 12 in. deep, being pressed into service for this purpose. The dividing line ran across the top to one side of the 18-in. dia. core, so that the centre of this core coincided with the last panel in one of the top boxes.

Grids were made to lift the various sections between the ribs in the top of the pattern, being toggled up through their respective top boxes. Ten flat gates, 3 in. by 1 in., were formed through the top, seven around the longer radius and three on the shorter radius, arranged to feed the metal down the mould thickness.

The building having been completed, the job

Fig. 14.—Bearings for Skeleton Pattern in Process of Sweeping.

was allowed to stiffen sufficiently to lift off the tops and turn them over; the four joint sections were removed, then the corner section between the prints at the axis of the pattern was lifted away, and the main core slung up. No trouble was experienced in lifting out the core and after one or two attempts a level sling was obtained. As soon as the core was floating evenly, it was moved away from the longer side of the pattern and lifted right out. The corner section was replaced and the remainder of the pattern drawn, the mould finished in the usual manner and lifted to the stove for drying.

The lifting lugs on the bottom plate proved of inestimable value in obtaining a level sling; by moving the chains off centre more on one side than the other the load was quickly balanced and transferred to the stove. After drying, the mould was lifted from the drying bogies and transferred to the casting pit. Referring to Fig. 13, it will be observed that the base or sole of the bend is built up solid and so requires coring out. There is a central web running horizontally through the sole, so that the core is in two portions, resting on prints at each end, the top half having a 16-in. dia. core cutting through the top thickness which serves to resist upward lift.

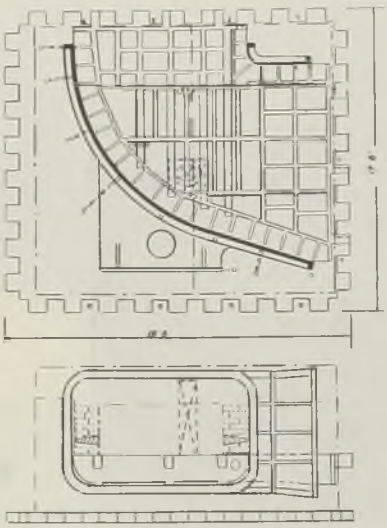


Fig. 15.—Arrangement of Bend Casting.

Coring up and Closing

Fig. 17 shows the cope of the mould with these two half-cores forming the sole in position and the joints made up. The main core was next lowered into position and presented no troubles beyond careful slinging. The four side drawbacks were next placed in position on the joint, being located by the usual system of marking. The first half top-part with the 18-in. dia. core bolted up into its print was then placed in position, a stamped joint being made between the 18-in. dia. core and the corresponding area on top of the main core. A 6½-in. square hole was carried through this core and the top-part. The second half top-part was placed in position and completed the closing operation, after which all joints were daubed up and vents secured.

The next operation to be undertaken was that of binding. It presented several interesting problems which were overcome in the following manner. At each corner of the building special cast-iron corner plates were bedded in position, being connected by 1½-in. dia. bolts running horizontally from corner to corner; sixteen bolts were used, four on each side binding the mould securely together.

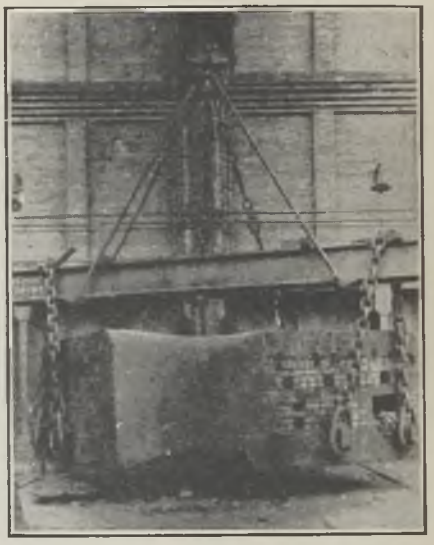


Fig. 16.—Main Core Slung from the Special Lugs.

To hold down the top-part, four bars 12 in. by 6 in. by 20 ft. long were placed across the mould, two across each half box-part and connected to the bottom plate by 1½-in. bolts. Then the beam used to lift the cope and core was pressed into commission; it was turned upside down, the lifting links were unbolted and slid out to the ends and allowed to hang down, one on each side of the cope. This beam straddled the four cast-iron binding bars and was located directly above the centre of the 18-in. diameter

core in the top-part, through which was passed a 6-in. diameter steel bar, making contact with the 8-in. square cast-iron pillar, which in turn rested on the main core-iron, as was previously explained.

An endless sling was passed over two separate lugs on the bottom plate and connected to the links of the beam by means of a shackle. Strain was applied to the middle of the large beam by the overhead crane, and wedges were driven between the beam and the four cross girders; finally the top of the 6-in. dia. bar was also wedged down securely. At each bearing of the main core, a slotted bar was placed across the three lifting lugs of the main core-iron and bolted down to the bottom plate. The mould having been securely bound, the pouring basins

Fig. 17.—Cope of Mould for Bend Casting.

and risers were prepared. Thirty tons of metal were required to pour the casting and were contained in two 15-ton and one 4-ton ladle. The shape of the pouring head more or less follows the contour of the casting.

Gating and Casting

The outside row of gates connecting with the underside of the mould, 2 in. by 2 in., were the first to receive the metal, and when it was considered that the whole of the bottom of the mould had been filled, the inner row of gates (which up to this time had been kept plugged) were opened, and fresh metal allowed to drop down the side wall thickness. The section of the pouring basin serving the down gates round the shorter radius was isolated by means of a loam shutter, until it was considered that the metal was beginning to flow over the top of the main core; at this stage, pouring with fresh hot metal from the 4-ton ladle was commenced.

When this section of the basin was filled, the shutter was removed so that, if the smaller ladle should by any chance be emptied before the larger ones, the head would be maintained and dirt and scum be prevented from flowing into the mould. Risers were taken off each end of the main flanges, each end of the stool flange and the centre branch in the top.

Within a matter of two hours after casting, the pouring basin and runners had been broken, top binding-bars removed, and the top-part cleared of all sand and tackle.

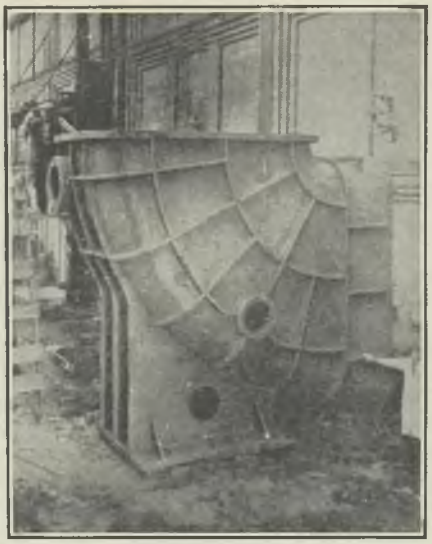


Fig. 18.—Bend Casting during Fettling.

Two gangs, each of four fettlers, now began the task of freeing the main core from the contracting metal. The internal pillars were first removed, the tapered blocks making this a comparatively simple job. Two baulks of timber were now placed in position, one at each end to support the top grating of the main core. Next the two slackening bars along the shorter radius of the casting were removed, using the overhead crane through the medium of a snatch-block and pulley. The brickwork in this area was removed from top to bottom so as to permit the smaller side of the casting to move in towards the large side.

Finally, the two slackening bars in the longer side of the core were removed, also by crane power. To complete the slackening operations, a chain was passed round the bottom of the timber baulks and a pull by the crane caused the top grid of the core to collapse, thereby freeing the casting in all directions. The ends were now

covered in with sheets to prevent cold air entering, and after several days had elapsed the casting was dug out and fettled. Fig. 18 shows the casting during fettling.

The analysis was T.C, 3.42; Si, 1.92; Mn, 0.75; S, 0.087 and P, 0.21 per cent. The casting temperature was 1,280 deg. C. and the pouring time 160 secs.

Vote of Thanks

Following the reading of the Paper, Mr. A. L. Key proposed a vote of thanks to Mr. Lawrie for his excellent lecture, which should convey to anybody not thoroughly acquainted with loam moulding the amount of effort, foresight and knowledge which was required to produce successfully castings such as those which had been described. One great difference between arranging to make a casting in loam and a casting in sand was that, with loam moulding, practically everything had to be constructed. When the drawing was received, the casting had to be visualised in the finished condition, and the various lifting weights involved had to be calculated and allowed for. Moreover, tackle had to be designed for loads with irregular distribution of weight, to obtain easy handling.

Mr. W. Holland, seconding, said he did not know another foundryman in the country who had had more experience than Mr. Lawrie in such work. The Branch would welcome an early return visit from him.

The vote of thanks was carried unanimously, and Mr. Lawrie briefly responded.

DISCUSSION

Mr. Holland asked whether the bend casting was rammed up in a pit before casting, after it had been bound down.

Mr. Lawrie replied that it was rammed up partially, although it was not considered necessary; after all, the four corner pieces took care of the holding of the job together. It was lightly rammed up round the longer side simply to prevent people falling into the pit.

Mr. A. Phillips referred to the boring bar, and asked whether any packing pieces were placed at the bottom of the pit, or whether the box was sufficiently strong to take the strain, because it seemed to be a heavy sectioned casting at the bottom. He did not notice any stoppers on the runners. Were they used, and, if so, of what type?

Mr. Lawrie had only stated the composition of the castings, but he would agree that this was not everything. The make-up of the charge was of more importance in getting a good casting, and he would like to hear something of its nature. Did Mr. Lawrie loosen the round runners on the top to help in the contraction, or did he leave them as they were, and release a plate?

Casting Details

Mr. Lawrie replied that the box was sufficiently strong to withstand any pressure. The boxes were all 2 in. thick, and, as shown in one of the illustrations, the box was suspended on two bars running the length of the box. There were no stoppers. The gates were all covered by pieces of tin, 6 in. square. As the material was used in conjunction with the Meehanite patented process, he asked to be excused from detailing the composition of the charge. He had omitted one point regarding the running of the boring bar; there was an 18-in. head on the casting. The casting was continued parallel for 18 in., and at a point where the casting finished and the head began there was a flow-off riser. When the metal came to the riser, it overflowed and the head was allowed to drain itself. The hole was botted up, and the head was supplied with fresh hot metal to permit of progressive solidification. After the head had set, the pouring basin was lifted off, and, being semi-plastic, it pulled itself away, so that the runners were left free and sticking up from the top of the casting. Both the boring bar and the bend pipe weighed 25 tons.

Drying *in Situ*

Mr. E. Longden, having had considerable experience of that class of work himself, said he was sure that Mr. Lawrie was working on the very safest lines possible. The company with which he had been associated was obviously well supplied with the essentials for making such work, and particularly with excellent cranes. He should imagine the firm had a 100-ton capacity crane to lift the heavy loads. He had in mind the bend casting, where they lifted a heavy mass of material. He, personally, would not lift such a mass of material, but would dry it on site. His firm dried very effectively much heavier masses *in situ*; a worthwhile amount of labour and tackle would thus be saved. Actually, the tackle for the bend casting must have been much greater than the weight of the casting itself.

It had been pointed out that there was an 18-in. head on the boring bar, and that this head had been fed early. It was evidently sufficient in the way which it had been treated, *i.e.*, to supply it later on with hot metal. Otherwise, to his mind, it would be hardly sufficient. No one could question the method of making either of the two castings, which were highly craftsmanlike accomplishments.

Mr. Lawrie said they had a 60-ton and a 30-ton crane, and the bend was lifted by the

60-ton crane. No more tackle was required for lifting the job into the stove than would have been required for making in the pit. The bottom plate was essential, and as he had to make one, he provided it with lugs, so that it would not only make the bend pipe, but could be re-used. It had, in fact, been used later for planing-machine tables.

Local Considerations

Mr. Longden suggested the bottom plate was not essential, as much heavier work had been done without a plate.

Mr. Lawrie agreed that that was possible by putting the bars in the pit. Fortunately, he had had stoves 36 ft. long, 12 ft. high and 20 ft. wide, and could dry more efficiently and quicker in a stove than on any floor.

Mr. Longden asked whether one was justified in making the tackle, which would be of greater weight than the casting itself.

Mr. Lawrie: The bottom plate weighed 30 tons and the casting 25 tons.

Mr. Phillips suggested that the foundry being against the river was the reason why the job had been dried in the stove.

Mr. Lawrie agreed. He added that the bend casting was made in the pit, and dried with two portable driers. The prime reason for the first casting being dried in the stove was because the pit was 7 ft. deep, and during the initial excavation a labourer was seen putting a bar into mud in the pit bottom, so that there was no point in drying the mould and drying the river at the same time! With regard to the head, the casting was continued for 18 in., and filled with hot metal, so that it was progressively fed from the bottom upwards.

Mr. Longden said the provision of appropriate tackle of suitable height in a foundry was very important. His firm, he said, had on hand at the moment three boring bars, the largest of which was 20 in. in diameter and 47 ft. in length, and, because of its length, had been cast flat on the floor. It was far more hazardous to cast on the flat than on end.

Run-off Risers

Mr. Key was rather surprised that Mr. Lawrie did not amplify his explanation of the run-off riser. It was possible, even although that tackle looked robust, that, had Mr. Lawrie failed to run without having an easing riser, probably, with the bolts that he had, the staple would not have been strong enough to hold the job. He recalled three hydraulic cylinders which were moulded on the flat and cast on end. The first two, when cast, burst in the pit. The third one the foundry determined should not burst. Four moulders and four labourers were busy for three days putting in bars, bracing, strapping and bolting. A safe lift was obtained, but as soon as the metal reached the top, the mould burst. That firm realised they could not make those particular castings, and gave out the work to another foundry, which made some very good castings. Upon the customer finding out, he insisted on the original firm making them. It happened that he (the speaker) then joined the original firm, and he asked to have his own way on the job. He worked along similar lines to those outlined by Mr. Lawrie. He procured two boxes, 32 in. long, and put a flow-off riser, which measured 6 in. by 2 in., three inches from the top of the head, which was 2 ft. deep. He controlled the pouring, and as soon as the metal came near the riser, he stopped pouring and ran off into a trough. Two castings were successfully made. After he had left he heard that the management returned to the system previously used with disastrous results.

The point of this experience was that, until the mould was filled, one only had what might be described as the ordinary specific weight, but with the metal rising, there were additionally dynamic conditions. As soon as the metal reached the top, the flow was arrested, and according to the height of the ladle, which increased the effect of height, there was a check in flow which caused a sudden rebound. Unless the boxes were exceptionally powerful, it was courting disaster. He had not cast a job on end for many years; nor had he allowed the box to be filled to the top, because he had seen many jobs fail in the same way. He thought that was the main reason why Mr. Lawrie did not fill his box to the top.

Conflicting Theories

Mr. Lawrie said that Mr. Key's suggestion was entirely wrong. The flow-off riser was definitely to carry off the dull, sluggish iron, on top of which there was always a certain amount of scum and dirt. He could quite easily cast such a job without a flow-off riser, and had done so. An interesting point, however, had been raised. There was a mould with the core coming right through, and a ladle pouring metal into the pouring basin and dropping through gates to the bottom. In this particular case the pressure was over 100 lbs. per sq. in. at the bottom. Mr. Key said that the height of the ladle had to be taken into consideration. With this he entirely disagreed.

Mr. Longden drew attention to the momentum of the metal.

Mr. Lawrie said that the height of the ladle could not be correlated with the pressure.

Speaking of the pressure, the static pressure was calculated from the highest level in the pouring basin, and not from the lip of the ladle. The municipal engineer would say that the pressure at any point was so much per sq. in., simply because he calculated the difference of height between that point and the level of the reservoir whence the water was flowing. According to Mr. Keys' theory, the municipal engineer should really take as his topmost level, not the reservoir level, but the heavens from which the water came!

Mr. Key differed from Mr. Lawrie. If an ordinary flat top-box, with fire bars in it, and with sufficient weights placed on top to hold it down, was poured and filled, nothing would happen. If, however, men elevated the ladle and continued pouring, what happened? The top would be lifted off.

Mr. Longden said that the stream of metal at the top of the head exercised a greater momentary pressure due to momentum. He thought both Mr. Key and Mr. Lawrie were right.

Mr. Phillips also thought the two opinions were correct, and gave figures showing the serious effect of gravity and momentum.

Loam Mixtures

Mr. J. Masters, Senr., said that he had had a great deal of experience of casting jobs of extensive length, and had never taken the metal to the top if it could be avoided. In Mr. Lawrie's opinion, was it necessary to have two separate mixtures of loam for the large boring bar? It was appreciated that the difference between the pressure at the bottom and at the top of the mould was very marked, and his rough estimate was 200 tons pressure at the bottom of the mould. Did Mr. Lawrie radius on the bottom of that bar and the joint, or did he bring it up dead square? A 12-in. section of the bottom had been shown; was that radiused off to break the strain?

The Branch-President (Mr. H. V. Grundy) asked whether Mr. Masters meant the avoidance of the knife-edge effect of the metal.

Mr. Masters agreed.

Mr. Lawrie said the same loam was used throughout for the mould and the core. The loam used in Ayrshire was made up from two parts of local river gravel to one part of gravel found on the shores of one of the inland lakes, ground in a pug mill for 20 minutes to develop the bond. If a pebble taken from river sand was broken, concentric rings could be seen, which were caused by the action of water and clay over many thousands of years. When these pebbles were ground, the clay bond was brought out; it was curious where it came from, but the bond was present on milling.

Mr. Masters asked if any bonding material such as manure was used.

Mr. Lawrie said it was not. Although sand experts would declare that there was no permeability in loam, in his opinion there was a certain amount.

Contraction of Meehanite

Mr. Phillips asked, when making a bend in ordinary cast iron, whether the same amount of easing should be afforded as with the example described.

Mr. Lawrie said there was no difference in the contraction of the Meehanite used and ordinary cast iron, and he, personally, would make it exactly the same. It would be appreciated that that job made in ordinary grey cast iron would contract considerably, and would require the same attention as did Meehanite.

Steam Feeding

The Branch-President said mention had been made of feeding. Had Mr. Lawrie had any experience of steam feeding? He (the speaker) had visited a Scottish foundry and found a very good illustration of the advantages of steam feeding. As a result, his firm had put the idea into operation, and experience had proved its worth in certain cases. Did Mr. Lawrie think this method would help in a job such as that referred to, to avoid rod feeding? Many castings required feeding for a considerable time—in some cases hours, which involved fatigue of the men.

Mr. Lawrie had not had experience of steam feeding. He had never rod-fed a boring bar, hydraulic arm or cylinder, but used a feeding head. For the bend, the risers were certainly above the flange. The four corner flanges were fed by rod-feeding, but wherever possible he tried to eliminate this procedure, because very few moulders could do it. Instead, he designed a riser which did the feeding itself, and which remained liquid until the casting had set.

The Branch-President said steam feeding had been detailed in a Paper* presented to the West Riding Yorkshire Branch of the Institute. He thought that method would prove advantageous in many instances where, at the present, recourse had to be made to hand feeding.

Mr. Longden asked why there was recourse to chaplets in the bend.

Mr. Lawrie said they were screwed studs of $\frac{3}{4}$ in. dia. with a piece of hoop iron on top.

* "Feeding of Castings, with Special Reference to the Steam Pressure Method," by B. Hird. Proc. I.B.F., Vol. XXXI, pp. 730-739.

Dirt in Riser Metal

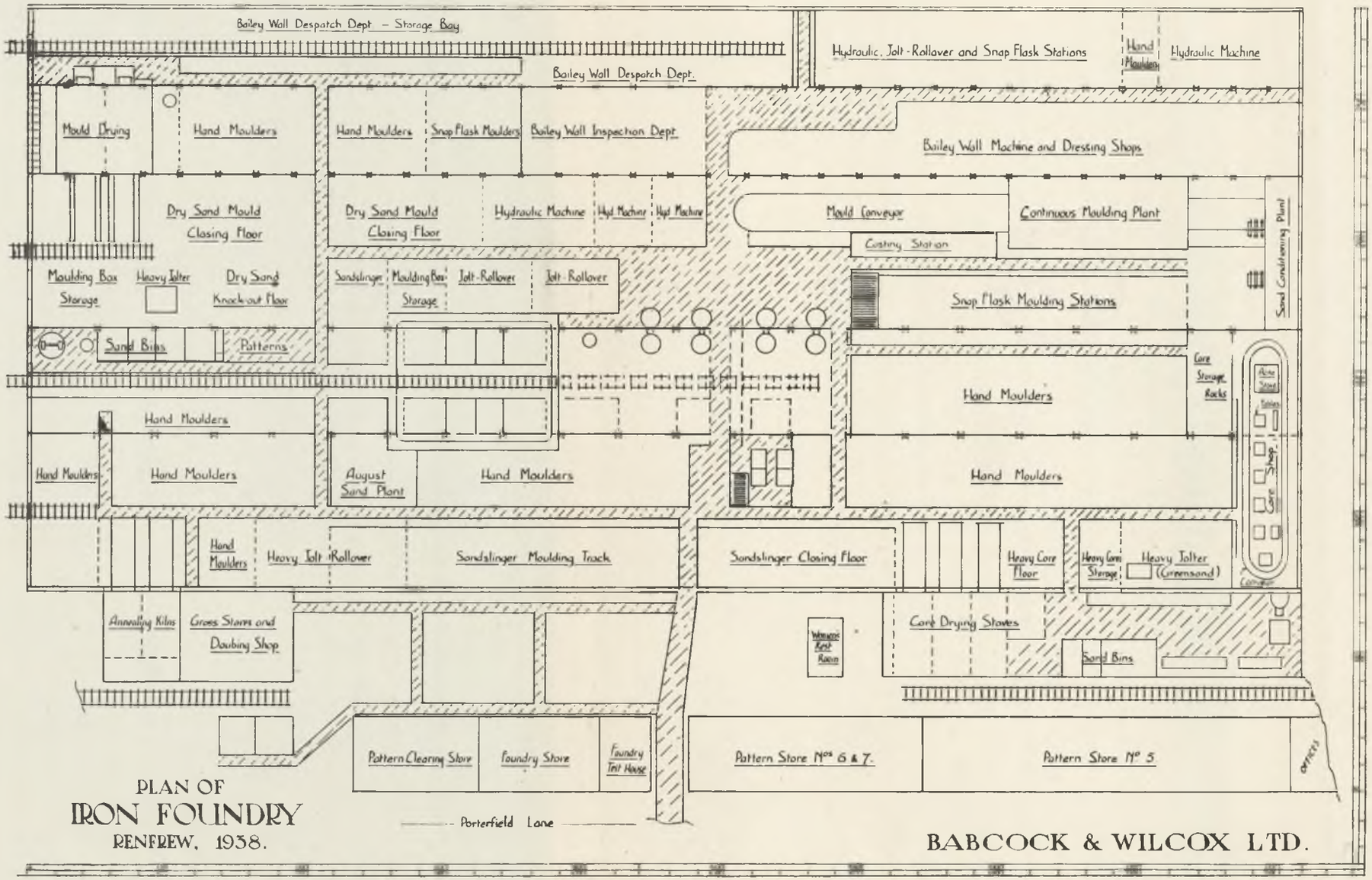
Mr. A. Sutcliffe wondered whether Mr. Grundy had examined the runners used when casting a flat plate. If he had done so, he would probably observe that the metal, immediately after casting, was a short distance down the runner, but that in a short time the distance had disappeared. This, he thought, explained the system of feeding with a cold plate covered by loam which prevented the metal from coming back. Mr. Lawrie had referred to dirt coming up a riser, and the speaker thought that was a mistake. The only dirt which came up a riser was what was underneath it. Mr. Lawrie had backed the casting with two wood baulks. He did not like this method, because of the fire hazard.

Mr. Lawrie, referring to dirt in the riser, agreed that the riser never took away dirt unless it was directly beneath it. He had said there was a riser at each corner, but he also said they were designed so that dirt originating there would go up these risers.

Mr. Sutcliffe: Some of the dirt.

Mr. Lawrie said that most of it rose. When the risers were chipped off there was no dirt at all; they were clean all over. The width of the flange was 6 in., and the riser was 9 in. or 10 in. at that point. As to timber baulks catching fire, there was 12 in. of loam below and 12 in. of bricks and loam above, thus yielding little or no heat. With regard to the question of gates going down and up, he referred members to an excellent Paper given several years ago by Mr. Dorsie, of the Scottish Branch, on light casting problems, in which were given the results of experiments carried out with ordinary rain-water gutters, with indicators on the ends, showing how much they went up and down.

Mr. Longden said the explanation was that there was an evacuation of gas from the mould. The shell expansion caused the sinking of the mould.



PLAN OF
IRON FOUNDRY
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Paper No. 698

Melting Practice in a Large Engineering Iron Foundry*

By W. W. BRAIDWOOD (Associate Member)

The foundry concerned is engaged in the production of castings for steam-raising and general engineering purposes. The melting plant comprises four cupolas, each with a capacity of from nine to ten tons per hour; one cupola, melting four tons per hour; and an oil-fired crucible furnace, but this Paper will deal only with the operation of the larger cupolas.

The general arrangement of the foundry is illustrated in Fig. 1, and it will be observed that the cupolas are situated almost centrally. This feature is probably a departure from the orthodox, yet such a position, especially in a large foundry with a heavy daily melt, may be claimed to possess the following advantages:—

(1) The "spout to mould" time interval approaches equality in all instances.

(2) Return of floor scrap to the charging system is rendered more easy.

(3) Melting plant accessory equipment may be utilised to a greater extent.

The latter point probably requires elaboration. In the present instance, the cost of construction of the very substantial charging platform made necessary by the technique employed is partially neutralised by utilisation of the main columns as supports for crane gantries in adjoining bays. Similarly, the overhead crane serving the cupola charging system is available for the handling of materials other than furnace requisites. Actually, the normal "spare time occupation" of this particular tool includes the handling of approximately five hundred tons of sand per week.

The larger cupolas, which are responsible for over 96 per cent. of the normal daily melt, are of the Balanced-Blast type, to the design of the British Cast Iron Research Association. They are normally operated as two units of two furnaces each, one unit providing the cupola which is in service throughout the entire working day, while a cupola from the second unit is in blast each afternoon. Each furnace, therefore, is in service only on alternate days, so that ample time is available for careful fettling between melts. Flexibility, however, is the keynote in their operation, and, in the event of a major breakdown or lengthy repair, the duties of all-day and of part-day melting can be allocated anywhere within the battery. These cupolas, all of which incorporate stationary, inert receivers, are of identical design, and are as shown in Fig. 2.

Underlying Principles of the Balanced Blast

The external appearance of a Balanced-Blast cupola is already familiar to most foundrymen, and the principal theory underlying its design is also generally understood. It may be re-stated briefly. When air comes in contact with incandescent coke, carbon dioxide is the product first formed. This reaction between oxygen and carbon is strongly exothermic, and great heat is generated. In presence of excess carbon at high temperature, however, the dioxide may be reduced with formation of carbon monoxide, an inflammable gas. This latter reaction is endothermic, a considerable amount of heat being absorbed. Actual heat values[1] may be quoted:—

1 lb. of carbon burning to form the dioxide, generates 14,550 B.Th.U.

1 lb. of carbon burning to form the monoxide, generates 4,350 B.Th.U.

1 lb. of carbon (as monoxide) burning to form the dioxide, generates 10,200 B.Th.U.

In the older type of cupola, the monoxide so formed was left free to pass up through the preheating zone, and into the stack. Generally, the presence of appreciable proportions of carbon monoxide in the waste gases of an ordinary cupola is indicated by the presence of a bluish flame at the sill, where this gas burns on coming into contact with the oxygen of the air. The principal aim of the Balanced-Blast design is the complete combustion, within the cupola, of this inevitably-formed monoxide, with consequent improvement in the thermal efficiency of the furnace, and this is effected by the introduction, above the producer zone, of sufficient air to burn the monoxide to dioxide.

Articles[2, 3] by well-known operators have already described this type of cupola, and con-

* The author was awarded a Diploma for this Paper,

troversies regarding the benefit, or otherwise, of such auxiliary tuyeres have been exhaustively waged. The present writer, as is his nature, was originally a sceptic, but now, after three years of experience with Balanced-Blast cupolas, operated during several months alongside orthodox cupolas of similar dimensions, the author, as may be judged by the form of his participation in a major controversy,[4] is a strong supporter of this particular type of recuperative cupola. There can be no doubt that the balanced-blast system constitutes a definite advance in cupola design, and, with understanding control, its economic potentialities are really considerable. In the opinion of the writer, however, the undoubtedly improved results associated with its use are not entirely, nor even principally, the product of the more complete combustion made possible.

Broadly speaking, the efficiency of a cupola is measured in terms of the temperature of the tapped metal. A recent preliminary investigation of the effects of operating one of the Balanced-Blast cupolas under the author's charge with various tuyere settings revealed that improvement in the efficiency of the process of combustion, as indicated by exhaust gas analysis, was not necessarily accompanied by increase in the temperature of the tapped metal. In fact, there was seen to be no direct relation of combustion efficiency with metal temperature, and the most definite indication yielded by this preliminary research was that, when conditions were such as might be expected to maintain a deep bed of highly-incandescent coke, the highest metal temperatures were obtained.

This finding has support in logic, since the prime factors determining the temperature of metal tapped from a cupola undoubtedly are "bed temperature" and "time of exposure." Therefore, it may be argued that, where a relatively deep bed is maintained, the temperature of each metal droplet, by reason of the longer time of exposure to high temperature conditions, is relatively more able to approach that of the heating medium.

It is in the light of this reasoning that the Balanced-Blast cupolas under the author's charge are operated. The principal aim is the economical maintenance, in a highly-incandescent condition, of a deep coke bed, this being accomplished by judicious distribution of the necessary air. In passing, it may be of interest to many operators of Balanced-Blast cupolas to learn that the tuyere settings at present very successfully employed in the cupolas under discussion are:—

All three rows of auxiliaries: Full open.
All main tuyeres: Half open.

The internal contour of these cupolas is a noteworthy feature, the taper from shaft to well being very pronounced. Calculations from the actual diameters, which are 66 in. and 36 in. in shaft and well respectively, show that the cross-sectional area of the shaft is 3.36 times that of the well. In the standard design of these cupolas, the latter diameter is quoted as 48 in.; this would give a ratio of only 1.9 to 1,

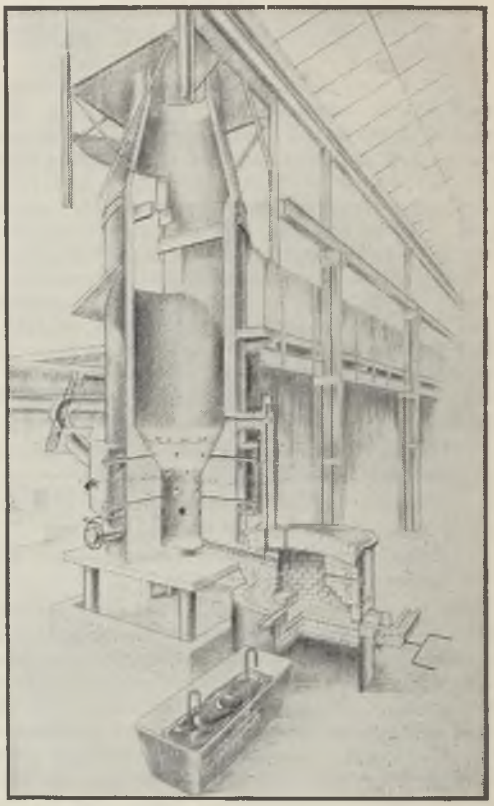


Fig. 2.—Sectional View of the Cupola and Receiver, together with the Method of Slag Disposal.

which is more representative of the conventional. Maintenance of the pronounced taper depicted has proved to be a very successful method of improving the efficiency of these cupolas, and the theoretical advantages may be enumerated.

(1) The air is introduced nearer to the centre of the cupola cross-section. Consequently, more complete penetration of the blast across the bed should be obtained, thus promoting more regular combustion of the

bed coke, and more uniform melting of each metal charge.

(2) The furnace gases pass from a narrow well into a relatively wide shaft. This may be expected to reduce the velocity of the ascending gases, and render more efficient the transfer of sensible heat from the hot ascending gases to the cooler descending materials.

(3) The required height of the coke bed is more economically obtained.

(4) The cost of lining wear is reduced.

As evidence in support of the second claim, it may be stated that the normal average temperature of the exhaust gases does not exceed 250 deg. C., while the coke saving referred to in the third paragraph is really appreciable, amounting to approximately 10 cwts. per bed, or 40 per cent. of that weight which would be required to give the desired bed height within a 48 in. diameter lining.

Fettling

This operation is carried out in a thorough manner at Renfrew, gauge sticks being used at each repair to ensure conformity with the contour shown. There is no doubt that such careful fettling pays a dividend by promoting uniform and safe cupola operation, and by reducing ultimate maintenance costs.

The condition of the lining of a Balanced-Blast cupola, after a long melt, can be a helpful pointer toward improvement in the method of its operation, and this general observation may be made. Localised wear, in the form of a distinct horizontal furrow, its centre about 24 in. above the level of the main tuyeres, may be expected when these are set in the fully open position. As the main tuyere openings are reduced, however, this tendency to produce localised erosion is correspondingly decreased till, with the tuyere settings normally in use, and already detailed, wear on the lower sections of the cupola lining becomes remarkably uniform, and really slight.

Costs are of particular moment when fettling methods are under review, and the following figures are probably of interest. Over a test period of four weeks' duration, the weight of material used at each repair following an all-day melt was carefully observed, and recorded, together with the metal throughput in each instance, and the ratio of purchased material to metal melted was found to be as 1 is to 105, the cost equivalent being 5.54d. per ton of metal melted. Lining wear on these cupolas melting for part of the day only is less, but not proportionately so, with the result that the overall cost of ganister per ton of the total melt is higher than in the particular instance quoted. Actual ganister cost for 1938, on a total melt of 30,166 tons, and using a high-grade material priced at 48s. 6d. per ton, delivered, was equivalent to 7.77d. per ton of metal melted.

(This figure, of course, includes those amounts of ganister employed for miscellaneous, and sometimes surreptitious, purposes throughout, and conceivably beyond the confines of the foundry).

When fettling is complete, and the sand bottom carefully rammed, kindling wood is inserted, care being taken to place flat boards on the bottom, and against the walls, in order to protect those parts from injury. Exactly half of the necessary weight of bed coke is then dropped in, gently, by hand.

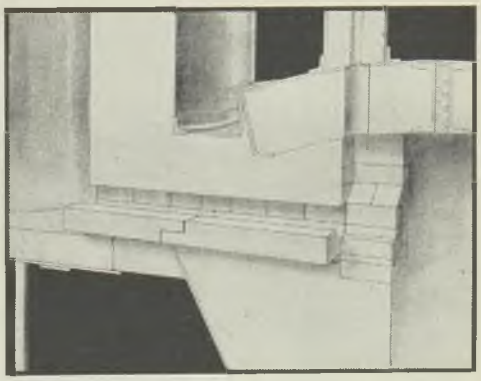


Fig. 3.—Details of Receiver Construction.

In the case of that cupola required to be in blast on the morning of the following day, the bed is lit in the late afternoon, and allowed to kindle freely for some 45 minutes. After this period, the back door is rammed up and covered, all tuyeres closed, and the bed left to burn very quietly overnight. This procedure has several advantages:—

(1) The patch is gently heated, initially, and is dry, hard and hot when the cupola goes into service.

(2) The furnace can be in blast next day in the shortest possible period of time.

(3) The bed eventually has a thoroughly incandescent lower layer which promotes rapid and uniform melting.

Receiver Practice

Opinion in foundry circles continues to be divided on the subject of hot-metal receivers. Generally, the disadvantages attending the use of cupola receivers are stated as under:—(a)

heavy heat losses are incurred, and (*b*) maintenance is an item of considerable extra expense.

It has been stated that sharp separation of differing and successive metal charges is difficult where a receiver is in use, but, to the author, this claim has always seemed unreasonable. Mathematically sharp separation of such charges is never possible in any cupola, unless exceptional coke separations are employed, and the best that normally can be expected is a swift transition from the characteristics of one charge into those of the other. This is no more difficult though a receiver be interposed between furnace and outlet, since the receiver can be drained at such stages just as the cupola may. It is surely logical to claim, then, that this alleged disadvantage does not, in fact, exist.

Regarding (*a*), heat losses, though undoubtedly incurred, are not so considerable as is often imagined, and may be reduced, as at Renfrew, by insulation. Tests carried out on insulated and uninsulated receivers of otherwise identical design, operated under standard conditions, confirmed that appreciably hotter metal was tapped from the former type, while their shell temperatures were much reduced. The opinion of the writer is that heat losses in, and from, an insulated receiver have little practical effect once the temperature of the inner surface has been raised to that of the metal delivered from the cupola. The inference, however, that the metal first tapped must be very cold, should not be drawn. Actually, the temperature of the first-run metal is somewhat lower than the normal, yet this difference is slight, particularly in the case of those furnaces kindled on the previous evening, and there is no difficulty attending the disposal of this first metal. The usual procedure at Renfrew is to take the first thirty cwts. in a ladle for the casting of heavy section structural work, the succeeding metal being supplied, immediately afterwards, to the continuous-casting plant, for the pouring of stoker links of light section.

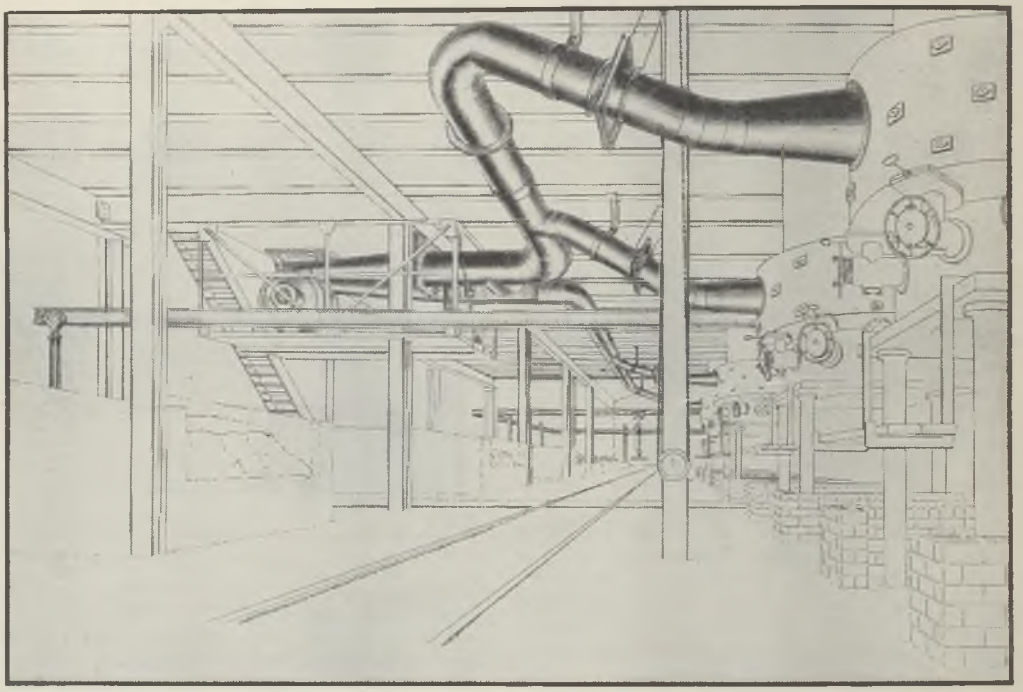


Fig. 4.—The Blowing Arrangements for the Cupola Plant.

Concerning (*b*), it may be claimed that money spent on the maintenance of a receiver is in some respects a sound investment. Because of the immediate transfer of metal and slag to the receiver, wear within the cupola is reduced, and, as a matter of actual fact, cupola repairs, apart from the routine fettling, are observable at Renfrew mainly by their absence. The furnace last re-lined, at the time of transfer to its

present situation, is still in perfect condition, after two years of service.

The special firebricks which form the runner from cupola to receiver, shown in Fig. 3, contain 42 to 44 per cent. alumina, and have an average life of 800 to 1,000 tons of metal melted. Renewal is a fairly easy matter, and is carried out without interruption of the melting sequence. Receiver bottoms are re-laid very infrequently, generally after total melts of 4,000 to 5,000 tons, while inner brick courses are good for twice that amount. The very useful segmented roofs are practically everlasting, and, altogether, the receivers in use, and as operated, are items of only moderate cost.

So much for the generally-accepted disadvantages of cupola receivers. What now, of the advantages associated with their use? They are:—

(1) Immediate removal from the cupola of its molten products dispenses with the necessity for providing storage space within the furnace proper. This permits of the main tuyeres being placed quite close to the cupola bottom, with consequent saving in bed coke. Furthermore, the safety factor is greatly increased, and the operator relieved of the necessity for constant watch on slag level within the cupola, while slag attack on the cupola lining is minimised.

(2) The reservoir of molten metal which can be maintained within the receiver assists in ensuring tapped metal of uniform composition, while affording ample opportunity for the removal, by flotation, of non-metallic inclusions.

(3) With a tap-hole of suitable diameter, the receiver is enabled to provide a continuous flow of clean metal over long periods, thus dispensing with the need for frequent botting and tapping.

(4) Relatively large quantities of hot metal may be accumulated for subsequent rapid tapping when heavy castings are required to be poured at high temperature.

(5) Slag removal is rendered an easy, infrequent, and thermally economical operation.

(At this juncture, it is difficult to resist the inclination to ponder whether those persons so conscious of, and emphatic regarding, the thermal losses attending the use of inert receivers realise how much heat, and metal, can be lost through the constantly-open slag notch which is a familiar feature of many foundries.)

The construction of the type of receiver in use is shown in Fig. 2. The runner is laid at an angle of 2 deg. to the horizontal, and a splash-block, built under the fall, protects the bottom from selective erosion at this part. The bottom consists of a single brick course laid on edge over a layer of silica sand approximately ½ in. thick. This facilitates removal when renewal becomes desirable. Below the sand is a double course of firebrick, insulated from the shell by a layer of compressed asbestos. The walls are built with an easily-removable inner course 4½ in. thick, backed by a further 9 in. of

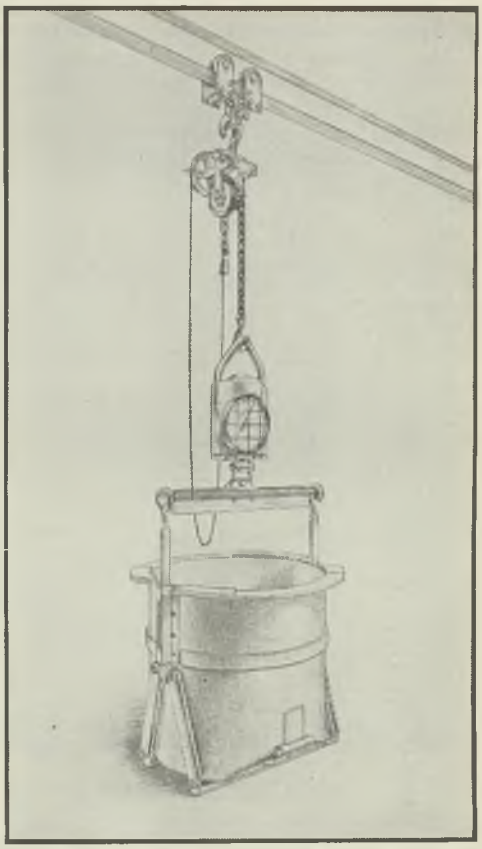


Fig. 5.—Type of Skip Used for Handling Charges for the Cupola.

firebrick. Behind this is an insulating layer, 3 in. thick, with a further 4½ in. of brick against the shell. The slag notch is positioned 5 in. above floor level. The segmented roof is noteworthy, and of real value in rendering the receiver readily cooled and easily accessible when repair is necessary. The tilting launder is very effective, and of simple design, yet sufficiently familiar to need no further description.

Slag

The operations of slag removal and disposal are simple, clean and inexpensive, the apparatus being as shown in Fig. 2, and the procedure as follows:—

Between the two receivers of each unit a cast iron vessel, bath-shaped and of heavy section, is secured. In each bath a 6 in. deep sand layer is maintained, and into this a lifting bar, of the type shown, is set. At intervals of from 2 to 3 hours each, and when the receiver has just been drained of metal, the notch is opened, and the accumulated slag allowed to flow from the receiver into the bath and over the bar,

TABLE I.—*Typical Slag Analyses, with Calculated Melting Losses.*

	October	November	December	Average
Silica ($Si\ O_2$)	47·46	48 50	46 76	47·57
Alumina ($Al_2\ O_3$)	8 51	9 72	10 30	9·51
Iron Oxide ($Fe\ O$)	10 14	10 39	10 69	10 41
Manganese Oxide ($Mn\ O$)	2·74	5 58	5 67	4 66
Lime ($Ca\ O$)	26·10	23 22	23 50	24 27
Magnesia ($Mg\ O$)	5 58	2·74	3 09	3·80

Average Silicon loss from metals charged - approx. 10% of that available

Average Silicon content of metals charged - 2 5%

Weight of metals charged : Weight of slag produced is as 22 : 1

∴ Concentration in the slag of Silicon oxidised from the metals charged :- $\frac{2\ 5 \times 10 \times 22}{100}$ % = 8·5%

Iron concentration in the Slag :- $\frac{10\ 41 \times 56}{72}$ % = 8·1%

Manganese concentration in the Slag :- $\frac{4\ 66 \times 55}{71}$ % = 3 6%

Total concentration in the slag of elements oxidised from the charged metals :- 17·2%

But the metal weight : Slag weight ratio is 22 : 1

Therefore oxidation loss from metals charged = $\frac{17\ 2}{22}$ = 0 8%

the blast being interrupted for a few seconds only, during replacement of the bott. On cooling, the block of slag is withdrawn by overhead crane, and transported to the yard by electric bogie. There it is shattered by a blow from a heavy ball, and the pieces utilised in a scheme of land reclamation. Slag remaining in the receiver at the end of a melt is similarly collected, a sand-covered bar being set in a trough below the receiver breast, which is then burst open.

Table I shows typical slag analyses, together with the calculated average total oxidation loss. This is found to be rather less than 1 per cent. of the weight of metal charged.

Air Supply

Fig. 4, which is a view from a vantage point under one end of the charging platform, effectively illustrates the layout of the air supply system. The two high-pressure fans serving the four larger cupolas are underslung from the main platform members in a position midway between the two furnace units. The blast mains are swept into the respective windbelts with only slight change of level, and in a manner calculated to offer a low degree of resistance to the air stream. Normally, No. 1 fan serves the first, and No. 2 fan the second, unit of cupolas, but the valves are positioned so as to make possible the serving of any cupola from either fan. Moreover, and this is further evidence of the flexibility of this melting plant, it is quite possible to supply any two cupolas from either single fan. This feature would be a convenience in the event of a breakdown of either fan—a circumstance which has not yet been experienced.

Twin "Kent-Hodgson" manometers, installed adjacent to the fans, indicate the respective volumes of free air passing in unit time to each of the cupolas in service. The entire absence of uprising mains represents a very real contribution to the neatness of the plant, and renders the cupola bottoms easily accessible.

Charging

Systems providing for the charging of cupolas by mechanical means are very frequently regarded as being, at best, only somewhat inferior substitutes for hand-charging. When such comparisons are attempted, a great deal depends upon the particular types of mechanical and of manual charging contrasted, and general verdicts are, therefore, quite impossible. Experience at Renfrew, however, definitely has shown that, since the installation and operation of the system of mechanical charging about to be described, the cupolas have attained to, and have maintained with absolute consistency, a standard of performance which had never before been possible. The management is proud of the charging system, principally because it was conceived and constructed within the organisation.

The two essential requirements of the design were:—

(1) The provision of means to ensure accurate weighing, in an easy and rapid manner, of all of the constituents of the furnace charges: these to be contained in self-discharging vessels of robust construction, simply operated, and (2) the provision of means whereby the charges, thus prepared and con-

tained, could readily be transported to, and deposited within, the cupolas.

The weighing apparatus is shown in detail in Fig. 5. The self-discharging vessels in use are suspended, by means of roller-block, chain-hoist and dial-registering scale, from a monorail which surrounds the material bins. The respective tares of every bucket, and of every lifting bar, have been standardised, and each scale is adjusted to read as zero the total weight of any bucket on any bar. Thereafter, each scale, by units of 7 lbs., registers loads up to 21 cwts.; a non-recording interval of 3 cwts. being provided initially.

The general layout at ground level is as illustrated in Fig. 6. Storage bins for the accommodation of furnace materials are built on both sides of the permanent way which serves the bay and passes under the cupola platform. The bay is spanned by an overhead crane of 2 tons capacity, fitted to use an electro-magnet as required, and gross handling is carried out in the following manner.

The purchased materials are shunted in each evening, and discharged into their respective bins overnight, the metals by electro-magnet, and the non-magnetic materials by hand. This operation, involving the handling of up to 150 tons of material per night requires the use of the crane for approximately half of its available working time and the services of one labourer, who discharges coke, limestone, refractory materials, etc. Home scrap is delivered to its particular bin, partly during the night and regularly throughout the day, by internal transport. During the day, the crane is in use for handling the buckets to and from the cupola platform, in the manner to be described.

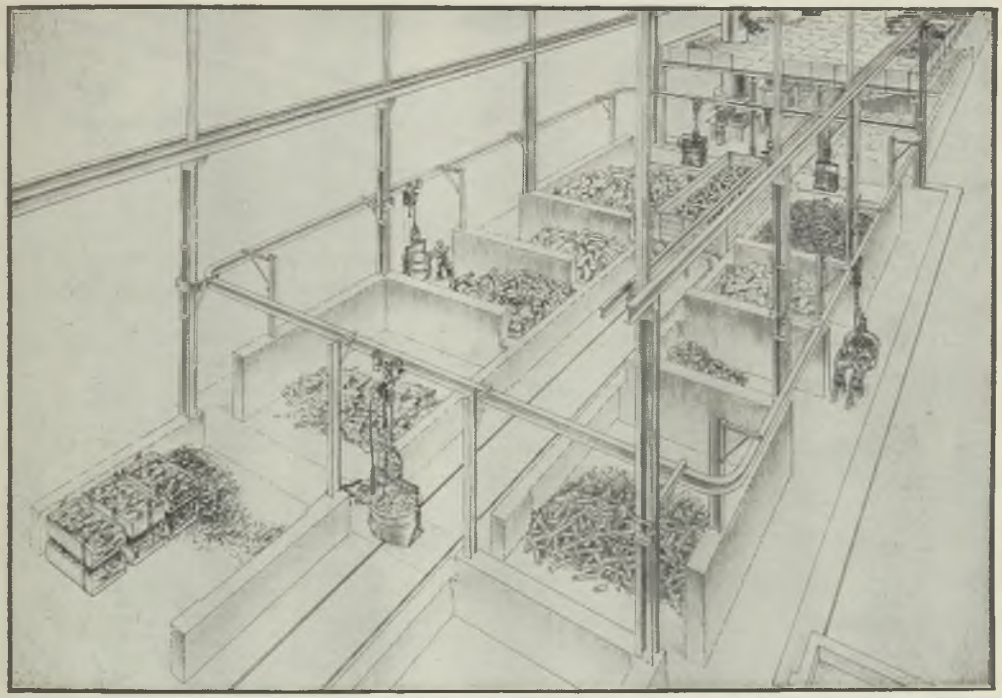


Fig. 6.—The Storage and Handling of Raw Materials for the Cupola.

Cycle of Charging Operations

Emptied buckets are deposited on the "descent platform" under the monorail, and before No. 1 Bin. A lifting bar is then engaged, and the bucket raised just clear of the concrete slab, the upper surface of which is 3 in. above ground level. This operation occupies only a few seconds.

The first constituent of the charge, generally purchased cast iron scrap, is then weighed in, and the bucket, attended by two men, proceeds to the subsequent bins, where the other constituent metals, in similar fashion are simultaneously charged and weighed, the final metal

weight being obtained with particular accuracy. Coke and limestone are then weighed in, the bucket lowered through a fraction of an inch on to the "ascent platform," and the charged bucket subsequently elevated to the cupola platform.

(The purpose served by the "ascent" and "descent" platforms has probably already been realised. A height of 3 in. to 4 in. between bucket and floor is necessary in order to avoid contact with the small pieces of scrap, etc., generally encountered during circuit of the bins, and also to bring the level of the bucket rim to that height found most desirable by the attendants. Provision of 3 in. thick slabs at the sections stated renders the required height obtainable and relinquishable with a minimum expenditure of time and energy.)

Six weighing units are in use, in conjunction with twelve buckets. These numbers are sufficient to prevent hold-up at any point, even during the peak periods, and make possible the retention, on the platform, of several charged buckets in reserve.

The actual charging operation is illustrated in Fig. 7. A jib crane, underslung from twin members erected over the whole length of the platform and running parallel with the cupolas, is employed for this purpose. This charger, of Babcock design and construction, travels longitudinally and laterally, hoists and lowers through a vertical distance of over 5 ft., and swivels completely in either direction, all of these movements being controlled from a push-button block suspended from the crane. The aperture of each cupola is shaped to permit the entry of a bucket suspended from the jib, and the operation of charging is simple. The loaded bucket is passed into the cupola, and the jib lowered. The downward movement of the bucket is arrested when the top angles meet the cast iron bearers built into the side walls, and further lowering of the jib allows the hinged bottom to move open, depositing the contents steadily within the cupola. The speed of discharge is, therefore, controllable, and charging may be prompt or gradual as the occasion requires.

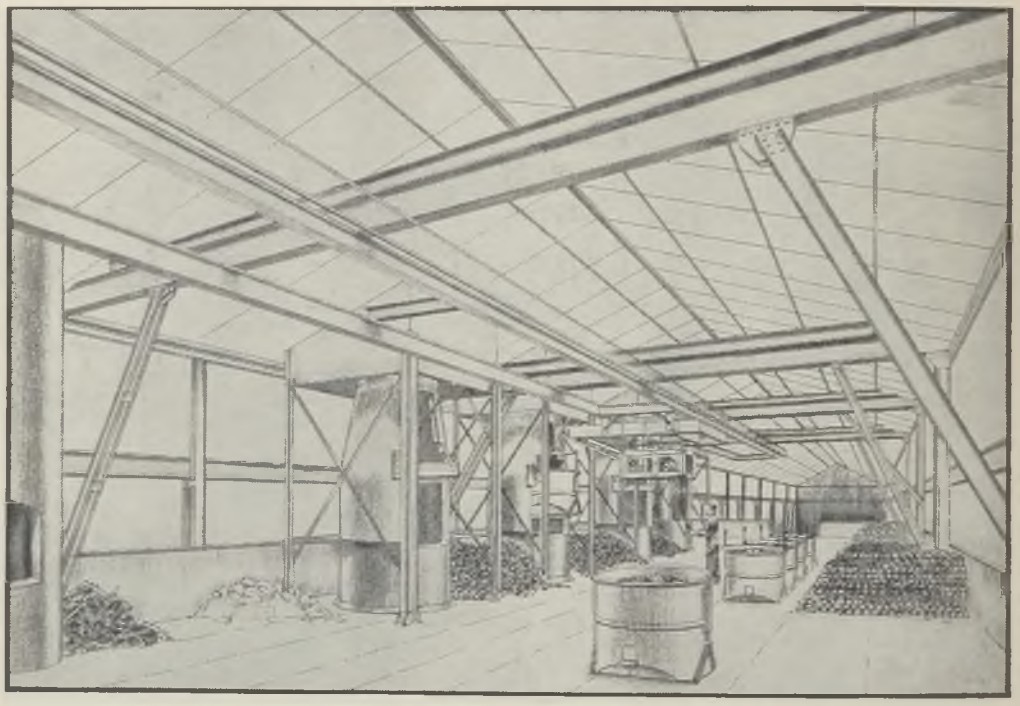


Fig. 7.—Cupola Charging Platform, showing Handling Methods.

The Charging Routine

One cupola is kindled on the previous day, and the bed allowed to burn, very gently, overnight. Also, on the previous evening, after

completion of charging and while the cupolas are blowing down, all twelve buckets are loaded. One contains coke only, in sufficient amount to raise the bed to the desired height, and the first operation next morning is the charging of this coke. The furnace is then promptly filled from the remaining buckets, and a typical log of this initial procedure, during the extremely busy period of a year ago, reads:—

6.00 a.m.—Start—coke charged.

6.20 a.m.—Furnace fully charged—blast on.

6.45 a.m.—Approximately 2 tons melted—tap-hole opened.

The "all-day" cupola normally melts Grade "C" cast iron only, and is kept filled to sill

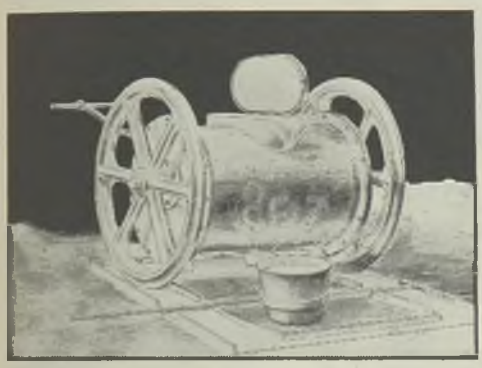


Fig. 8.—Type of Bogie Used and Pouring Station.

level with identical charges until late afternoon.

A morning consultation with the moulding foreman precedes preparation of the charging arrangements for the second cupola. This list of the special charges is generally available by 9 a.m., and shows on one side the particular castings in their planned pouring sequence, the metal grade employed in each instance being denoted by symbols in an adjoining column. On the reverse side, the constituents of the required charges are detailed, in order. This programme passes first to the charging squad, then consisting of five men at ground level. They thereupon commence preparation of the special charges, simultaneously with those required by the cupola in operation. By late forenoon, the second cupola, the bed of which was kindled at the start of the day, is fully charged and ready to be put in blast. The list then passes to the tapper, and, on completion of pouring, to the labour-squad leader, who is then enabled to identify and eventually to return the scrap metals of various grades to their proper sections within one of the charging bins.

Accurate weighing of all of the constituents of each charge profoundly influences the performance of a cupola. At Renfrew, the constancy of the metal temperature is rivalled only by the uniformity in composition of the tapped metal. A further advantage of this careful preparation is that quite considerable proportions of miscellaneous cast iron scrap, of cheap quality and indeterminate composition, may be utilised without much risk of obtaining metal of erratic analysis. In personal experience, the Grade "C" charges, normally composed within the following limits:—

	Approximate %
Miscellaneous cast iron scrap	25-30
Cast iron scrap of known composition	35-30
Foundry pig irons	40

produce metal of very constant composition, as will be shown.

Metal to coke weight ratios are usually accepted as the criterion of economical cupola operation. This standard of measurement, though palpably open to criticism, undoubtedly has a strong appeal to foundrymen, and details on the conventional lines will probably be welcomed. The Grade "C" charges comprise:—

Metals	17 cwts.
Coke	133 lbs.
Limestone	35 lbs.

and give the weight ratio, "Metals charged" to "Coke charged," of 14.3 to 1.

In the case of charges for the Grade "A" and other special cast irons, however, where the tapped metal is required to be exceptionally hot, the total weight of the metal charge is reduced to a minimum of 12 cwts., the quoted ratio thus becoming a minimum of 10.1 to 1.

The routine practice is to make the last four charges of each melt without coke. This procedure effects a saving in coke without causing overmuch fall in the temperature of the tapped metal, and also gives a really small and easily-handled "drop." The necessary weight of bed coke has already been indicated, and it remains only to be stated that the normal overall weight ratio of "metal melted" to "coke consumed," taken over the normal total melt from these cupolas, and including all special charges, is somewhat higher than 12 to 1.

Cast irons to satisfy all of the existing British Standard Specifications are produced from these Balanced-Blast cupolas, but it is impossible, within the bounds of the present Paper, to enter into detailed discussion of charges or associated technique.

Personnel

The staff engaged in the operation of these cupolas in the manner described, totals fifteen men and one youth, this complement including charge-hand, tappers, fettlers and attendants, loaders and crane operatives. Payment is made partly by basic time rates and partly by equal participation in a tonnage bonus, the ultimate "direct labour" cost being 2s. 2¾d. per ton of metal melted.

By a smooth system of relief, charging staffs are maintained during the works' dinner-hour, when melting is uninterrupted, and are augmented during the peak hours of the afternoon, all by interchange within the ranks of the personnel enumerated.

Emergency Stocks

Stocks of all purchased constituents of the furnace charges are maintained upon the cupola platform, ready for use in the event of a mechanical breakdown. Actually, these stocks would be sufficient to keep the furnaces supplied throughout a full day's melt, this arrangement being an effective insurance against the possibility of a major breakdown occurring in the early morning.

Transport of Molten Metal

Until some months ago, distribution of hot metal throughout this foundry was effected entirely by means of geared ladles and wheeled bogies of the traditional cup shape. Following, however, upon the successful trial and subsequent improvement of the drum-type bogie illustrated in Fig. 8, replacement of the existing bogies is proceeding, while the construction of an experimental geared ladle of this type is contemplated. The main advantages attending the use of vessels of this design are:—

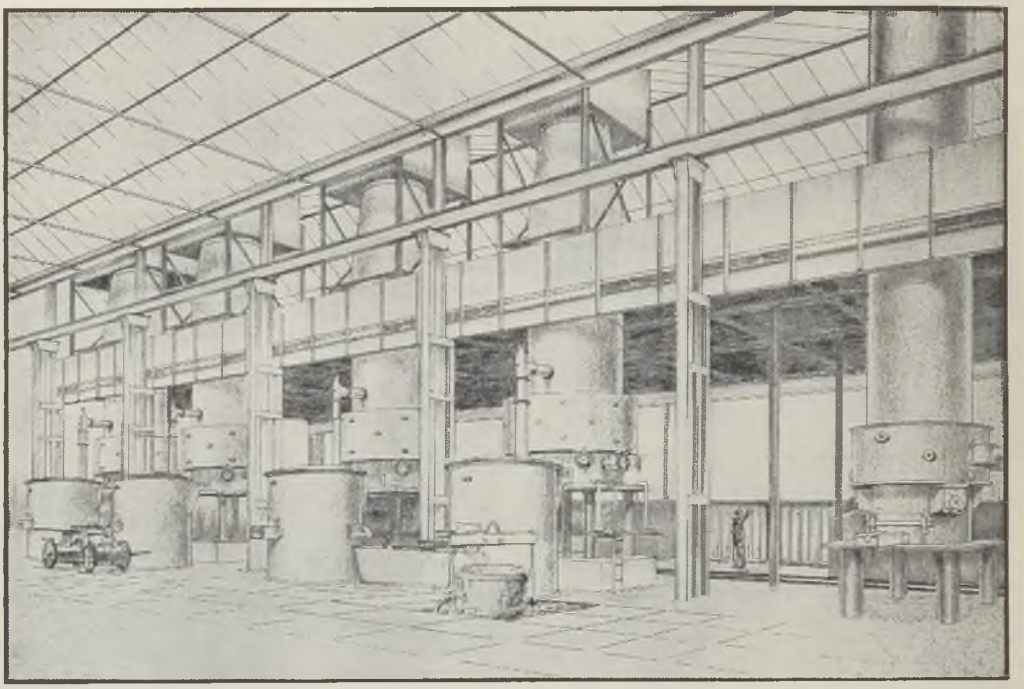


Fig. 9.—Appearance of Cupola Plant at Ground Level.

(1) Heat losses are considerably reduced, mainly by prevention of unimpeded radiation.

(2) Ease of movement in pulling and pouring is greatly increased, by reason of the low centre of gravity and the safe employment of roller bearings.

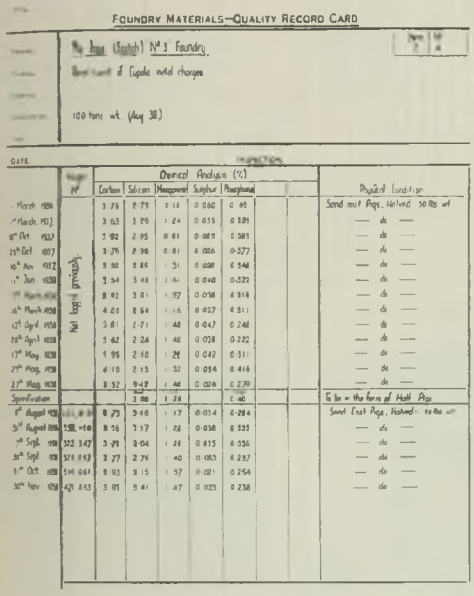
(3) Transport is much safer, since splashing is quite prevented.

These advantages are all very real, and, in conjunction with the greater degree of convenience afforded the user, have made this type of bogie a very popular innovation.

The drawing requires correction in two of its details. The hinged lid, shown in the open

position for illustrative purposes, is closed at all times other than during the actual operation of filling. The eccentric mounting shown is employed only on that type of bogie designed for transport by crane, in which case it serves to provide an effective counterpoise, on tilting, to the moment gained by the lifting frame.

Pouring stands of the type illustrated are placed at strategic points throughout the foundry, adjoining and at right angles to the roadways. Bogies are thus easily drawn off the passageways, and safely secured while the contents are tapped into shanks, etc.



FOUNDRY MATERIALS—QUALITY RECORD CARD

(Scotch) No 3 Foundry

100 tons wt. (Avg 38)

DATE	Weight	Chemical Analysis (%) Carbon	Silicon	Manganese	Sulphur	Phosphorus	Physical Condition
March 1926	Not logged previously	3.76	2.79	1.14	0.060	0.95	Sand cast Pigs, Halved 50 lbs wt
March 1927		3.63	3.29	1.24	0.015	0.389	— do —
Oct. 1927		3.92	2.95	0.81	0.089	0.383	— do —
25th Oct 1927		3.76	2.96	0.81	0.026	0.577	— do —
16th Nov 1927		3.88	2.86	.51	0.028	0.548	— do —
1st Jan 1928		3.54	3.48	1.04	0.040	0.572	— do —
1st March 1928		3.92	3.01	1.37	0.058	0.314	— do —
26th March 1928		4.08	2.54	1.16	0.057	0.511	— do —
12th April 1928		3.81	2.71	1.48	0.047	0.248	— do —
28th April 1928		3.62	2.24	1.46	0.028	0.222	— do —
17th May 1928		3.96	2.10	1.29	0.042	0.311	— do —
27th May 1928		4.10	2.15	1.32	0.034	0.416	— do —
27th May 1928		3.32	2.42	1.46	0.028	0.270	— do —
Specification			3.00	1.28		0.40	To be = the form of Half Pigs
1st August 1928	[illegible]	3.73	3.10	1.17	0.014	0.284	Sand Cast Pigs, Halved: 50 lbs wt
30th August 1928	528,450	3.56	3.17	1.22	0.038	0.335	— do —
7th Sept 1928	522,347	3.78	2.04	1.28	0.015	0.336	— do —
20th Sept 1928	571,143	3.77	2.74	.40	0.013	0.297	— do —
3rd Oct 1928	594,061	3.93	3.15	1.57	0.021	0.254	— do —
20th Nov 1928	471,243	3.91	3.41	1.47	0.023	0.238	— do —

FIG. 10.—QUALITY RECORD CARD FOR FOUNDRY MATERIALS.

The capacity of the newly-lined bogie is rather more than 10 cwts. of metal, the lining being prepared by ramming a suitable refractory material around a former. In order to ensure complete emptying of the contents, the lining thickness should taper from both ends towards the centre. This is successfully accomplished, at Renfrew, by the employment of a hinged, collapsible pattern, and the re-lining of a bogie is a surprisingly simple and quick operation. The lining lasts for several weeks, and daily attention is confined to repair of the lip and lid.

Fig. 9, a front view of the cupolas, shows drum-type bogies in position for filling, and also features a ladle-pit, uncovered and containing one of the large ladles.

Technical Control of the Foundry Product

At Renfrew, this begins with control of all raw materials. These are tested and evaluated in many ways, the results of all such determinations being carefully logged on "quality record cards" of the form illustrated. (Fig. 10.) This procedure, initially, assists in the establishing of specifications, and, subsequently, ensures their observance.

Only furnace materials, however, come within the scope of this Paper, and that featured is, very properly, a foundry pig-iron, this card having been chosen because it illustrates, with particular clarity, two distinct and typical phases:—

(*a*) *Pre-Specification.*—The inconstancy of the tabulated analyses indicates the need for definite specification of requirements, and

(*b*) *Post-Specification.*—The much greater degree of uniformity serves to emphasise the improvement obtainable when the requirements of the purchaser are clearly defined.

Begun in this fashion, technical control, continued by standardisation of successful manufacturing methods, ends with observation and systematic recording of procedure and results. Fig. 11 shows the log in which all matters relating to furnace charges are detailed. This is also a materials stock sheet, and sets out every aspect of the position with regard to each furnace requisite. The accounts of a typical week are inserted for the purpose of illustration, and the arrangement is probably self-explanatory.

All chemical analyses, physical test results, and relevant observations are set down in the "Metallurgical Record," which also is shown in a typically completed form (Fig. 12).

These records have proved of immeasurable value to the metallurgical section of this foundry, retaining, as they do, in singularly concise form, complete accounts of all experiences, the results of routine practice or of special procedure being preserved with equal certainty. By this means, details of successful procedure, often costly to develop, are accurately recorded, and are subsequently available to ensure safe handling of a recurring situation, or to assist in the solution of a new problem.

Acknowledgment

Thanks are due to the Directors of Babcock & Wilcox, Limited, and to Mr. W. H. Birks, M.I.Mech.E., Manager of the Renfrew Works, for permission to present this Paper.

The author is also deeply indebted to Mr. Hector G. Paton, his colleague and friend, whose drawings have so enhanced the value of this Paper, and to all of those associates who have in any way assisted in its preparation.

LOG OF MELTING PROCESSES

Metal	Grade	Furnace No — Metal Charges 1	2	3	4	5	6	7	8	Furnace Materials: 29/56 Fuel Oil (Gallons)	27/270 R.M.	47/240 Clay	27/187 Flux	27/65 Coke (Tons)	Metals Charged to Crucible Furnace (lbs): 1/7 Copper	2/1	2/111 Ironite	8/4 Steel	48/196 Fe-Mn	48/201 Fe-Si	48/203 Fe-Cr	48/199 Nickel	48/198 "F"	Scrap	Total	Spout Additions etc. (lbs): 48/196 Fe-Mn	48/201 "F"	Metals Charged to Cupolas (Tons): 8/1	9/1	9/1	2/4	2/111 Ironite	8/4 Steel	27/196 C.I. Scrap	Own C.I. Scrap	Total
Monday 29/11/38	A.			6				7						0·43														1·80					1·20		0·60	3·60
	B.			9										0·85														5·40								5·40
	C.	96		33										8·39															32·25	12·90				32·25	32·25	109·65
	H.R.3					5				65					-	709	-	334	8	114	36	220	59	380	1,800											
	W-W.R.				12									0·85												10						0·90	0·90		1·80	3·60
Blast on:		8·40		1·00	4·00																															
Blast off:		3·00		6·20	5·30	4·15																														
Tuesday 29/11/38	A.				15									0·92														3·30					5·00		1·30	7·80
	B.				9									0·84														5·40								5·40
	C		96		36									8·71																15·20	35·00			35·00	35·00	112·20
	H.R.3					5				62					-	705	-	350	10	93	50	-	292	315	1,815											
	W-W.R.				15									0·85												10						0·90	0·90		1·80	3·60
Blast on:			8·15		1·00	4·00																														
Blast off:			5·30		6·45	5·30	5·40																													
Wednesday 30/11/38	A			8										0·68														2·65					1·35		0·80	4·80
	B			9										0·85														5·40								5·40
	C	95		34										8·58																12·90	32·25			30·30	34·20	109·65
	H.R.3					5				64					-	705		330	10	92	50		293	300	1,800											
	W-W.R.				11									0·68												12						0·80	0·85		1·65	3·30
Blast on:			8·15		1·00	4·00																														
Blast off:			5·15		6·20	5·20	4·00																													
Thursday 1/12/38	A - H.T.				11									0·79													12	3·30					2·00		1·10	6·60
	B				9									0·65														5·40								5·40
	C		95		32									8·42																12·70	51·75			50·50	53·00	107·95
	H.R.3					4				13					-	564	-	280	8	74	40	-	234	240	1,440											
	W.W.R.				12									0·65												10						0·90	0·90		1·60	3·60
Blast on:	"		8·05		1·00	4·00																														
Blast off:			5·00		6·35	5·20	1·45																													
Friday 2/12/38	A			16										1·02														3·85					3·15		1·40	8·40
	B			9										0·65														5·40								5·40
	C	92		27										7·89																11·90	29·75			29·75	29·75	101·15
	H.R.3					4				70					-	423	-	210	6	55	30	-	176	540	1,440											
	W.W.R.				9									0·70																		0·70	0·65		1·35	2·70
Blast on:		8·20		12·40	4·00																															
Blast off:		4·40		5·55	5·15	6·00																														
Saturday 3/12/38																																				
Blast on:	No																																			
Blast off:	Melting																																			
Individual Totals for Week	"A"												8·85	3·74														15·30					10·70		5·20	31·20
	H.T. —— (A base plus —)																										12									
	B												0·70	3·24														27·00								27·00
	C												9·95	42·19															32·25	63·60	126·75			155·80	162·20	540·60
	H.R.3									310					-	3106	-	1524	42	428	226	220	1054	1695	8,295											
	W.												0·35	4·05																		4·20	4·20		8·40	16·80
	W.R. —— (W base plus —)									310																42										
Combined Totals:										310	8·00	4·00	12·05	53·22		3106		1524	42	428	226	220	1054	1695	8,295	42	12	42·30	32·25	63·60	126·75	4·20	14·90	155·80	175·80	615·60
Absolute Totals:																					268		1066					43·69					15·58			619·30
Stocks at end of previous week:										540	55·20	7·00	35·46	364·25					463	664	2885	456	4500					102·75	85·00	75·10	343·25	53·70	33·45	135·15		
Balances remaining:										230	47·20	3·00	23·41	251·01					421	236	2617	236	3434					1059·96	52·75	9·50	216·50	49·50	17·87	- 22·65		
Deliveries during week:										-	11·00	-	35·56	109·80					-	-	-	-	-					592·05	343·20	-	-	-	6·60	224·90		
Present Stocks:										230	58·20	3·00	62·77	360·81					421	236	2617	236	3434					1641·11	395·95	9·50	216·50	49·50	24·47	202·25		
Still on order:										2,000	Contract	10·00	-	Contract					-	Transfer	-	2240	44·80					260·00	1636·00	-	-	-	Transfer	Contract		

Fig. 11. Log of Crucible Melting Processes

METALLURGICAL RECORD

Date of casting	Sample Submitted: Symbol	Sample Submitted: Form	Chemical Composition: Carbon Total	Carbon Combined	Silicon	Manganese	Sulphur	Phosphorus	Chromium	Nickel	Copper	Physical Properties: Micro-Structure	Transverse Test: Condition of bar	Dia.	Span	Deflection	T.R.S. Tons/□"	Tensile Test: Strength	Elongation %	Hardness: Specimen	Brinell No.	Remarks.
			%										Inches									
Monday 28/11/36												Heat treatable Cast Iron										
												Effect of heat treatment on 2½% Nickel Cast Iron										
	C	1" × 1" × 6" Plug	3.93	0.45	2.36	0.59	0.096	0.661														No 1 - 11 a.m.
	C	1·2" Dia. Test Bar	3.41	0.39	2.36	0.61	0.085	0.702					AC-86	1.18	18	0.28	22.8					No 1 - 3 p.m.
	W	1" × 1" × 6" Plug	3.02		0.54	0.28	0.162	0.047														
Tuesday 29/11/36	As	1·2" Dia. Test Bar	3.25	0.45	1.99	0.96	0.067	0.515					AC-58	1.17	18	0.47	36.0					
	C	1" × 1" × 6" Plug	3.61	0.32	2.36	0.59	0.075	0.610														No 2 - 11 a.m.
	C	1" × 1" × 6" Plug	3.46	0.28	2.36	0.65	0.090	0.756														No 2 - 3 p.m.
Wednesday 30/11/36	B	1" × 1" × 6" Plug	3.80	0.17	2.50	1.08	0.051	0.592														
	C	1" × 1" × 6" Plug	3.46	0.41	2.24	0.53	0.090	0.745				Etched 2% Nital × 350 Diams "as cast" condition										No 1 - 11 a.m.
	C	1" × 1" × 6" Plug	3.54	0.34	2.27	0.59	0.079	0.610													(Av. shop test)	No 1 - 3 p.m.
	W.R.1	1" × 1" × 6" Plug	3.44		0.24	0.34	0.123	0.042	0.23											Mill Liners 7½" Av. Section	580	5 lbs Fe-Chrome app. Brazil Nut size (64.6% Chr, 4.75% C) added to 850 lbs total iron. Efficiency of addition - 100%
Thursday 1/12/36	H.T.	1·2" Dia. Bar	3.15	0.38	1.61	0.71	0.074	0.194	-	2.58										1·2" Dia × 3"	250	Cooled in mould. Four tests on transverse bars, average quoted
																				1·2" Dia × 3"	426	Same test piece and procedure, after oil-quench from 850°C.
	C	1" × 1" × 6" Plug	3.45	0.32	2.43	0.66	0.081	0.753														No 2 - 11 a.m.
	C	1" × 1" × 6" Plug	3.50	0.35	2.36	0.66	0.081	0.756														No 2 - 3 p.m.
	H.R.3	1·2" Dia. Test Bar	2.34		3.33	0.95	0.033	0.157	2.01	(7.67)			AC-3.6	1.153	18	1.25	28.6					Flaw. Crucible melt
Friday 2/12/36	C	1" × 1" × 6" Plug	3.38	0.32	2.36	0.65	0.077	0.723				Etched 2% Nital × 350 Diams Oil quenched from 850°C.										No 1 - 11 a.m.
	C	1" × 1" × 6" Plug	3.32	0.20	2.36	0.65	0.070	0.726														No 1 - 3 p.m.
	W.	1" × 1" × 6" Plug	3.45		0.68	0.43	0.130	0.036														
Saturday 3/12/36																						
30/11/36		Pig Iron	3.93		3.41	1.47	0.035	0.238														In accordance with specification
1/12/36		Pig Iron	3.77		3.18	1.05	0.015	0.430														Internally in accordance with specification
5/12/36		Purchased C.I. Scrap	3.33		2.22	0.36	0.083	1.20														Medium-Light section. Moderately clean. (Wagon No 127.058.)

Spent addition of Chromium, using 4-6% Carbon Ferro-Chrome approximately of Brazil Nut size, established as 100% efficient for the percentage addition observed.

Heat-treatable Cast-Iron (2½% Nickel) Hardness increase on quenching in oil from 850°C observed to be of the order of 200 Brinell.

Drum type basic re-lined. Metal capacity 10½ Cwts. Put into service on C.C. Plant 2/12/36.

Pig Iron analysis not quite within specification. Keep closer check on future consignments.

Fig. 12.—Method of Recording Metallurgical Data. (The photomicrographs, being much reduced, only illustrate the system of recording.)

Finally, the author desires publicly to express his gratitude to Mr. Robert O. Patterson, Superintendent of the Renfrew Foundries, whose kindly interest, constructive criticism, and unfailing support are a constant encouragement.

REFERENCES.

1 "The Function of Tuyeres in Cupola Control." H. V. Crawford, "Foundry Trade Journal," August 19, 1937.

2 "Some Experiences with the Balanced-Blast Cupola." H. H. Shepherd, Proc., I.B.F., Vol. XXVI, pp. 348 to 379.

3 "The Balanced-Blast Cupola." W. Y. Buchanan, "Foundry Trade Journal," January 16, 1936.

4 "Correspondence," "Foundry Trade Journal," September 30, 1937.

DISCUSSION

The Chairman (Mr. R. Ballantine), in opening the discussion, said he had never previously listened to a Paper with such a wealth of detail. He was particularly interested in the design of the interior of the cupola, but he regretted Mr. Braidwood did not mention blast volume. He would also like to know whether the author had made any thermal tests of the drum ladle.

Mr. Braidwood, in reply, said that the fans in use supplied air at a constant pressure, the volume passing into the cupola being dependent mainly on the permeability of the furnace contents. The volume meters mentioned were not used to ensure a constant and predetermined input of air, except during "blowing-down." It might be stated that the normal input was 3,500 cub. ft. of free air per minute. Metal temperatures were read by means of a Siemens' optical pyrometer. The procedure was useful in providing readings which were of value for control purposes, but comparative only on their own scale. He hesitated to quote these readings because he felt that they were much below the true temperatures, and, if taken literally, would give the impression that the metal temperatures were low. He remarked, jocularly, that in the present instance it might be best to make use of the empirical scale established by a member of the Branch, and state that the temperatures of the metal tapped from the cupola under discussion ranged from "hot" to—well—"very hot." No thermal determinations had been carried out on the drum ladle, principally because the improved results associated with its use were very obvious.

Furnace Contour

Mr. John Cameron, Jnr., congratulated Mr. Braidwood on his excellent Paper, but he also questioned the internal design of the cupola. He wondered whether the shape was exaggerated in the drawing which had been shown, and if the melting zone were above the narrow throat. If so, he thought it was too far away from the main tuyeres. He would like to know if Mr. Braidwood was making castings to all the British Standard specifications.

Mr. Braidwood explained that the present contour had been evolved gradually, and that improved results had been found to be associated with the development. No scaffolding had ever been experienced, and he agreed that this undoubtedly was due to the fact that melting occurred above the narrowed section. Regarding the coke bed, he wished further to emphasise his conviction that the deep bed maintained in the operation of these cupolas was the most potent single factor influencing their performance. The metal produced was meeting a tensile test of 20 tons per sq. in. on the 1.2-in. dia. bar.

Tuyere Systems and Carbon Control

Mr. J. Longden said he found the Paper very interesting and of considerable value, but he wanted more light on details. Did Mr. Braidwood use high total carbon? He (Mr. Longden) had tried to get low total carbon in a Poumay cupola, but found it impossible. He also considered that auxiliary tuyeres did not give hotter metal; at least he had not found that to be the case with the Poumay cupola. It might be that the receiver made a difference, but he thought that the argument in favour of the receiver could be overstated. He would like to know whether the receiver made for "clean" metal. The open slag hole, he said, had some advantages, and gave a good datum line of the progress in the cupola. He thought the best test of the performance of a cupola was the analysis of the gases, the temperature of the metal and the metal/coke ratio.

Mr. Braidwood said that in his high-duty cast irons the total carbon contents varied generally between 2.8 and 3.0 per cent., and were certainly never higher than 3.2 per cent. He used from 25 to 60 per cent. of mild steel scrap in these charges. He had never operated a Poumay cupola; but since, in that type of furnace, the secondary air was introduced at intervals up to a considerable height above the bed, and therefore into relatively cool regions, he expected it to give very efficient combustion. He had found, however, that improved gas analysis was not necessarily accompanied by increased metal temperatures; this he believed to be influenced primarily by the depth and condition of the bed.

On the subject of receivers generally, Mr. Braidwood said that he did not advocate the fitting of a receiver to every cupola. Where comparatively small amounts of metal were being melted, for example, the use of a receiver was hardly justifiable, unless required for special purposes. He had tried to show, however, that the hot-metal receiver could be an extremely

useful component possessed of advantages greater than was generally realised.

Mr. W. Y. Buchanan complimented the lecturer on his presentation of the Paper, especially on the remarkably good drawings, which were a credit to the artist. He had seen the lay-out of the cupola plant, and it was undoubtedly good. He was especially interested in the balanced-blast cupolas, as members of the Babcock & Wilcox staff had studied his own firm's cupolas and melting control system before planning their installation, and as the cupolas described were of similar dimensions, comparison of performance was possible and of particular interest to himself.

The only part of the lecture which he could not accept was the exaggerated shape of the lining. The bosh was present in all Balanced-Blast cupolas to the extent of 2 in. or so a side, but why increase it to 15 in. a side, thus reducing the area to less than one-third for the same blast input? What was wrong with these furnaces that such a radical alteration was necessary or advisable? It was an old style of lining which was, he thought, obsolete. He thought it was bound to come in for considerable criticism.

He suggested that coke saving could be had by reducing the depth of the bed below the tuyeres to a few inches, say as low as 3 in., if coke saving was important; but the method suggested must be at the expense of the quality of the metal, probably making the tuyere zone cold. Mr. Braidwood's figure of 0.8 per cent. loss for the Balanced-Blast operation, due to oxidation and slag, etc., confirmed his own practice.

Temperatures on different optical instruments were sometimes uncertain for comparison, but statements that the metal was "hot" or "very hot" were, of course, quite useless in technical literature. He concluded that the temperature of the metal was much lower than usually used. The temperature indicated by, say, the average of several thousand readings before and after the lining modification, taken on the same pyrometer by the same man, would have given a reliable guide on this question.

Mr. Braidwood had raised the stock line of the furnace by 3 ft., he understood, in order to cool the exit gases. His own experience was that above the normal height this might defeat the object which was intended, and by slowing the furnace, produce colder metal at the spout.

The author had made out a strong case for receivers on the grounds of reduced heat losses, but his data on temperature did not bring this out clearly.

Mr. Buchanan also asked for the extra cost of lining the furnace so heavily at the lower part. His own ganister to metal was about 1 to 75, which seemed quite as good for melting every day with the consequent lack of drying time. Finally, he would like to know how much metal was rejected daily as being unfit for casting.

Metal Temperatures

Mr. Braidwood said that he had fully expected the matter of the furnace contour to be controversial. It was surprising, however, and somewhat disappointing, to hear it described as "an old style" and "obsolete," when he had regarded it as extremely new—indeed, as his own invention. There had been nothing "wrong" with the cupola before the alteration of contour, but the change had been associated with considerable improvement in the cupola performance. He recommended Mr. Buchanan to try out this contour. It was difficult to estimate the cost of lining-in to the diameter shown; in the existing case this had been effected by regular decrease of the diameter when patching.

Mr. Buchanan had suggested saving coke by reducing the height between the sand bottom and the main tuyeres. At present this dimension was only 12 in., and he did not think that any reduction was advisable, especially since this alteration, by reducing the depth of incandescent coke, would tend to lower the temperature of the tapped metal. Mr. Buchanan had misinterpreted his information about the overall dimensions of the cupola. The height from main tuyeres to stock line (14 ft. 6 in.) was the same as before the alteration in contour.

He was glad to have confirmation, from Mr. Buchanan's own experience, of the figures quoted for oxidation loss. He felt that their publication would be of interest, especially since it was thought by many that operation of the Balanced-Blast system must give rise to high oxidation losses.

He could not allow Mr. Buchanan to observe that the temperature of the metal tapped was other than very satisfactorily hot. The actual readings made at the spout varied from 1,300 to 1,350 deg. C., but these figures should not be accepted as correct temperatures. He remembered one occasion when Mr. Marshall, of Thomas White & Sons, Limited, visited the foundry and commented on the high temperature of the metal being tapped, estimating it as "well over 1,400 deg. C." The actual reading which had just been observed and recorded on that occasion was in the region of 1,320 deg. C.

Mr. Marshall: That is the case.

Continuing, Mr. Braidwood said the query regarding the weight of metal rejected daily as being unfit for casting might best be answered by quoting the official returns for the year ended

December 31, 1938. These showed that, with a total metal weight of 30,166 tons, the total weight of castings produced was 21,931 tons, or over 70 per cent. of the total melt. This might modestly be described as representing very good practice, and these figures certainly did nothing to encourage the belief that a considerable proportion of the melt was unfit for casting.

After further discussion, Mr. A. L. Mortimer moved a hearty vote of thanks to the lecturer.

Mr. Braidwood, in returning thanks, mentioned that this was his maiden "opus," and said that he had been rather worried regarding its presentation. Fortunately, he had thoroughly enjoyed the experience.

Paper No. 699

Porosity and Sinking in Cast Iron*

SOME NEW EXPERIMENTAL EVIDENCE

By W. WEST (Member) and C. C. HODGSON (Associate Member)

It is now generally recognised that the very marked progress in the physical properties of cast iron has been brought about by a better and more searching examination of its composition and structure. If it were possible always to keep a well-balanced eutectic mixture for each type of casting commercially produced, less trouble from internal porosity and external sinking in iron castings would be experienced by founders. Most foundries have developed their own technique to suit the multifarious types of castings produced; practical obstacles, many of which are obvious and in the main locked up with this individual technique, make it impossible to select an iron of eutectic mixture to meet all requirements. In spite of this fact, some of the peculiar effects experienced which make their contribution to the defective scrap pile are common to all foundries. Internal porosity in heavier sections adjoining thinner ones is still sufficiently common to be a nuisance. The use of certain kinds of pig-iron may contribute largely to this phenomenon or to external sinking in remote corners where sections meet.

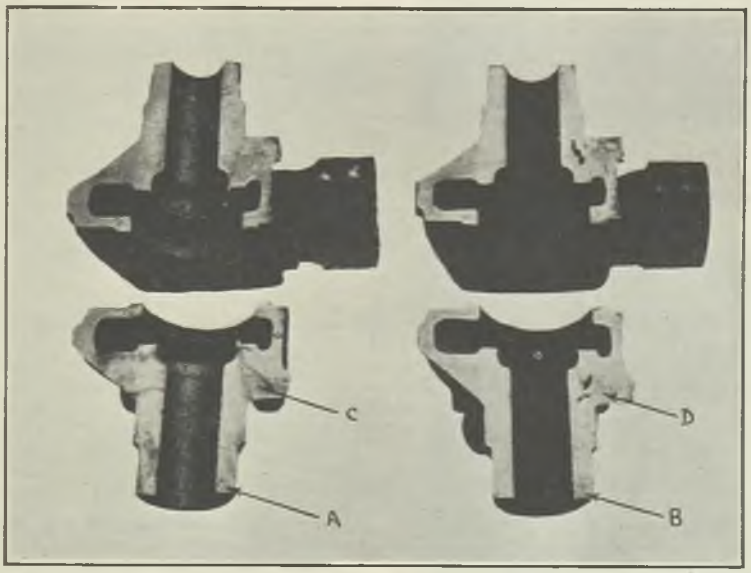


Fig. 1.—Pump-body Casting Sawn into Two. Left: Sound. Right: Porous in Thick Section, and (not shown) Sunken in Boss.

External sinking of castings is much more frequent since the practice of lowering the total carbon by the addition of steel has been followed in order to produce high-strength iron in particular. This result is not altogether unexpected when the decrease in total carbon

* The authors were awarded Diplomas for this Paper.

reaches a certain point, but when external sinking takes place with cast iron having an average content of $3\frac{1}{2}$ per cent. total carbon, and then only with particular brands of raw material, some investigation is called for, and in the authors' case actual observations of this sort commenced these experiments.

In the first instance, external sinking occurred more or less suddenly, coinciding with the use of a particular brand of pig-iron. A change of raw material from A and B to D and E (Table I) brought the relief required, though at a later stage the reproduction of this sinking effect could not be accomplished at will. Such an incident occurs frequently in all foundries, but the means of the relief from the trouble leaves a very unsettled and unsatisfactory state of mind. It was decided, therefore, to pursue the problem in search of a satisfactory solution. The castings under question were made in moulds from hand-press machines and the moulds in turn were poured from metal melted in an orthodox way in the cupola.

Originally it was thought that the sinking effect was associated with the pig-iron used, or the sand moulds and the particular method of making them. The change of raw material which brought about the elimination of the sinking was rather misleading. It was known that between the two sets of pig-iron there was little difference in chemical composition, except for a larger amount of titanium in one of them. In pursuance of the effect of titanium, experiments were carried out by making additions of ferro-silicon-titanium and treating in a crucible furnace, the results of which are recorded later.

Titanium Treatment

The credit for the pioneer study of graphite formation and its relation to titanium treatment should in the first place be given to the British Cast Iron Research Association, because the published work of this Association gave the initial encouragement to the authors to attempt the more practical interpretation of their results with particular designs under foundry conditions.

TABLE I.—*Analysis of Typical Examples of Pig-Iron Used.*

Pig mark.	C.	Si.	Mn.	S.	P.	Cr.	Ti.
A.	3.75	3.56	0.99	0.014	0.16	0.03	0.12
B.	4.17	1.63	1.09	0.018	0.16	0.03	0.08
C.	3.00	2.38	1.06	—	0.30	2.71	—
	3.00	2.00	1.00	0.07	0.33	3.16	0.03
D.	4.26	1.72	1.10	0.020	0.27	0.03	0.19
	4.21	1.85	1.49	0.020	0.19	0.02	0.17
E.	3.76	3.02	0.53	0.018	0.06	0.01	0.03
F.	2.77	2.04	1.00	0.033	0.22	0.36	—
	2.86	2.08	1.05	0.030	0.27	0.28	—
G.	2.76	2.12	1.19	0.06	0.05	—	—
	2.78	2.18	1.38	0.05	0.07	—	—
H.	2.73	2.04	1.04	0.104	0.10	0.03	0.02
	2.69	2.04	1.12	0.100	0.09	0.04	0.02
J.	2.24	1.89	0.87	0.088	0.20	0.03	0.02
	2.04	1.84	0.98	0.090	0.23	0.03	0.02
Ferro-silicon titanium	—	14	—	—	—	—	20

As a short summary of the work of the Association, it might be helpful to note that by a special treatment of molten iron the conventional type of flake graphite can be changed at will throughout the mass to the finest form of distribution which graphite is capable of taking. This process is covered by British and foreign patents.

The process consists of treating molten cast iron containing about 0.2 per cent. titanium with carbon dioxide for a short period. Two outstanding advantages are obtained from this treatment. First, there is its direct effect upon the mechanical properties of the cast iron by increasing the tensile and transverse strengths. Examples are quoted by the Association wherein the transverse strength of hematite iron, as a

result of the titanium and carbon-dioxide treatment, was raised from 17.4 tons to 30.3 tons per sq. in. on a 3-in. test-bar, and a corresponding improvement in the tensile strength from 7.5 tons to 19.5 tons per sq. in. was obtained with the same diameter test-piece.

One of the features of the process is that it may be applied to irons irrespective of carbon content, provided that, as in most cast irons, the eutectic carbon figure is not exceeded. In relatively high-carbon irons the coarseness of the graphite when in the flake condition makes these irons relatively weak, and hence the gain by transforming to the fine graphite condition is proportionately great. As the carbon content of the iron decreases, the gain on transformation is naturally reduced.

TABLE II.—*Water-Pump Body Casting, Weight* 10 *Lbs.* (See Fig. 1).

	Sound casting.	Drawn casting, external sink near base of boss, shrinkage cavity inside boss when cut up.	Sound casting.
Mixture— (For average analyses of pig-irons, see Table I)	Pig A. 1 cwt. Pig B. 2½ ,, Soft scrap 1½ ,,	Pig A. 2 cwt. Pig B. 5 ,, Soft scrap 3 ,,	Pig C. ½ cwt. Pig D. 4½ ,, Pig E. 2 ,, Soft scrap 3 ,,
Method of Melting—	In small experimental cupola.	In large production cupola.	In large production cupola.
Chemical Composition— Reference No.	M. 2336	M. 2337.	M. 2347.
C	3.84	3.82	3.78
Si	1.97	2.08	2.06
Mn	0.77	0.67	0.94
S	0.080	0.104	0.084
P	0.16	0.22	0.21
Ni	0.10	0.02	0.05
Cr	0.10	Nil	0.33
Ti	0.04	0.05	0.08
V	Nil	Nil	0.02
Mo	0.04	0.04	0.02
Sn	0.03	0.03	0.01
Al	0.04	0.03	0.03
Cu	0.06	0.02	0.02

Secondly, the titanium treatment assists in the production of castings which are dense and free from internal porosities, which otherwise might be difficult to manufacture without such deficiencies. A further feature of the refining treatment is the uniformity in the structure of the sections, making it possible to cast sections exceeding 6 in. thick with a uniformly close grain throughout the section. It is also stated that melts containing titanium appear to have a greater degree of "life" when molten than cast irons which have not received the treatment.

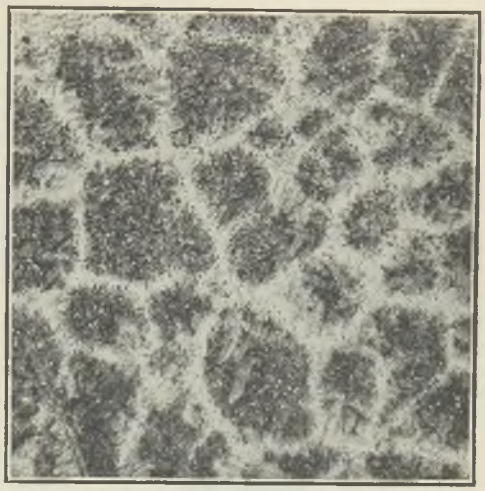


FIG. 2.—MICROSTRUCTURE AT POSITION A, FIG. 1. × 50.

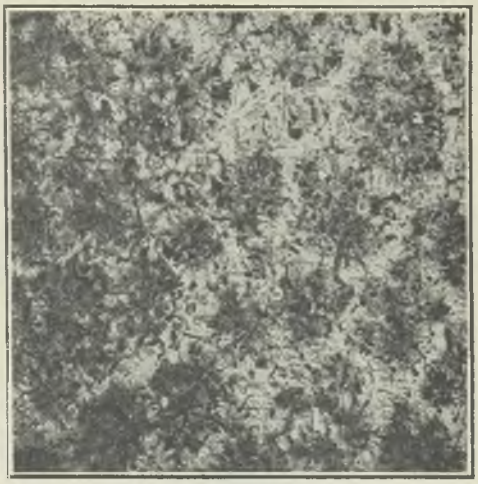


FIG. 3.—MICROSTRUCTURE AT POSITION B, FIG. 1. × 50.

Theory of the Treatment

The theory of such reactions from the treatment appears to be a very debatable point. Boyles* believes that the real action of carbon dioxide in the treatment is to free the melt of hydrogen. In this summary, however, it is not the authors' intention to pursue the theoretical reasons, but to state the opinions of the workers of the Association. In this connection, they suggest that the form of graphite distribution depends upon the composition of the iron, the speed of cooling, and, most important of all, on the nature and distribution of the inclusions present in the melt. Small crystalline inclusions act as nuclei which inoculate the melt and thus cause crystallisation to take place with

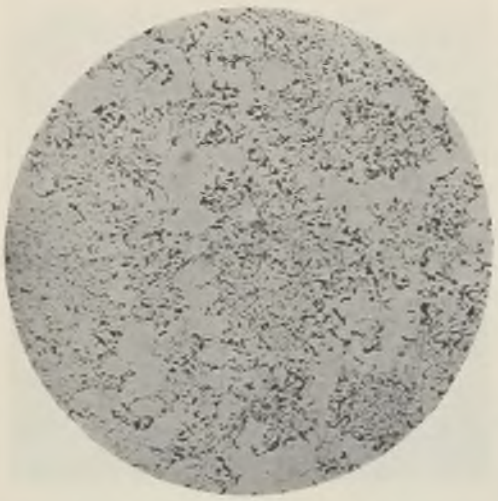


Fig. 4.—Microstructure at Position A, Fig. 1. Unetched. × 100.

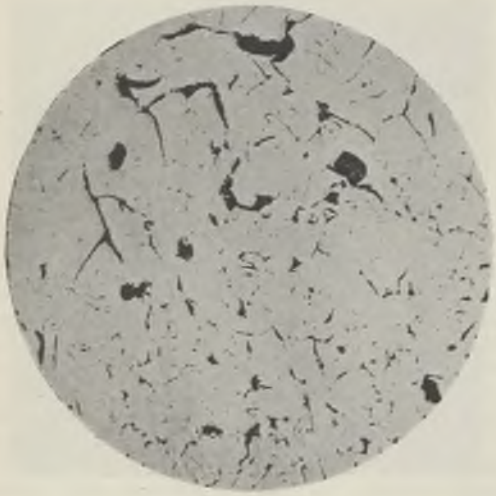


Fig. 5.—Microstructure at Position B, Fig. 1. Unetched. × 100.

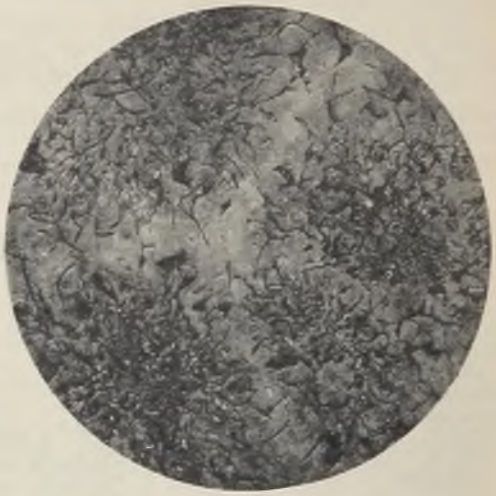


Fig. 6.—Microstructure at Position C, Fig. 1. Etched. × 100. Junction of Three Cell Boundaries.

Fig. 7.—Microstructure at Position C, Fig. 1. Etched. × 100. No Cell Walls in Evidence.

* Trans. A.I.M.E., Iron and Steel Div., T.P. 809, 1927.

very little under-cooling. These inclusions, they think, are effective only while they are in the crystalline form, and suggest that the effect of the titanium and carbon-dioxide treatment is that the titanium is made to form a fluid slag, which covers or combines with the solid silicate particles to form combinations which are liquid externally, when the graphite separates out, and that, being liquid, they do not act as inoculants, and super-cooling occurs which produces fine graphite.

Whatever the true explanation be for this finely distributed or super-cooled graphite formation, it is acknowledged by those who have worked upon the problem that the conditions

Fig. 8.—Microstructure at Position D, Fig. 1. Unetched. × 100.

under which melting and treatment take place are all-important. For example, the production of modified graphite at will is comparatively easy when the cast iron is melted and treated in a crucible furnace, but more difficult in the cupola, although the authors have been informed by the Association that it is now possible to produce supercooled graphite structures in cupola-melted irons if certain precautions are observed in melting.

It has been observed by most ironfounders that mixed structures of flaky and supercooled graphite have occurred in certain types of commercial castings made from the cupola, chiefly at the extreme edges of the casting. These mixed structures may have been produced by the presence of titanium which is contained in varying amounts in many British pig-irons, and that complete modification of the graphite form had not taken place because of the absence of an oxidising treatment in the molten condition. Experiments carried out by the Association proved that a titanium-bearing mixture which is readily modified by carbon dioxide when crucible-melted may not respond to the treatment when cupola-melted.

Several conditions contributing to cupola melting have since been investigated, and a general review indicates that the cupola coke may be regarded as a vehicle for the introduction of inclusions into molten cast iron. The presence of sulphur is not harmful to the titanium process.

The authors, however, thought that the modification to the structure of cast iron might have some further value to the foundryman, and they decided to carry out experiments under their own foundry conditions.

These experiments did not, however, give them a direct relation with the major problem of sinking. It was, therefore, decided to give attention to the sand and its condition. Certain physical characteristics were determined, such as permeability, moisture content, clay and coal-dust contents, and also the effect of a dry condition

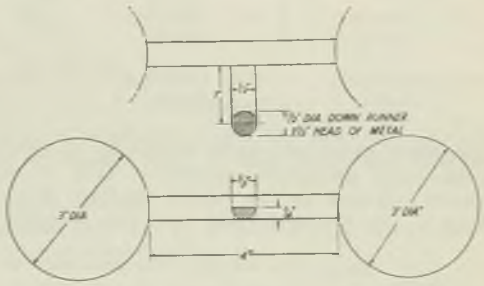


Fig. 9.—B.C.I.R.A. Dumb-bell Type Test-Piece for Shrinkage and Porosity Tests.

of the mould. A full account of the details of the experiments is now given with such explanations as the results permit.

Examination of Specimen Castings

The first step in the investigation was to carry out a metallurgical examination of specimen castings. Three castings made from the same pattern and of known history were available. They are detailed in Table II.

Microscopic Examination

Sections were cut from the thin and thick portions of the castings. The micro-structures of the two sound castings were very similar and only one set will be described; the following descriptions refer to the first and second castings above (Ref. M. 2336, M. 2337, *i.e.*, those made from similar mixtures).

Sound casting (thin section A, Fig. 1) and unsound casting (thin section B, Fig. 1).—At low magnification (50 diameters), the etched specimens show cell walls consisting of pearlite with some phosphide eutectic. This is more clearly marked in the sound casting (Fig. 2) than in the unsound (Fig. 3). The graphite in section A is mainly of the super-cooled type (Fig. 4), with a considerable amount of ferrite separated; some of the pearlite is well laminated, but much of it is too fine to be resolved with a 3-mm. objective. In section B there is a little super-cooled graphite near the surface, but it quickly coarsens until, at a little distance from the surface, it exists in fine to medium flake form (Fig. 5); the pearlite is well laminated. The outer corners of section A show what appears to be chilling, but on examination at high magnification the white portions turn out to be ferrite (there are traces of cementite); the dendritic cementite originally formed has evidently decomposed during cooling into fine graphite and

TABLE III.—*Details of Melting, Treatments, and Casting Temperature.*

Series 1.	Series 2.	Series 3.	Series 4.	Series 5.
Charges—				
Pig A. 1¾ cwt. Pig B. 2½ cwt.	Pig D. 1¾ cwt. Pig E. 1 „ Pig C ¼ „ Soft scrap 1¼ „	Pig A. 1¼ cwt. Pig B. 3 „	Pig A. 1 cwt. Pig B. 7 „	Pig A. 1¼ cwt. Pig B. 3 „
Method of melting—				
Oil-fired crucible	Oil-fired crucible	Oil-fired crucible	Cupola	Oil-fired crucible
Casting temperature and additional treatment—				
1/1 1,380 deg. C. heating.	2/1 1,370 deg. C. heating.	Treated with 11 lbs. of Fe-Si-Ti. Steel for container 5½ lbs. 3/1, 1,415 deg. C. (heating).	4/1 1,420 deg. C.	5/1 1,300 deg. C.
			4/2, 5 cwt. transferred to crucible of oil-fired furnace and treated with 12 lbs. Fe-Si-Ti. 1,280 deg. C.	5/2 treated with 11-lbs Fe-Si-Ti. 1,320 deg. C.
1/2 1,420 deg. C. heating.	2/2 1,420 deg. C. heating.	3/2 1,430 deg. C. heating.		
1/3 1.460 deg. C.	2/3 1,440 deg. C.	3/3 1,440 deg. C.	4/3, As 4/2 treated for 2½ mins. with CO_2. 1,310 deg. C.	5/3 treated with CO_2 for 2 mins. 1,310 deg. C.
1/4 1,430 deg. C. cooling.	2/4 1,360 deg. C. cooling.	3/4 1,400 deg. C. cooling.	4/4 As 4/3 after allowing to cool in shank.	
1/5 1,390 deg. C. cooling.	2/5 1,300 deg. C. cooling.	3/5 1,330 deg. C. cooling.	1,240 deg. C.	

TABLE IV.—*Chemical Composition of the Castings made during Part I of the Investigation.*

Per cent.	C.	Si.	Mn.	S.	P.	Cr.	Ti.
Series 1 ..	3.74	2.18	1.09	0.028	0.138	0.03	0.07
Series 2 ..	3.82	2.10	0.92	0.040	0.184	0.26	0.08
Series 3/1 ..	3.82	2.00	0.98	0.026	0.15	0.02	0.17
3/2 ..		2.20					0.38
3/3 ..		2.24					0.38
3/4 ..		2.22					0.36
3/5 ..	3.70	2.22			0.16		0.36
Series 4/1 ..	3.87	2.10	0.94	0.068	0.12	0.03	0.07
4/2 ..	3.79	2.14					0.19
4/3 ..	3.70	2.30					0.42
Series 5/1 ..	3.92	1.89	0.87	0.035	0.16	0.03	0.06
5/2 ..	3.76	2.09					0.33
5/3 ..	3.72	2.13					0.44
5/4 ..	Not analysed						

ferrite. In B the chilling effect noted in A is absent.

Sound casting (thick section C, Fig. 1) and unsound casting (thick section D, Fig. 1).—The pearlite cell walls are still in evidence in some parts of sections C (Fig. 6), in others they are missing (Fig. 7); there is a considerable variation in graphite size. In section D, the ghost network has disappeared entirely and the graphite is present as very large flakes (Fig. 8).

From this short summary it will be seen that the chief differences between the sound and the unsound castings appear to be the size of the graphite flakes and the distribution of the phosphide.

TABLE V.—*Mechanical Properties, Series* 1.

Chemical Composition : C, 3.74 ; Si, 2.18 ; Mn, 1.09 ; S, 0.028 ; P, 0.138 ; Cr, 0.03 and Ti, 0.07 per cent.
Test-bars nominal size 0.875 in. dia. cast in oil-sand moulds.

Expt.	Casting temp. Deg. C.	Transverse on 12-in. centres, tested without machining.					Tensile machined to 0.564 in. dia. M.S. Tons per sq. in.
		Dia. of bar. In.	Breaking load. Lbs.	Corrected breaking load. Lbs.	Modulus of rupture. Tons per sq. in.	Deflection. In.	
1	1,380 heating	0.875 0.875	1,120 1,098	1,120 1,098	22.8 22.36	0.18 0.18	12.32 12.00
2	1,420 heating	0.890 0.895	1,120 1,210	1,064 1,131	21.67 23.02	0.19 0.22	11.20 11.20
3	1,460	0.90 0.89	1,187 1,053	1,090 1,000	22.22 20.37	0.22 0.20	9.24 9.36
4	1,430 cooling	0.89 0.87	1,232 1,030	1,170 1,048	23.83 21.33	0.18 0.17	10.2 10.16
5		No test-bars cast.					

TABLE VI.—*Mechanical Properties, Series* 2.

Chemical Composition : C, 3.82 ; Si, 2.10 ; Mn, 0.92 ; S, 0.040 ; P, 0.184 ; Cr, 0.26 ; and Ti, 0.08 per cent.
Test-bars nominal size, 0.875 in. dia., cast in oil-sand moulds.

Expt.	Casting temp. Deg. C.	Transverse on 12-in. centres, tested without machining.					Tensile machined to 0.564 in. dia. M.S. Tons per sq. in.
		Dia. of bar. In.	Breaking load. Lbs.	Corrected breaking load. Lbs.	Modulus of rupture. Tons per sq. in.	Deflection. In.	
1	1,370 heating	0.875 0.880	1,456 1,344	1,456 1,321	29.64 26.89	0.19 0.16	13.2 12.72
2	1,420 heating	0.845 0.880	1,165 1,344	1,293 1,321	26.33 26.89	0.19 0.17	13.72 13.6
3	1,440	0.855 0.865	1,255 1,456	1,345 1,507	27.38 30.68	0.14 0.15	13.4 12.8
4	1,360 cooling	0.850 0.860	1,299 1,478	1,418 1,556	28.86 31.69	0.14 0.16	14.16 14.08
5	1,300 cooling	0.865 0.860	1,456 1,344	1,507 1,416	31.39 29.49	0.15 0.16	13.92 13.8

Experimental

The experimental work has been divided into two sections. Part I deals with the relationship between metal and soundness, and Part II with that between sand and soundness. In describing the results of Part I, attention will be directed first to mechanical properties, then to

a consideration of shrinkage spheres, and finally to the castings for the sake of continuity with Part II.

PART I.—RELATIONSHIP BETWEEN METAL AND SOUNDNESS

In this series of experiments, pump bodies similar in design and size to those shown in Fig. 1 were used as the test castings, and some additional experiments on stabilus bodies similar to Fig. 15. In addition, shrinkage spheres similar to those used by the B.C.I.R.A. (see

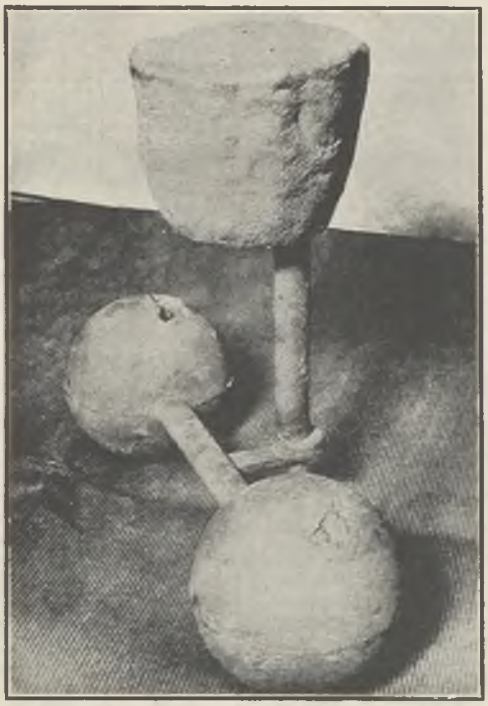


Fig. 10.—B.C.I.R.A. Test Spheres.

Figs. 9 and 10) and transverse test-bars 0.875 in. dia. were cast, the details of which (see Fig. 11) are as follow:—

Pump Body Castings.—Moulded in green sand on hand-press machines, two per box using one common runner; two boxes cast for each experiment.

Shrinkage Spheres.—Moulded in green sand on hand-press machines, spheres 3 in. dia. joined by a runner ½ in. dia., this in turn being fed by one of D section of ¼ in. radius; the head of molten metal was 3½ in.

Test-Bars.—These were 0.875 in. dia., cast in oil sand (and in some instances a similar set hand-rammed in green sand).

All the castings (except test-bars) discussed in Part I were cast in green sand made up as follows:—Mansfield sand, 7 parts; used sand, 23 parts, and coal-dust, 10 lbs. per 4 cwts. of sand mixture. This sand gives the following average tests:—Moisture, 5.8 per cent.; green permeability, 125 secs.; green compression, 9.5 lbs. per sq. in., and loss on ignition, 5.7 per cent.

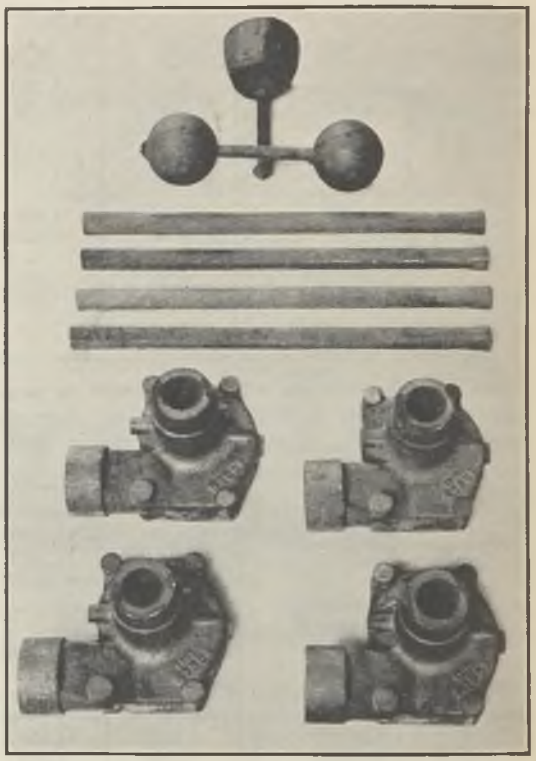


Fig. 11.—Set of Test Castings.

Details of charges, method of melting, addition treatment and casting temperature will be found in Table III. Analyses of the pig-irons and ferro-silicon-titanium are given in Table I. The ferro-silicon-titanium was packed into a steel canister attached to a steel rod protected by a graphite sleeve. The steel rod was provided with a ring by means of which it could be attached to the crane hook and lowered into the crucible; a weight on the rod enabled the canister to be kept immersed in the molten iron, shown diagrammatically in Fig. 12. In all experiments in this series, treatment with ferro-silicon-

titanium and with carbon dioxide took place in the crucible. Some difficulty was experienced in obtaining thorough mixing of the metal in the crucible after the addition of the ferro-silicon-titanium, with the result that there was a gradual increase in the silicon and titanium contents of the treated members of series 3, 4 and 5; details of these variations are given in Table IV. Temperatures were measured with a platinum/platinum-rhodium thermo-couple encased in a fused silica sheath protected with a refractory wash.

A full examination was made of the various specimens obtained, but it would be wearisome to discuss the results here in detail item by item, the complete results are included in Tables III *et seq.* The salient features may be summarised as follows:—

TABLE VII.—*Mechanical Properties, Series* 3.
Test-bars nominal size 0.875 in. dia. cast in oil-sand moulds.

Expt.	Casting temp. Deg. C.	Transverse on 12 in. centres, tested without machining.					Tensile machined to 0.564 in. dia. M.S. Tons per sq. in.	Analysis.	
		Dia. of bar. In.	Breaking load. Lbs.	Corrected breaking load. Lbs.	Modulus of rupture. Tons per sq. in.	Deflection. In.		Si.	Ti.
1	1,415 heating	0.870	1,523	1,550	31.55	0.16	15.72 15.80	2.00	0.17
2	1,430 heating	0.865 0.870	1,568 1,523	1,623 1,550	33.05 31.55	0.17 0.19	15.4 15.4	2.20	0.38
3	1,440	0.865 0.865	1,456 1,456	1,507 1,507	30.68 30.68	0.17 0.16	15.8 15.8	2.24	0.38
4	1,400 cooling	0.865 0.870	1,456 1,523	1,507 1,550	30.68 31.55	0.17 0.19	15.8 15.8	2.22	0.36
	1,330	0.870	1,568	1,595	32.48	0.17	15.2	2.22	0.36

TABLE VIII.—*Mechanical Properties, Series* 4.
Test-bars nominal size 0.875 in. dia. cast in oil-sand moulds.

Expt.	Casting temp. Deg. C.	Transverse 12-in. centres tested without machining.					Tensile machined to 0.564 in. dia. M.S. Tons per sq. in.	Analysis.		
		Dia. of bar. In.	Breaking load. Lbs.	Corrected breaking load. Lbs.	Modulus of rupture. Tons per per in.	Deflection. In.		C.	Si.	Ti.
1	1,420	0.90 0.90	1,187 1,164	1,091 1,070	22.20 21.78	0.24 0.26	9.68 9.68	3.87	2.10	0.07
2	1,280 Ti treated	0.89 0.90	1,523 1,680	1,447 1,543	29.39 31.41	0.21 0.17	15.52 15.36	3.79	2.14	0.19
3	1,310 CO_2 treated	0.89 0.90	1,568 1,612	1,489 1,482	30.26 30.16	0.20 0.20	15.00 15.20	3.70	2.30	0.42
4	1,240 CO_2 treated and cooled	0.90 0.89	1,500 1,478	1,379 1,404	28.05 28.53	0.19 0.21	13.12 13.20			

Mechanical Properties

Throughout the experiments, all mechanical properties refer to results obtained from test-bars cast to a nominal size of 0.875 in. dia. All tests were made in duplicate, and in general there was fairly good agreement between the

duplicate tests. A large number of mechanical tests have been made, but with the exception of a few additional examples where necessary, only those referring to Series 1 to 5 will be given.

The results of the tests made in Series 1 and 2 are given in Tables V and VI. The mechanical properties of the metal of Series 1 were considerably influenced by casting temperature, whereas those of Series 2 show very little variation over a similar range of temperature. The authors believe this to be due to the form and distribution of the graphite which existed as flakes, increasing in size with the casting temperature in Series 1, and mainly as fine graphite in Series 2.

TABLE IX.—*Mechanical Properties, Series 5.*

Test-bars nominal size 0.875 in. dia. cast in oil-sand moulds.

Expt.	Casting temp. Deg. C.	Transverse 12-in. centres tested without machining. Dia. of bar. In.	Breaking load. Lbs.	Corrected breaking load. Lbs.	Modulus of rupture. Tons per per in.	Deflection. In.	Tensile machined to 0.564 in. dia. M.S. Tons per sq. in.	Analysis. C.	Si.	Ti.
1	1,300	0.92 0.90	1,232 1,187	1,059 1,091	21.46 22.20	0.13 0.15	10.88 10.88	3.92	1.89	0.06
2	1,320 Ti treated	0.90 0.90	1,657 1,568	1,523 1,441	30.99 29.32	0.14 0.17	14.28 14.28	3.76	2.09	0.33
3	1,310 CO_2 treated	0.89 0.875	1,657 1,545	1,574 1,545	31.99 31.53	0.15 0.14	14.40 15.20	3.72	2.13	0.44

TABLE X.—*Influence of Titanium Treatment on Cupola-Melted Iron.*

	Mould.	Transverse 12-in. centres. Tested without machining. Dia. of bar. In.	Breaking load. Lbs.	Corrected breaking load. Lbs.	Modulus of rupture. Tons per sq. in.	Deflection. In.	Tensile machined to 0.564 in. dia. M.S. Tons per sq. in.
Cupola metal. Cast 1,350 deg. C. Ref. M.2441	Green sand	0.875 0.89	1,187 1,187	1,187 1,120	24.22 22.92	0.17 0.19	10.32 9.96
Do.	Oil sand ..	0.88 0.895	1,210 1,232	1,187 1,142	24.18 23.41	0.17 0.17	10.12 10.04
As above, crucible treated with Fe-Si-Ti. Cast 1,360 deg. C. Ref. M.2442	Green sand	0.875 0.875	1,680 1,344	1,680 1,344	34.27 27.42*	0.15 0.13	16.40 16.84
Do.	Oil sand ..	0.91 0.88	1,837 1,568	1,635 1,545	33.24 31.35	0.18 0.17	15.68 15.28

Chemical composition :—

	C.	Si.	Mn.	S.	P.	Cr.	Ti.
M.2441	3.75	1.80	0.82	0.072	0.14	0.06	0.07
M.2442	3.71	1.96	0.82	0.080	0.13	0.06	0.35

Cupola charge :— Pig A. 1¼ cwts.
Pig B. 3 cwts.

* Test-piece unsound at surface.

The mechanical properties of Series 3 show remarkable uniformity over a range of casting temperatures varying by more than 100 deg. C. The graphite in these specimens was wholely of the super-cooled variety. The mixture and method

of melting are the same as used for Series 1 (which gave rather poor results), and the improvement is to be attributed entirely to the change in structure brought about by the treatment with ferro-silicon-titanium (Table VII).

TABLE XI.—*Influence of Titanium Treatment on Cupola-Melted Iron.*

	Casting temp. Deg. C.	Transverse 12-in. centres. Tested without machining.					Tensile machined to 0.564 in. dia. M.S. Tons per sq. in.
		Dia. of bar. In.	Breaking load. Lbs.	Corrected breaking load. Lbs.	Modulus of rupture. Tons per sq. in.	Deflection. In.	
Cupola metal. Ref. M.2382	1,340	0.92 0.91	1,277 1,254	1,098 1,115	22.4 22.74	0.24 0.25	11.60 11.36
As above, crucible treated with Fe-Si-Ti. Ref. M.2383	1,320	0.875 0.88	1,501 1,546	1,501 1,520	30.62 31.00	0.24 0.24	14.4 14.0
	C.	Si.	Mn.	S.	P.	Cr.	Ti.
M.2382	3.78	1.94	0.97	0.068	0.195	0.26	0.08
M.2383	3.75	2.06	1.00	0.068	0.190	0.26	0.28

Cupola charge :—Pig C, ½ cwt. ; pig E, 1½ cwt. ; pig F, 5 cwts. ; and soft scrap, 3 cwts.

In Series 4 and 5, treatment with carbon dioxide was used additional to treatment with titanium, and the results (Tables VIII and IX) show that under the conditions of these experiments, no notable improvement was obtained by using CO_2. These experiments were also intended to show the influence of the method of melting, but unfortunately the disparity between the casting temperatures of the untreated metal in the two series, and between the untreated and treated metal in Series 4, renders such a comparison impossible. The authors have, however, ample proof that titanium treatment brings about equally good results whether the metal is melted in the cupola or the crucible, and they offer the results shown in Tables X and XI as evidence of this, the titanium treatment in each instance being carried out in the crucible. It may be mentioned here that very little improvement has been found when applying the titanium treatment to cast irons which in their normal condition possess good mechanical properties, say of the order of 17 or more tons per sq. in. maximum stress in tensile.

Shrinkage Spheres—(Results Summarised in Table XII)

These spheres may be regarded as castings for which no provision has been made for feeding. There was a relationship between casting temperature and shrinkage in the spheres; the higher the casting temperature, the larger the shrinkage cavity. In these experiments treatment with ferro-silicon-titanium (or with the same alloy followed by bubbling carbon dioxide through the melt) did not appear greatly to influence the size of the primary shrinkage cavity, but such treatment appeared to cause molten or partly-molten metal to be exuded into the primary cavity at a later stage in solidification. A similar secondary effect was produced

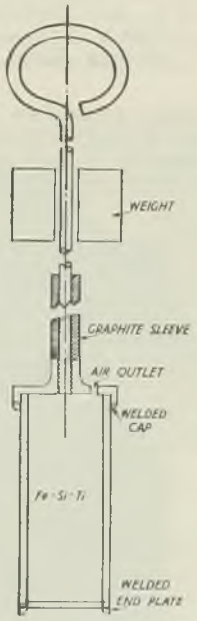


FIG. 12. — ARRANGEMENT STEEL CANISTER CONTAINING FERRO-SILICON-TITANIUM FOR IMMERSION.

in iron from certain pig-iron mixtures, but not in that from other mixtures; for example, mixtures of pigs A and B produced castings having

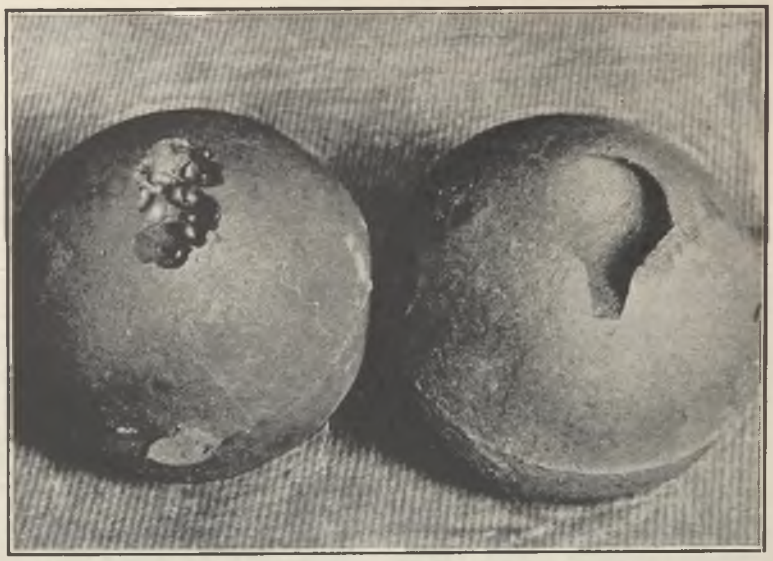


Fig. 13.—Shrinkage Spheres. Right—Test Sphere 4/1, Cupola Metal Cast at 1,420 deg. C. Left—Test Sphere 4/2, Ti-treated Metal Cast at 1,280 deg. C.

shrinkage cavities quite free from exudation whether melted in crucible or cupola; a typical example is shown in Fig. 13 (4/1), whilst 4/2 in the same illustration is typical of a cavity containing a number of small exudation beads. Spheres cast at low temperature from titanium treated metal had their shrinkage cavities almost completely filled with large exuded beads

Fig. 14.—Shrinkage Spheres. Right—3/5, Cast at 1,330 deg. C. Left—3/3, Cast at 1,440 deg. C.

—see Fig. 14 (3/5). Sphere 3/3 in the same illustration contained a number of small exuded beads which do not show in the photograph. The two spheres show the influence of casting temperature.

Some of the globules from the shrinkage cavities of two of the spheres of series 3 were detached and analysed. There was a marked difference between their chemical composition and that of the parent metal:—

Sphere.	Parent Metal.				Exuded Globules.			
	C.	Si.	P.	Ti.	C.	Si.	P.	Ti.
3/1	3.82	2.00	0.15	0.17	3.5	1.64	0.38	0.17
3/5	3.70	2.22	0.16	0.36	3.7	1.79	0.48	0.26

The authors are of the opinion that there is a relationship between these exudations and the pearlite-phosphide cellular structure, but before enlarging on this it is desirable to refer in greater detail to this cellular structure (see, for example, Fig. 2).

The cellular phosphide network has frequently been described in the literature of cast iron. Such cellular structures are generally pearlitic and contain more or less phosphide eutectic according to the amount of phosphorus present in the iron. They are certainly much richer in phosphide than the regions which they enclose, and general considerations of the mechanism of solidification make it probable that the pearlitic cell walls themselves contain more phosphorus in solution than the cell centres. The concentration of phosphide eutectic in the cell walls indicates that the metal here was the last to freeze and suggests at once that they represent the boundaries of allotrimorphic crystals that crystallised during solidification.

Many of the irons that show pronounced cell walls exhibit also a well-defined dendritic structure (Figs. 16 and 17), and in many instances the dendrites pass without changing direction straight through two or more network encircled grains. An excellent example is shown in Fig. 18, in which a long dendrite passes completely across the field, traversing in its course five grains. There are, indeed, two structures, one imposed on the other: the primary structure, the dendrites; and the secondary cellular structure.

An adequate explanation could be given for either structure singly, but the authors were unable to put forward a satisfactory one to account for the two together. Whilst this Paper was in course of preparation a simple and satisfactory explanation accounting for the formation of these structures was put forward by Boyles.* He regards crystallisation of the type under consideration as taking place in two stages: primary dendrite formation, during which dendrites push forward into the molten metal, then before they have had time to complete their growth independent solidification from a number of centres (having no particular relationship to the dendritic families) commences in the still liquid metal surrounding the dendrites and their branches. This secondary crystallisation produces the cell structure.

Having reached this stage and accepting Boyles' explanation of the formation of this duplex structure, an acceptance which it seems to the authors is fully justified, it becomes pos-

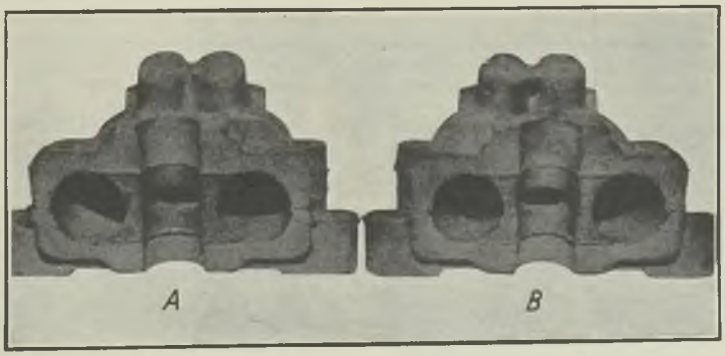


Fig. 15.—Stabilus Body Castings. Left, M.27; right, M.22

* "The Formation of Graphite in Grey Iron." Trans.A.F.A., 1938, Vol. 46, p. 297.

sible to picture a relationship between the cellular structure and the exudations, and to account for their volume increasing as the casting temperature is lowered. As the casting cools and solidification proceeds, a stage is reached where the combined effect produced by the contraction of the already solid shell and the expansion resulting from the precipitation of fine graphite within the interstices of the dendrites forces the enriched molten liquor into the shrinkage cavity *via* the still liquid metal surrounding the growing cells. When the metal is cast hot there is a steep temperature gradient across the casting, and liquid metal squeezed from the solidifying shell is rejected into the still mainly liquid interior, and just before the casting is completely solid there is only a small portion in which liquid metal still exists. On the other hand, when the metal is cast at a lower temperature, the temperature gradient is less steep, and during the later stages of solidification a greater volume of the casting consists of a scaffolding of

TABLE XII.—*Results of Tests on 3-in. Dia. Shrinkage Spheres.*

Series.	Fracture of ½ in. dia. runner.	External appearance of spheres.	Appearance of interior when bisected vertically.	Microscopic examination.
1/1	Normal soft grey iron fracture.	One sphere (apparently) sound, the other showing small pinhole.	All the spheres showed cavities; most of these were roughly spherical in shape and had fairly smooth, oxidised interiors. The size of the shrinkage cavity increased from 1/1 to 1/3 and then decreased to 1/5. The difference in size of the cavities in specimens 1/2, 1/3, 1/4 was not great.	The metal at the top of the spheres (roughly two thirds of the total volume) had a much more open structure than the metal at the bottom of the spheres; on the surface of this denser metal the cellular phosphide / pearlite boundaries could be seen.
1/2	As 1/1.	All exhibit open shrinkage cavities of considerable size.		
1/3	Very coarse graphite flakes.			
1/4	Normal soft grey iron fracture.			
1/5	As 1/4.	One sphere (apparently) sound, the other showing small pinhole.		
2/1	Half matt grey; signs of cellular structure as bright veins; half fine graphite flakes.	All showed large open shrinkage cavities; into most of these a considerable amount of metal had exuded. There was no great difference in the volume of the cavities from spheres 2/1, 2/2, 2/4; the shrinkage cavities of spheres 2/3 were slightly larger. Spheres 2/5 showed very little shrinkage.	In general agreement with remarks at left. Spheres 2/5 were interesting; there had evidently been a shrinkage cavity at the top of each sphere, but into this molten or pasty metal had exuded so that in one instance the original cavity was entirely filled and in the other almost filled.	Sections cut from 2/3 and 2/5 indicated 2/3 top, coarse flake graphite. 2/3 bottom, a little supercooled mixed with fine and coarse flake graphite. 2/5 top. 2/5 bottom. Graphite in both, finer than corresponding 2/3 specimens.
2/2	As 1/2 but three quarters matt.			
2/3	Matt grey with cellular structure as thin bright veins.			
2/4				
2/5				
3.	All matt grey with thin bright veins of cellular structure. Cellular structure increases in size with casting temperature.	3/1, 3/2, 3/3, 3/4 have large open shrinkage cavities containing exudations. The shrinkage cavities of 3/5 have, to a large extent, been refilled.	All spheres showed phosphide/pearlite cellular structure quite clearly on their sawn surfaces. One specimen of 3/1 showed slight opening of the grain from the centre towards the top; all other specimens had a very dense looking structure (Fig. 14).	Specimens from ½ in. dia. runners all had supercooled graphite, and marked dendritic and superimposed cellular structure. The graphite in sphere 3/1 was coarse flake at top and fine flake at bottom. In sphere 3/3 graphite was medium and fine flake at top and bottom respectively. Sphere 3/5 had supercooled graphite throughout.

(*Continued on next page*)

TABLE XII—(*continued*).

4.	Mainly coarse crystalline with traces of matt grey(4/1). Others matt grey with cellular structure.	4/1. One sphere shows a large shrinkage cavity with no sign of exudation, interior of the sunken hole being quite smooth; there was no apparent shrinkage cavity in the other 4/1 sphere. (Fig. 13.)	The sphere from 4/1 which appeared to be sound was found to have a cavity under the skin when cut open, no exudation, centres slightly unsound (porous). One of 4/2 appeared quite sound; 4/3, large cavities partly filled with exudations. 4/4, cavities almost closed with a skin of metal, large exudations almost filling cavities. No centre porosity in 4/2, 4/3, 4/4.	4/1 did not, and 4/2, 4/3, 4/4 did show cellular phosphide - pearlite structure. There is the usual refining of graphite structure following titanium treatment, but in all instances the structures were of the mixed type. The amount of supercooled graphite present is certainly greatest in those specimens that have been treated with CO_2.
5.	5/1 crystalline. 5/2, 5/3 matt grey, signs of cellular structure as bright veins.	5/1 shrinkage cavities partly covered with a skin of metal, interiors smooth. 5/2, 5/3, considerable amount of exuded metal has again been forced into the shrinkage cavities.	Not cut up.	Not cut up.

already solid dendrites surrounded by liquid, and the enriched molten liquor, having no liquid central reservoir to receive it, is forced outwards into the shrinkage cavity.

CASTINGS

Influence of Casting Temperature—(Summarised in Table XIII)

The influence of casting temperature was determined in the experiments, Series 1 and 2. Of the 40 castings made, only one showed signs of an external sink, and this was in one of the castings cast at the highest temperature (1,460 deg. C.) from Series 1. There is an indication that high casting temperature tends to produce external sinking. The evidence for this is, however, somewhat slender, based as it is on one example, and the authors are not prepared to press the point at the moment. The experiments in Series 3 also refer to the influence of casting temperature, in this instance treated with ferro-silicon-titanium and using iron substantially as for Series 1, making only such alterations as were necessary to balance the silicon introduced by the ferro-alloy. The results very clearly indicate the improvement in soundness, brought about by such treatment.

Influence of Base Irons

By a comparison of the results obtained from Series 1 and 2, it was intended to illustrate the contention, based on the authors' experience in production work, that certain mixtures of pig-irons produce sounder castings than others, although the final chemical analysis of the metal in the castings may differ but little. The cast-

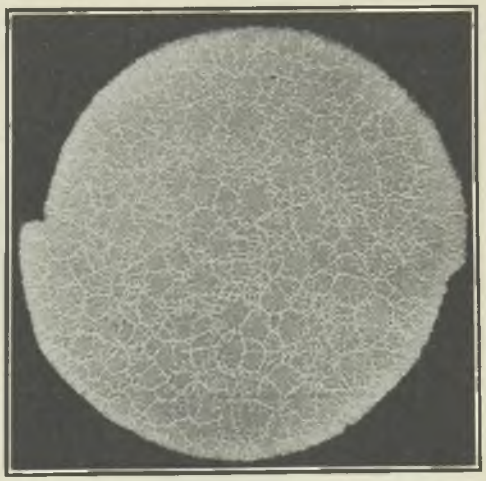


FIG. 16.—RUNNER FROM TEST SPHERES, 3/3.

ings of Series 2 were free from external sinks and distinctly sounder internally than those of Series 1, a result that is in agreement with the previous reports received about the behaviour

of these two mixtures in the foundry. It is true that the two irons are not strictly comparable, for that in Series 2 contains a small amount of chromium, although the authors do not believe this in itself to have had any important influence. Whatever the views on the influence of this small percentage of chromium may be, the castings confirm the relationship between structure and soundness which was outlined when recording the results of the preliminary examination, and indicate that iron with a dense structure seems, in the matter of internal unsoundness, less susceptible to variations in casting temperature than metal of open structure.

TABLE XIII.—*Record of Pump Body Castings made in Series* 1 *to* 5.

Series.	Expt.	Box.	Surface appearance.	Castings cut in two (see Fig. 1). Condition of interior.
1	1	A B	Poor surface, no sinks. Mis-run and cold shuts, no sinks.	Not cut up.
	2	A B	Good surface, no sinks.	One drawn, one sound. One badly drawn, one sound.
	3	A B	Sand burnt on surface of casting. One showed slight sink.	One very slightly drawn, one sound. Both sound.
	4	A B	Good surface, no sinks.	All sound.
	5	A B	Good surface, faint traces of cold shuts, no sinks.	One very slightly drawn, one sound. One very slightly drawn, one sound.
2	1	A B	Surface satisfactory, no sinks.	One slightly drawn, one sound. One considerably drawn, one sound.
	2	A & B		All sound.
	3	A & B		All sound.
	4	A & B		All sound.
	5	A B		One very slightly drawn, one sound. Both sound.
3	1 to 5	—	Surface satisfactory, no sinks.	All sound, the outlines of the cellular structure were quite marked and clearly visible on the sawn surfaces.
4	1	A & B	Slight evidence of scabbing; one casting showed what might be a slight sink.	All showed slight porosity at the centre of thick sections.
	2 & 3	—	Surface satisfactory, no sinks.	All sound in thick sections, but there seemed to be a tendency for the castings to contain small blowholes existing just under the skin. Marked cellular structure.
	4	A & B	Cold shuts, no sinks.	
5	1	A & B	No sinks.	Two castings show small but definite cavities, and two no cavities but openness of structure.
	2	A & B	No sinks in the usual place, but one casting had a hole at the side of one of the side bosses.	All dense and sound. Marked cellular structure.
	3	—	No sinks.	

Influence of Titanium and Carbon-Dioxide Treatment

Reference has already been made to the improvement in internal soundness brought about by treatment with ferro-silicon-titanium when

TABLE XIV.—*Details of Stabilus Body Experiments.*

Type of casting: Stabilus body (Fig. 18). Weight of casting, 24 lbs. Cast in green-sand moulds, hand-pressed, one per box.

Method of melting.

Production cupola.	*Experimental cupola.*
Charge.	
Cwts.	Cwts.
Pig C .. .. .. $\frac{1}{2}$	Pig A .. .. .. $1\frac{3}{4}$
,, G .. .. .. $2\frac{1}{2}$	,, B .. .. .. $2\frac{1}{4}$
,, H .. .. .. $2\frac{1}{2}$	
,, J 1	
Cyl. scrap .. .. .. $3\frac{1}{2}$	
Additional treatment.	
None. 3 cwts. treated in crucible with 9 lbs. Fe-Si-Ti.	None. 3 cwts. treated in crucible with 9 lbs. Fe-Si-Ti.
Ref. M.21. Ref. M.22.	Ref. M.27. Ref. M.28.

Casting temperature and condition of castings.

1,310 deg. C. Both sunk between bosses.	1,315 deg. C. Both sunk between bosses.	1,320 deg. C. Neither sunk.	1,360 deg. C. Neither sunk, both slightly blown on boss.

Analysis.

Ref.	C.	Si.	Mn.	S.	P.	Cr.	Ti.
M.21	3.29	2.08	0.80	0.120	0.20	0.26	0.03
M.22	3.19	2.34	0.76	0.128	0.20	0.26	0.23
M.27	3.84	2.06	0.85	0.038	0.16	0.02	0.07
M.28	3.60	2.26	0.87	0.040	0.17	0.02	0.23

recording the influence of casting temperature (Series 3). In view of the excellent results obtained from Series 3, it was not to be expected that any improvement in soundness would be obtained in this particular kind of casting after additional treatment with CO_2. It will be noticed that the iron for Series 4 was cupola-melted; variations in the method of melting had apparently no influence on the final results under the conditions of these experiments.

FIG. 17.—STRUCTURE OF TEST-BAR 2/4. × 50.

FIG. 18.—STRUCTURE OF TEST-BAR 3/1. × 50.

Relationship Between Metal and Sinking

The primary object of these experiments was to determine the factors controlling external sinking. Although there is ample evidence that titanium treatment aids internal soundness, it cannot be said that the examination of these pump bodies provides any clear indication of the influence of such treatment on external sinking. There was slight evidence of a connection between casting temperature and sink-

ing, but at the time it was not possible to pursue this further. The authors hope shortly to be able to reopen this part of the investigation. In all these experiments the titanium was added in the crucible, a procedure not economically possible in practice. Methods for introducing the titanium in the cupola are now being investigated.

Additional Experiments

The results of the experiments on pump bodies having been distinctly disappointing with regard to sinking, they were discontinued. At a later date a number of castings similar to those shown in Fig. 15 had to be made. These showed the sinking phenomenon to a marked extent, and provided excellent specimens for use in extending the work already done. Data relevant to some of these experiments on the influence of metal and treatment are collected in Table XIV. As would be expected, iron of low total-carbon content is more susceptible to sinking than high-carbon iron, but in these experiments on castings more prone to the sinking defect than the pump body castings previously used, there was no evidence of any improvement following titanium treatment. What the influence of such treatment would be on iron of intermediate carbon content it is difficult to say at this juncture. It is true that M.28 with 3.60 per cent. carbon is free from sinks, but there is, however, no untreated specimen of similar carbon content for comparison. Within the limits of their experiments, the authors have not been able to find that titanium treatment exerts any pronounced influence on sinking.

PART II.—THE RELATIONSHIP BETWEEN SAND AND SOUNDNESS

The experiments recorded in Part I of the Paper represent only a portion of those made on similar lines, and their execution extended intermittently over a considerable period of time. During this time the authors were not unmindful of the possible influence of sand and mould conditions. It was suggested that the action of hand-pressing set up conditions in the mould that were different from those present when hand-ramming. The sinking defect was stated to be much more prevalent on hand-pressed than on hand-rammed work, but experiments made later to establish this showed it to be erroneous, the error being due, apparently, to a failure to appreciate that in many instances an attempt was being made to compare green sand in the one instance with dry sand in the other. However, before these points were brought out, some preliminary work was done on sand, and although the results have no direct bearing on the subject of this Paper, they seem to be of sufficient interest to justify their inclusion.

Assuming for the moment that the sinking was in some way connected with the method

TABLE XIVA.

	Position of test cylinder (See Fig. 19).	Green permeability. Seconds.	Green compression. Lbs. per sq. in.
Hand-rammed; average of six moulds made by operator No. 1	A	34	2.2
	B	33	2.1
	C	74	3.0
Hand-rammed; average of six moulds made by operator No. 2	A	53	2.7
	B	73	3.9
	C	74	5.7
Hand-pressed; average of six moulds made by operator No. 3	A	74	7.4
	B	97	7.6
	C	87	14.7
Hand-pressed; average of six moulds made by operator No. 4	A	58	4.0
	B	91	6.2
	C	94	9.8

of moulding, the cause might be the difference in the consistency of the sand. For instance, it can be imagined that if the sand varied much in permeability, gas flow would be greatest where the permeability was high, and conse-

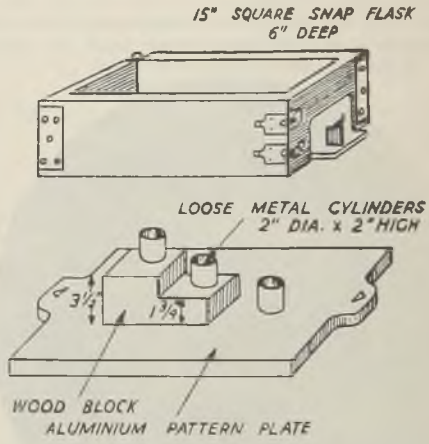


FIG. 19.—PATTERN-PLATE AND PATTERN SHOWING POSITION FROM WHICH SAND SPECIMENS WERE TAKEN. THE TEST CYLINDERS REFERRED TO IN TABLE XIVA ARE (A) EXTREME RIGHT, (B) CENTRE, AND (C) THE EXTREME LEFT.

quently there might be a considerable difference in the temperature of the sand at the time the mould was completely filled, and that sinking might take place in an overheated region. Again, where the sand had been pressed very

hard and had high strength and poor permeability, the metal might not lie satisfactorily.

In order to determine what difference in permeability existed between hand-rammed moulds and moulds made on a hand-press machine, a wooden pattern was made, having two steps, the first $1\frac{3}{4}$ in. high and the second $3\frac{1}{2}$ in. high. This was placed on an aluminium bottom-plate inside a 15 in. square snap-flask 6 in. deep. The moulds were made up in the ordinary way and thin sheet-metal cylinders 2 in. internal diameter by 2 in. high, made of 20-gauge material, were then pushed through the sand until their lower edges came into contact either with the aluminium pattern-plate or the steps on the wooden pattern (Fig. 19). The cylinders were sharpened at their entering ends to assist penetration without disturbing the sand. The cylinders, with sand still *in situ*, were then cut from the moulds and permeability and compression tests made. Green sand similar to that for which details have already been given was used; average tests of this sand gave:—Moisture, 5.8 per cent.; green permeability, 125 secs.; green compression, 9.5 lbs. per sq. in.; and loss on ignition, 5.7 per cent.

TABLE XV.—*Comparison of Castings made in Dry-Sand and Green-Sand Moulds.*

Type of Casting :—Stabilus body, hand-pressed, cast one per box, two boxes. Method of Melting :—Production cupola.

Charge :—
Pig C, $\frac{1}{2}$ cwt.; pig G, $2\frac{1}{2}$ cwt.; pig H, $2\frac{1}{2}$ cwt.; pig J, 1 cwt.
Cylinder scrap, $3\frac{1}{2}$ cwt.
Casting temperature, 1,330 deg. C.

Type of mould.	Condition of castings.
Black sand, cast green ..	One box only, casting sunk
Black sand, dried and blacked	No castings showing external sinking
Brown sand, cast green ..	Both castings showing external sinking
Brown sand, dried and blacked	No castings showing external sinking

Analysis :—C, 3.45; Si, 2.02; Mn, 0.85; S, 0.12; P, 0.26; and Cr, 0.24 per cent.

Charge :—
Pig H, 2 cwt.; pig J, 1 cwt.; pig F, $3\frac{1}{2}$ cwt.
Cylinder scrap, $3\frac{1}{2}$ cwt.
Casting temperature, 1,390 deg. C.

Type of mould.	Condition of castings.
Black sand, cast green ..	Both castings showing external sinking.
Black sand, dried and blacked	No castings showing external sinking.
Brown sand, cast green ..	Both castings showing external sinking.
Brown sand, dried and blacked	No castings showing external sinking.

Analysis :—C, 3.28; Si, 2.07; Mn, 0.86; S, 0.12; P, 0.17; and Cr, 0.27 per cent.

The results obtained are contained in Table XIVA. It would be idle to contend that such large differences are without influence upon the manner of solidification of cast iron in a sand mould, but in this instance no connection has been established between sinking and method of moulding. The present indication is that actual method of moulding, *i.e.*, whether hand-rammed or pressed, is without influence on the main problem. The specimens were rammed with

TABLE XVI.—*Influence of Blacking the Mould Surface on External Sinking.*

Type of casting :—Stabilus body, moulds hand rammed. Method of melting :—Production cupola.
Charge :—
Pig C, $\frac{1}{2}$ cwt.; pig F, 2 cwt.; pig H, 3 cwt.; pig J, 1 cwt. Cylinder scrap, $3\frac{1}{2}$ cwt.
Casting temperature :—
First casting, 1,360 deg. C.; last casting, 1,340 deg. C.

Type of mould.	Condition of castings.	Order of casting.
Black sand, cast green	Both castings show deep sinks between bosses; one casting hollow in one box	5
Black sand, dried, not blacked ..	Neither casting with external sinks	4
Black sand, blacked and dried ..	Neither casting with external sinks	3
Brown sand, dried, not blacked ..	Neither casting with external sinks	2
Brown sand, blacked and dried ..	Neither casting with external sinks	1

Analysis :—C, 3.15; Si, 1.96; Mn, 0.73; S, 0.13; P, 0.24; and Cr, 0.22 per cent.

a B.C.I.R.A. pattern of A.F.A. rammer, and permeability was determined with the B.C.I.R.A. permeability apparatus, and compression strength in a Dietert compression machine.

Green-Sand *versus* Dried Moulds

It is a well-known fact that better castings can be obtained from dried than from green-sand moulds, but to conclude from this that drying is the dominant factor would be, in many instances, an unwarranted assumption, for often the sands used for the two types of moulds are entirely different from each other. Particulars of the "black" sand used throughout these experiments have been given in Part I. Particulars of one of the sands used by the authors for dry-sand work are given below, and this sand mixture has been used where "brown" sand moulds are referred to in the experiments in the following section:—York yellow, 6 parts; Leighton Buzzard, 2 parts; used sand, 22 parts; and a half-pint of dextrine to each 4 cwts.

When considering the difference in behaviour of metal cast in green sand and dry sand, the two most important variants appear to be sand make-up and the amount of moisture present. If sound castings are obtained from "brown" sand dried moulds and castings with external sinks from "black" sand moulds cast green, is it possible to reverse the results by casting into the normally dried "brown" sand green, and into the normally cast green "black" sand after drying?

In order to determine this, two sets of experiments were made, in which the normal method of using the two sands was compared with methods reversed; the results of these experiments are summarised in Table XV. It will be seen that both sand mixtures give sound castings when the moulds are dried, and that external sinking takes place when they are used green, and from this it would seem that the moisture in the sand is the determining factor. The influence of the blacking used on the surfaces of the dried moulds remained undetermined, and, as it was possible that this was not unimportant, another series of experiments was made to determine the possible influence of blacking the mould surface before drying. The results have been collected in Table XVI, and it will be seen from these that sinking is uninfluenced by the presence or absence of blacking from the surface of the dried moulds.

A final batch of castings was made in which the influence of having one half of the mould dry and the other green was determined, and also the influence of somewhat increasing the size of the ingate used for an all-green mould. A check test in dry sand was included in the series, and B.C.I.R.A. shrinkage spheres as well as stabilus bodies were cast (Table XVII). The D-section runner for the shrinkage spheres which should have had a radius of ¼ in. was cut larger in error, but the runner joining the two spheres had the standard ½ in diameter.

The shrinkage spheres are shown in Fig. 20, and one of each pair sectioned in Fig. 21. The

TABLE XVII.—*Comparison of Castings Made in Dry-Sand and Green-Sand Moulds.*

Method of melting :—Production cupola.
Charge :—Pig H, 2 cwts.; pig J, 1 cwt.; pig F, 3½ cwts. Cylinder scrap, 3½ cwts.
Casting temperature :—First casting 1,330 deg. C.; last casting, 1,300 deg. C.
Method of moulding :—Hand-rammed; parts of moulds that were dried were blacked in the wet state; green-sand parts not blacked.
Sand :—Black sand.

Type of mould.	Order of casting.	Stabilus bodies, four castings cast, one per box.	Shrinkage spheres.
Dry-sand top	3	One blown on boss (or small open sink)	—
Green-sand bottom	4	—	Large open saucer-shaped sinks with small exudations.
Green-sand top	1	Two badly-sunken. One slightly sunken	—
Dry-sand bottom	6	—	Large spherical sink with exudation at bottom.
Dry-sand top and bottom	2	Free from external sinking ..	—
	5	—	Slight depression with exudation.
Green-sand top and bottom, with increased size of runner and gates on stabilus bodies ..	8	Three badly sunken	—
	7	—	Large spherical sink with exudation at bottom.

Analysis :—C, 3.22; Si, 2.08; Mn, 0.03; S, 0.13; P, 0.19; and Cr, 0.25 per cent.

spheres cast in green sand and those cast in the mould having a dry-sand bottom part and green-sand top part were very similar in appearance externally; they had a thin skin of metal almost completely covering their shrinkage cavities beneath, the cavities themselves being roughly spherical in shape. The spheres cast in moulds with dry top and green bottom sank less than those cast in a mould made wholly in green sand, or with the top part in green sand.

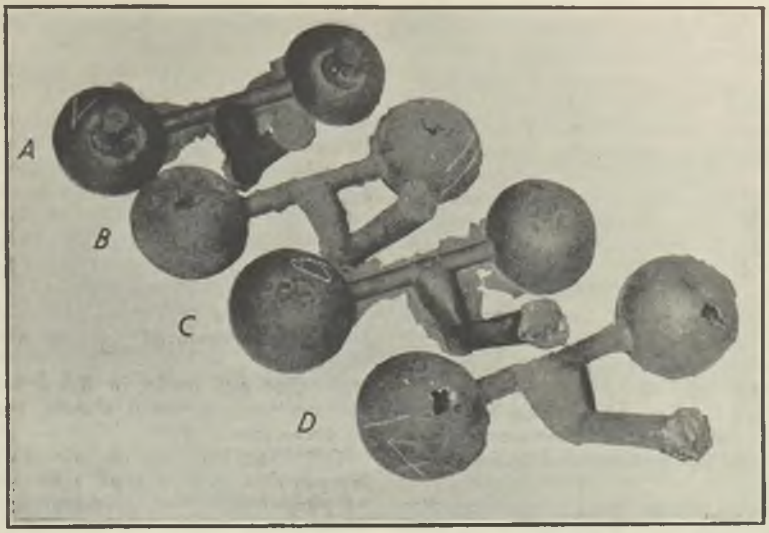


Fig. 20.—B.C.I.R.A. Shrinkage Spheres.

The behaviour in green sand indicates that a thin skin of solidified metal is formed almost immediately the mould is full, at least when casting components such as these test spheres; the moist sand acts as a mild chill.

The specimens cast with green-sand bottom and dry-sand top have characteristics which one would expect from a casting cast in a chill with a refractory top; the skin of the top-half has evidently not solidified as quickly as those of the two previous examples, and it contains a large open sink. To be in conformity one would expect the spheres cast entirely in dry sand to have solidified still more slowly and to have shown a still larger open sink at their upper surfaces, but actually they are almost entirely free from any obvious external sinking or internal shrinkage. To elucidate this apparent anomaly will be to elucidate the phenomenon of sinking, or at least go a long way towards it.

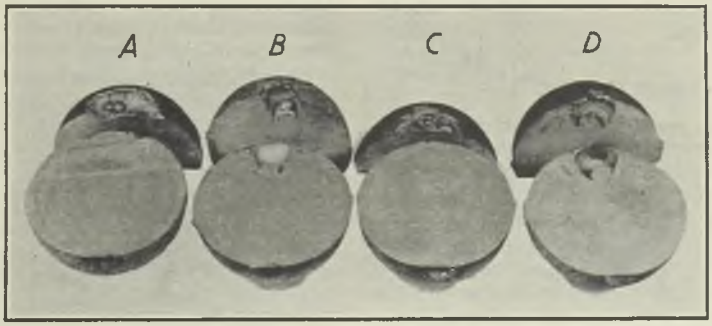


Fig. 21.—Shrinkage Spheres Sectioned.

While the results from the foregoing experiments do not define any clear foundry practice which would give outstanding results in advance of that already known, certain deductions can be made. The most direct method of avoiding external sinking in cast iron is to maintain the total carbon content over 3.5 per cent. This shows that there is a definite connection between the two factors. The disadvantage of following this practice is that, in castings of any other than plain design, internal porosity at heavy sections will occur. That internal porosity can be dispersed in high total-carbon iron by the treatment of ferro-silicon-titanium has been clearly shown by the respective experiments. To what extent this can be carried out has not been proved, and this point awaits further development.

On the other hand, the "sinking effect" brought about by the use of lower total-carbon cast iron when using green-sand moulds can be avoided by casting into moulds which have been previously dried.

The explanation for this difference in behaviour is not so easy; that it is directly connected with the presence of gas at the time of solidification is highly probable.

Examples of this can be found by casting other metals such as steel or aluminium in a chill mould in which the metal sets with little or no evidence of gas being present, yet the same metal cast into green-sand moulds can show an amount of gas sufficient to form a "cauliflower" head on the risers. Further to this, the suggestion has been put forward in a certain quarter that the liquid metal is capable of breaking down a proportion of water vapour from a green-sand mould, to create in the metal a hydrogen absorption sufficient to cause the "sinking effect" during solidification.

CONCLUSIONS

(1) High-carbon cast iron composed of pigs from different sources may vary considerably in mechanical properties, although their chemical compositions may be similar.

(2) Changes in casting temperature affect the strength of some high-carbon cast irons more than others of similar composition but different structure. Irons which show well-marked pearlite cell walls and fine graphite are influenced less than irons in which the graphite exists as large flakes.

(3) Treatment with ferro-silicon-titanium effects a marked improvement in the mechanical properties of low-strength high-carbon cast irons. Additional treatment with carbon dioxide did not affect the results obtained to any noteworthy extent. Carbon-dioxide treatment does not appear to be a method that can be conveniently applied in the foundry.

(4) Titanium treatment applied in the crucible produces equally good results irrespective of whether the metal was originally crucible- or cupola-melted.

(5) No marked improvement was found after applying titanium treatment to medium-strength irons.

(6) Castings made from irons which solidify with a pearlite cellular structure are denser and less subject to internal porosity (shrinkage) than those made from irons which do not show this characteristic. Titanium additions greatly assist in the production of this type of structure.

(7) The method by which the moulds are made (*i.e.*, whether hand rammed or pressed) is not of primary importance in relation to the phenomenon of external sinking.

(8) Titanium treatment is not effective in preventing pronounced examples of external sinking.

(9) Castings made in dried moulds are less susceptible to external sinking than those made in green sand.

(10) Provided that the moulds are dried, the composition of the sand does not seem to be of importance in relation to the sinking phenomenon.

DISCUSSION

Mr. W. Holland proposed a vote of thanks to the authors, remarking that the Paper would evoke much thought on the part of those who had heard it.

The Sphere Tests

Mr. E. Longden, after seconding the vote of thanks, which was carried with acclamation, asked whether any riser had been placed above the dome of the spheres, which had been shown.

Mr. West: None whatever.

Mr. Longden remarked that, generally speaking, sinking occurred through the combined effect of gas and the weakness of the mould-resistance to cast-iron expansion on graphitisation. If the gas in such a mould could not be evacuated with sufficient rapidity it occupied space in the mould under pressure. The metal did not feed back to replace the gases eventually evacuated from the cavity sufficiently to fill up during the solidification period. If for any reason the freezing rate was such that the runner, risers and gates were frozen up in a short time, and the mould had not been evacuated of gas, there would be as a consequence excessive sinking on the summit of the sphere. The degree of sinking would also be in direct ratio to the strength of the containing mould and also the heat conduc-

tivity of the mould material. The soundness of a casting depended upon the freezing rate as much as other factors. In the case of cast iron there were expansions from the growth of graphite from primary and secondary dissociation of carbon. If the directional growth of graphite could be controlled then sound castings might be secured. He claimed that with the aid of graphite growth in normal cast irons—he was not speaking of steel mix or cast iron below 3 per cent. of total carbon—a sound casting could be made so long as the mould conditions were of the order described, namely, that the mould was rigid, as gas-free as possible and had a high heat-conductivity class of material. In this way graphite growth was controlled to counteract liquid shrinkage. Growth was directed internally more than externally and soundness increased. A green-sand mould gave way when the initial carbon was precipitated on the outer shell of the casting. With a stronger order of conditions, say of dry sand, ganister, or a metal mould, there was an increasing control of the expansion of the metal. Consequently, there were several forces which were conducive to the production of a sound casting—freezing rate, minimum gas in the mould and resistance to shell expansion. Immediately there was a solidified shell the casting began to contract, exerting pressure on the still molten interior of the metal.

A Large Boring Bar

The firm with which he was associated had recently made and poured horizontally a 22 in. dia. cast-iron boring bar, 47 ft. in length and 20 tons in weight, perfectly sound, without feeders. Most foundrymen would have had to put on the casting about sixteen 12 in. feeders. These would be needed if made by ordinary sand practice. The casting, however, was made in a metal faced mould. When pouring the metal, gas was entrained, which, with the mould gases and occluded gas from the metal, created instability in shrinkage. So long as the temperature was sufficient to allow of a balancing and a rest for the metal in the mould, and outlets enabled gas to pass out of the mould, there would be a perfectly sound casting.

Effect of Gating

Mr. A. Sutcliffe said he recently had seen a "Y" pipe which was blowing at a certain point, and upon his (the speaker's) advice the gating was changed, whereupon the blowing ceased without using any different metal.

Referring to sinking, he once received a box of rollers for textile work. They continually sank in the middle owing to the way in which they were being run. Some foundries ran them on the top with a large mass of metal carrying a small niche. The result was that there was no chance for the rollers to sink if they were run at the proper temperature. If run too hot, there would be a sink hole in the lower shank.

If a man was tapping out into a ladle or into a shank (it did not matter which), and he skimmed it at the finish, and went away, upon returning he found the same sort of material had formed again. Where did it come from?

Mr. Sutcliffe also presented a number of exhibits for inspection.

Possible Causes of Blowing

Mr. West replied that blowing of the "Y" pipe could arise through insufficient venting of the core and mould, the use of chills, and, in point of fact, so many factors were concerned that a really definite answer to the question was difficult to give.

In reply to the suggestion that some alteration to the gating arrangements would overcome the examples of "sinking" shown in the lecture, it was not disputed. It was, however, necessary to bear in mind the object of the experiments. By the use of a standard set of mould conditions with the exception of the moulding sand, sinking of the metal occurred in one and not in another. The query arose as to why this should be.

Dirty Metal

The rising of globules of fluid slag in a ladle of molten iron had been observed from time to time, especially where the temperature was on the low side. Accepting in the first place that the ladle used was perfectly clean, Mr. West could only advance an explanation that this phenomenon was mostly observed with low-phosphorus and high total-carbon irons—these factors therefore indicated the need for hot melting, which would allow of a more rapid rise of the slag particles to the surface.

Risers and Shrinkage

He was much obliged to Mr. Longden for his remarks. His work in connection with ganister moulds was well known, but the speaker could not quite accept the remark that the absence of risers would have such a marked effect upon the spheres or upon the castings.

As a matter of fact, in the stabilus body castings there was a pencil whistler; there was no such thing in the case of the spheres, but by eliminating the use of whistlers a truer comparison was possible between the results obtained.

The American practice of using an ordinary type of iron and steel addition in the cupola,

and running into an electric furnace, he was afraid had led to a fair amount of unforeseen trouble.

Gas in Metal

He thought Mr. Phillips would bear him out that, in comparison with aluminium, it was an advantage to have some gas in the metal. In certain types of die-castings it was necessary to put gas in, in order to get a sound casting. It was essential to look further into the matter of molten cast iron free from gas and to observe the effect of it, because most foundries were dealing with cupolas where as much air was blown through as possible, and the metal was taking up as much as it could during the time it passed down the cupola.

Probably when investigation had been made it would be found there was a good comparison with aluminium and that a certain amount of gas was needed in order to give soundness.

The question of casting heavy sections and the use of chilled moulds had been mentioned. Experiments of that kind could be made with heavy sections without any danger of chilling or of difficulty in the machine shop. In the case of castings with $\frac{3}{16}$-in. outside walls coming up to sections of $\frac{3}{4}$-in. or even 1-in. thickness in bosses, a different proposition had to be faced.

Titanium and CO_2 Bubbling

Dr. A. L. Norbury, opening his remarks by complimenting the authors upon the work, which was particularly interesting and useful, said he would also like to thank Mr. West for his generous reference to the work of the British Cast Iron Research Association.

The reference to the different pig-irons was very interesting, namely, that pig-irons A and B gave sound castings, while C and D gave unsound castings. Would Mr. West care to give an indication of their particular titanium contents, and whether they were the cause of the difference? He was under the impression that some people thought the work on titanium and CO_2 was interesting but that it had no great practical application. The members of the Association had always held the other view. He was very much in sympathy with the Paper because it demonstrated this point very clearly.

Another point was that Mr. West might have given the impression that CO_2 treatment was not necessary. There was, however, ample evidence that it had a graphite-refining action, and in some foundries was actually being carried out in practice. The Association had some members who made "Silal," which had to have a fine graphite structure. If the graphite was not fine enough, then CO_2 was bubbled through the molten metal in the ladle before casting. Other members tapped the "Silal" metal on to soda ash in the ladle, and thickened the soda ash with limestone in the usual manner.

Soda Ash and CO_2

Incidentally, the fact that soda ash gave off such a tremendous amount of gas in the metal suggested that CO_2 or CO did not produce unsoundness in castings. It was known that the one gas which did produce blowholes was hydrogen. If a damp ladle was used, for example, steam bubbled up into the metal, was reduced and dissolved in the form of hydrogen, and castings could be obtained which were almost like sponges.

Effect of CO_2 Bubbling

Mr. West stated that in the case of the two pump bodies described, there was not a marked difference in the titanium content; it was something like 0.04 and 0.20 per cent. He did not wish to convey the idea there was no beneficial effect from CO_2 treatment, but he had not yet found any in the experiments made. There might be some benefit from that treatment in other directions, but in the limited amount of work which his collaborator and himself had carried out, it was not ascertained that the CO_2 treatment gave any better results than the titanium additions. Neither had they done any work in connection with the use of soda ash.

Heavy Cylinder Practice

Mr. J. R. Platt asked for explanation with regard to the casting of heavy cylinders weighing about $1\frac{1}{2}$ tons and of $\frac{3}{4}$-in. section, with a top and bottom flange, and also with regard to the casting of pots with a top flange. About two years ago the firm with which he was associated cast a number of such cylinders using iron with approximately 1.2 per cent. phosphorus. While some proved to be satisfactory under a hydraulic test, others showed porosity in one or two isolated spots on the inner rim of the casting. It occurred to him that such isolated spots of porosity were likely to be due to the sinking away of the phosphide eutectic at those points. They occurred in every case under the running gate. A low-phosphorus iron was tried of 0.4 per cent. phosphorus and the total carbon was reduced from about 3.7 to about 3.5 per cent. The porosity was eliminated. Several pots were cast which did not exhibit any sign of porosity, but another trouble was experienced.

Flanged Pots and Shrinkage

Mr. Platt then illustrated his point by means of a diagrammatic sketch on the blackboard. The top side of the pot was not cast with the usual type of feeding head. It was a $\frac{3}{4}$-in. section body. The flange itself was about $1\frac{1}{2}$ in.

thick as-cast. A facing was cast on, giving a clean face about 1½ in. wide. The total width of the flange was about 3 in.

Mr Platt then indicated where the points of porosity occurred in the case of a high-phosphorus iron, and stated that there was porosity in the neck of the flange. In the next casting a low-phosphorus and low-carbon content was used. A similar trouble was experienced as was mentioned in the case of the casting of the spheres; there was a definite sinking of the top flange as well as the appearance of little beads of metal almost detached from the surface of the sink cavity. The metal itself was quite sound and withstood the pressure test perfectly. Since then the total carbon content had been raised to about 3.6 per cent. and an occasional porosity spot occurred. The size of the runner was increased to about 1 in. diameter, and particular attention was paid to the feeding. As a result a perfectly solid flange had been obtained which did not exhibit any sign of porosity.

Remote Runners

He noticed that several of the castings referred to in the Paper were run at a point remote from the point of sinking. It would be interesting to know what would happen if the cylinder castings were run lower down the body.

Trouble which had occurred at the bottom of a casting, about 5 ft. below the top flange, in a foot, had been immediately cured by means of a chill.

Gating and Porosity

Mr. West observed that notice must be taken of the point raised by Mr. Sutcliffe. The point of introduction of the metal had a very great bearing on the type of casting. Mr. Platt had a bigger runner and a direct drop of his metal, so that it was rather to be expected there would be such an effect as he had described by means of a sketch.

He would like to make it clear that, as far as forms of gating were concerned, they could provide an open discussion in themselves. It was not his desire to put forward any theories concerning them. What was more desirable was to concentrate attention upon the effect obtained by means of standard methods, and then at a later date pursue the question of variation of the gate sizes and shapes.

With respect to the question of high phosphorus and total carbon, he hoped the chairman would call upon Mr. Timmins, of the British Cast Iron Research Association, to say something. The Paper which the Association had published was full of excellent information for founders who made pots of heavy section with cast iron of high phosphorus and high carbon on the one hand, and low carbon and low phosphorus on the other. Definitely, he would have worked with a lower phosphorus than Mr. Platt had done, and then a rather higher carbon could have been used. The higher the phosphorus present the lower the carbon appeared to be necessary to form the eutectic which had been mentioned. The chills immediately inhibited any porosity in one particular place, but, as he often said: "Do not think you have lost the porosity; you have only moved it somewhere else."

Perhaps the difficulty was even more pronounced in the case of aluminium where the feeding could not be made to heavy sections and chills had to be used.

The points raised by Mr. Platt were both practical and valuable. An increased size of runner was most likely to cure the fault as far as sinking was concerned. Porosity might occur through the runner causing a local hot spot.

Undercooling and Simultaneous Solidification

Mr. A. Phillips referred to the suspension of slag particles and agreed that hydrogen gas caused all the trouble.

In regard to the addition of titanium to cast irons, Boyles, in America, found he had to bubble CO_2 through the metal in order to eliminate some of the difficulty encountered. Were the authors of the Paper of a similar opinion?

Could not the term under-cooling be altered to internal solidification, as being more correct. In castings there was solidification from the outside. If it was possible to get the material to solidify as a whole, or internally and externally simultaneously, then a sound casting could be obtained.

Figures had been mentioned regarding the exudation of beads in a casting which had, he understood, 3.8 per cent. total carbon. The titanium in the bead was reduced 0.1 per cent. and the carbon 0.3 per cent. Regarding the one with 3.7 per cent., the titanium and carbon in the bead and casting remained constant. Had the titanium during the exudation of the bead anything to do with the lowering of the carbon in that particular instance?

With reference to the spidery graphite, if one took a high-carbon iron and added an inoculant to it, there would probably be spidery graphite, yet if one went the other way and took a low total-carbon iron, would there be the same kind of spidery graphite?

Crystalline Slag Inclusions

Mr. West said that with regard to the suspended slag particles he was quoting the British Cast Iron Research Association's theory regarding the crystalline slag inclusions and the

titanium which either covered or combined with the slag particles to form an innocuous medium. He was prepared to accept the theory at the moment, from the point of view that he had not a better one to substitute for it, and that the effect could be neutralised by the presence of hydrogen gas.

Boyles did raise the question of the CO_2 and hydrogen; but he (the speaker) had only mentioned points as they had been observed in the experiments made by his co-worker and himself. Just as good results were obtained without the CO_2 treatment as with it. From a practical point of view he would not like to be troubled with bubbling CO_2 through molten metal. Both his hearers and himself might do it in a perfectly satisfactory manner, but they had to remember that someone might have to do it who neither understood nor cared what happened as long as "something" was bubbling through. These things were somewhat in the nature of frills to foundry work, but if CO_2 did give decided advantages, then foundry practice would have to be adapted accordingly.

Titanium addition and CO_2 treatment were more effective in the case of the higher carbons than the lower carbons, but, as a matter of fact, with 3.2 per cent. and 3.3 per cent. total carbon, he found very little effect ensued from the titanium treatment. At 3.5 per cent., and even higher, the difference was remarkable. It was very helpful that this should be so, because it was possible to get increased mechanical properties from the higher carbon iron, whereas no such increase was produced in lower total-carbon iron with the same treatment.

Phosphorus and Shrinkage

Mr. A. A. Timmins remarked that the Paper had been extremely interesting to him personally, because for the past two years he had been responsible for the investigations on shrinkage which had been carried out by the Association in Birmingham. Again, the Paper was particularly noteworthy, because it was the first occasion on which a public announcement had been made of a case where the research results on the effect of titanium in relation to shrinkage had been confirmed in practice.

Some years ago Mr. West did a very interesting and useful piece of work dealing with the relationship of phosphorus to shrinkage. Work by the B.C.I.R.A. had now been carried out over a much wider range of compositions than those with which Mr. West originally started. The Association had been able to confirm the relationship between carbon, silicon and phosphorus which had to be obtained to remove porosity and which was originally pointed out by Mr. West.

The iron which Mr. West and his colleague had been using was low in phosphorus, actually, he thought, 0.2 per cent. For that reason it would not normally be expected that that iron would be porous. It was due to the fact that the investigators had used a very high carbon that porosity had been produced. At the same time, the effects which had been obtained were particularly noteworthy, because they were good examples of the possibilities obtainable with two irons which differed only in their titanium content.

This was exactly the type of thing which had been obtained with the shrinkage of the sphere, or the "dumb-bell" as it was termed. The titanium treatment in relation to shrinkage was not confined merely to that type of iron. It had been applied to numerous irons, and the belief now obtained that the titanium treatment could remove porosity in the case of any ordinary engineering irons.

Shrinkage Reduction by Ti

As a result of the investigational work which had been done, he was of the opinion that the effect of titanium in relation to shrinkage was far greater than any alteration in composition. He did not mean small changes in composition, but wide ones of 0.3 to 1.0 per cent. of phosphorus and 1.5 to 3 per cent. of silicon.

Mr. West had stated that two irons of the same analysis with respect to ordinary elements showed widely different results dependent upon the presence of and the addition of the titanium in the iron. The B.C.I.R.A. staff had been well aware of this effect for some time now, and they also knew that the same iron containing titanium was capable of giving widely different results according to the working conditions. Therefore, titanium should not be regarded in the same light as an ordinary alloying element, but as a material which, when present in cast iron in exceedingly small quantities (*i.e.*, 0.1 per cent. or 0.2 per cent.), exerted a predominating effect upon the properties of the iron. This fact was even more important when it was realised that most British pig-irons contained sufficient titanium to be susceptible to such melting conditions.

Enamelling Irons

Numerous examples had been met with in actual works practice where the solution of the shrinkage problem could be directly traced to the influence of titanium. One case occurred to him of a foundry making light castings for enamelling, where a similar iron was used day in and day out. One day the castings were showing porosity in the bosses. Examination showed that they had very coarse fractures and exhibited a coarse flake graphite. They produced a very

bad enamelling finish. Another day, for no apparent reason at all, the castings were perfectly sound and showed no sign of porosity in the bosses, and they had a fine graphite structure similar to that shown by Mr. West, while the enamel finish was far superior. The iron which was being used contained, he thought, about 0.15 per cent. of titanium. It was quite feasible and quite correct to assume that the differences which had been obtained were due to the variations in melting conditions which had produced a corresponding variation in the condition of the titanium.

Tests on Porosity

He had already referred to the fact that the treatment had been applied to all types of iron, but there was one point he would like to emphasise. It was not essential to achieve the full refinement of the graphite in order to obtain freedom from porosity, *i.e.*, it was not necessary to achieve the very fine graphite which was present in Mr. West's photographs.

This point was then illustrated by the speaker by means of a slide (Fig. A) showing sketches of actual dumb-bell sections. Little dots shown in the centre represented the extent of porosity. The depressions shown at the top of sections were merely an attempt to reproduce the sinking which occurred on the top of the dumb-bell. The irons used were of high-phosphorus type containing about 1.2 per cent. phosphorus and also sufficient titanium to make them susceptible to variations in melting conditions.

The top series varied in silicon content only; the total carbon content did not vary very much. It would be observed that the porosity appeared at about 1.7 per cent. silicon and increased with further increase in silicon.

The series was produced in the crucible, but the coke was in contact with the metal during the whole of the time the metal was melting; in fact it was stewed with it. When the coke was excluded from the top of the metal a lid was put on the top of the crucible and no coke came in contact with the metal, and a vastly different result was obtained as would be observed from the second series of results. Up to 2.6 per cent. silicon, irons were perfectly sound, but over 2.8 per cent. there was porosity again. The fractures were very coarse. Excluding the coke from the metal had a tendency to make the fractures much finer and the graphite size was much finer also. The point he wanted to make was the size of the graphite in the series was nothing nearly approaching the size of the graphite which could be obtained by the full titanium and CO_2 treatment.

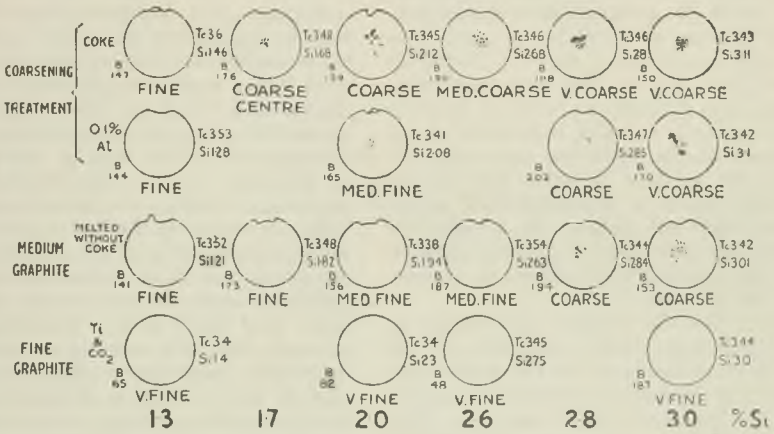


Fig. A.—Effect of Graphite Size and Silicon Content on Porosity.

The bottom line of Fig. A showed the effect of the titanium-CO_2 treatment. There was perfect soundness right up to 3 per cent. silicon.

WRITTEN CONTRIBUTION TO THE DISCUSSION

Mr. W. E. Dennison wrote:—It has been said that imagination is the mightiest instrument of the scientist. Simple known facts, however, should be given precedence in any investigation of chemical or physical behaviour before recourse to that creative faculty of the mind.

For instance, the difference in results obtained with the cast irons melted in the large cupola is simply explained. The authors have inferred that the beneficial results reflected in the sound casting must be credited to the action of titanium and have completely ignored the presence

of 0.33 per cent. chromium in the sound casting compared with the absence of chromium in the defective casting. It is also stated that there is little difference in chemical composition of the pig-irons listed in Table I, except for the titanium, which ranges from 0.03 to 0.19 per cent., whereas the salient variation is in the chromium content, which ranges from a trace to 3.16 per cent.

It is thought that the 0.33 per cent. chromium content of the sound casting provides the medicine required by the carbon-surfeited irons listed as M.2337 and M.2347 to produce the desired solidification characteristics. It is unfortunate that the adoption of the British Standard round test-bar which serves the dual purpose of providing transverse and tensile tests has tended to eliminate the lineal shrinkage test which is best made with a test-bar cast in a mould with carefully-adjusted chilled ends. This simple test is of prime value in gauging the casting property and, in the case of the 0.33 per cent. chromium cast iron, would have shown a distinctly higher result than that of the plain cast iron. The shrinkage test provides an indirect measure of the specific gravity, and is indicative of the denser structure of the chromium cast iron. To some extent, the relative densities may be explained by the degree of graphitisation, as reflected by the combined carbon. To a major extent, however, the difference lies in the physical character of the graphite as it affects the volume of voids in the structure.

It is assumed that the authors have chosen an unsuitable composition as a postulate to the subsequent theories in favour of the inoculation value of titanium in regard to crystallisation, as it influences the graphitisation of cast iron. This conjecture appears to be confirmed by the authors' statement that "very little improvement has been found when applying the titanium treatment to cast irons which in their normal condition possess good mechanical properties." The 17 tons tensile mentioned as conferring these properties offers no particular difficulties, and would seem to fit the requirements of the water-pump body castings in question.

The problem of porosity is one that perplexes many foundrymen, design and composition, temperature, melting conditions and gating being some of the factors involved. In the writer's opinion, practical solutions are generally available for such castings as the one described without recourse to expensive alloy additions or special pig-irons, and there is no doubt that the authors could substantiate this expression of opinion.

The cost of production is to-day a main item in the earning of profit, and, strangely enough, the more expensive virgin materials are not conducive to reducing porosity, and used in excess are those which demand the use of still more expensive additions.

Authors' Rep'y

In reply, the AUTHORS thanked Mr. Dennison for his suggestions and stated that the presence of chromium in some of the experimental irons used was a matter of no importance in this instance, for it had no direct connection with the particular phase of the problem which had been investigated. This was to study the influence of titanium on graphite formation in relation to external sinking and internal porosity.

The criticism of Table I appeared to be based upon a mis-reading of the Paper—the statements regarding the slight difference in chemical compositions were confined to the two sets of pig-irons A & B, D & E. Mr. Dennison correctly assumed that the making of pump castings in iron of 17 tons tensile offers no particular difficulty if made in dry-sand moulds. On the other hand, experience shows that the use of green sand produces external sinking with such iron.

They were in complete agreement that the addition of expensive alloys or special pig-irons was not to be taken as the only solution of the problem of porosity. It was not the authors' intention to cover all the possible solutions of this problem.

Paper No. 700

Molybdenum in Cast Iron

By W. F. CHUBB, Ph.D., B.Sc. (Member)

As will probably be known, the adoption of molybdenum as an alloying addition to cast iron has been more general in America than in England, and this has sometimes been ascribed to a too conservative attitude on the part of British foundries. It is hoped, however, to show that this statement is in a large measure unjustified. Before a prospective user can be asked to adopt a new suggestion, it is necessary to satisfy him that not only are there definite benefits to be obtained, but that these benefits can be secured at a price which he can afford. Also, he must be convinced that, unless he is willing to pay the price, he cannot hope to derive the same benefits by other and cheaper means. It is thus the purpose of this lecture to attempt to determine how far molybdenum will meet and satisfy the demands of the up-to-date foundry and of modern engineering design.

There are several methods of attack for a lecture such as this. One could trace out the history of molybdenum in cast iron, showing the development of the subject and describing in detail the major and minor researches which have been undertaken. This does not, however, appear to be the best procedure, for the evidence and results of research are somewhat conflicting, and for this reason a very imperfect conception of the benefits which molybdenum can bring would be obtained. Instead, it is proposed to deal with the subject in a more general way and confine attention chiefly to tendencies. This treatment of the subject, it is hoped, will have several advantages, namely, that it will give all the most essential facts, deprived of unnecessary detail; the main facts are likely to be more easily grasped, and on that account more capable of immediate application, and, finally, future lines of development will perhaps be more readily apparent.

Forms of Molybdenum

In Table I are detailed the several forms in which molybdenum is available, and of these the pure metal is quite unsuitable for direct addition to cast iron. The analysis given in each instance may be taken as representative of the material, and little comment need be made at this stage beyond saying that ferro-molybdenum, calcium molybdate and molyte satisfy many requirements as addition agents.

Adding Molybdenum to Cast Iron

In the cupola, high recoveries are only possible when the cupola is reserved solely for producing molybdenum irons. If more than one type of iron is being made, then it is recommended that those castings required to contain molybdenum should be made from the first few tappings. Both ferro-molybdenum and calcium molybdate can be used in the cupola, the latter being added with each charge of coke and preferably by adding it as briquettes in order to avoid loss due to the formation of dust.

TABLE I.—*Forms of Molybdenum.*

Form.	Typical Analysis.	Remarks.
Ferro-Molybdenum (Lump or powder)	Per cent. Mo .. 72.02 Si .. 0.65 S .. 0.046 P .. 0.020 C .. 0.039 As .. 0.008 Mn .. 0.011 Cu .. 0.34	
Calcium Molybdate (Powder)	Per cent. Mo .. 42.47 SiO_2 .. 5.75 Fe_2O_3 .. 3.70 Al_2O_3 .. 2.20 CaO .. 19.00 S .. 0.04 P .. 0.02 (MoO_3 equivalent to 63.7 per cent.)	Varies, *e.g.*, Mo 46 per cent.
Molyte (lump)	Per cent. Mo .. 43.50 SiO_2 .. 39.80 Fe_2O_3 .. 4.94 Al_2O_3 .. 3.00 MnO .. 0.08 CaO .. 6.80 S .. 0.05 P .. 0.02 C .. 0.05	Varies, *e.g.*, Mo 47.75 per cent.
Molybdenum metal (powder)	(*a*) Mo .. 95 to 97 per cent. (*b*) Mo .. 99 per cent. Min.	

Ferro-molybdenum is usually added to the spout or ladle, but when calcium molybdate is added in this way, time is necessary for reduction to molybdenum metal to take place at the lower temperature there prevailing. The recovery of molybdenum when calcium molybdate is added to the ladle is not as high as when it is added to the charge. Ferro-molybdenum of the composition given in Table I is likely to give non-uniform irons if added to the ladle, but this can be partly corrected by adding it to the charge, although recovery of molybdenum is then almost certain to be lower. For the air furnace, calcium molybdate and molyte can be added, but complete reduction to metal requires time. In the electric-furnace method of producing cast iron, both ferro-molybdenum and calcium molybdate are permissible.

For ladle additions, undoubtedly the best agent for adding molybdenum would be a molybdenum-iron alloy of low melting point, and having a melting point considerably lower than that of 70 per cent. ferro-molybdenum, the melting range of which is 1,540 to 2,060 deg. C., as shown in Fig. 1. A lower melting point can be obtained in several ways, namely, by the use of high carbon contents, high silicon, or by reducing the molybdenum content to 40 per cent. It will be seen that, at the latter composition, the melting point is 1,440 deg. C., and that the alloy melts at constant temperature. It would therefore appear that the ferro-molybdenum now available is not necessarily the best means of adding molybdenum to cast iron, especially when it is necessary to obtain rapid alloying and mixing of the constituent metals.

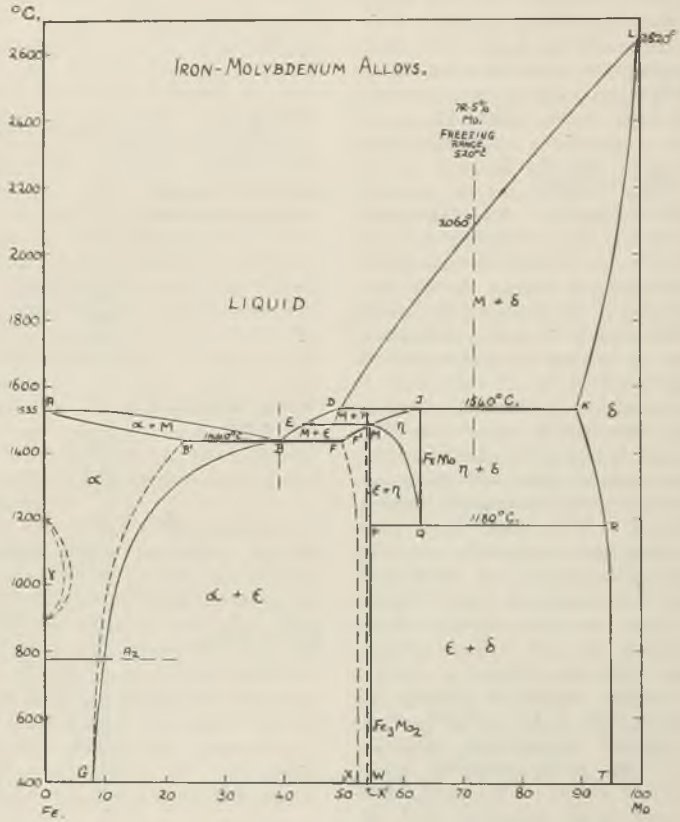


FIG. 1.—IRON-MOLYBDENUM EQUILIBRIUM SYSTEM.

Molybdenum Pig-Iron

There is a growing tendency for users to adopt molybdenum pig-iron in preference to the other forms of molybdenum, as in that form it is perhaps the best means of adding molybdenum to cast iron, for cupola losses are then very much lower and the metal is more uniformly

alloyed in the iron. There are two grades of molybdenum pig-iron available:—(1) T.C, 3.0 per cent. max.; Si, 1.5 to 2.0; Mn, 0.8 to 1.0; S, 0.07 max.; P, as required; and Mo, 1.0 to 5.0 per cent. This is a refined molybdenum pig-iron available as sand-cast or machine-cast pigs. (2) T.C, 3.5 per cent. max.; Si, 1.5 to 2.0; Mn, 0.8 to 1.0; S, 0.07 max.; P, as required; and Mo, 1.0 to 5.0 per cent. This is refined all-mine molybdenum pig-iron.

In addition there are other pig-irons available for the simultaneous addition of molybdenum and other alloying elements, but there would be no point in giving specifications, as they are almost invariably manufactured for individual requirements.

Metallographic Aspects

The metallographic influence of molybdenum on iron-carbon alloys may be summarised as follows:—

(1) The eutectic temperature is approximately the same as in pure iron-carbon alloys, namely, 1,130 deg. C.

(2) The percentage of carbon in the eutectic is not altered appreciably (4.3 per cent. carbon).

(3) The eutectoid transformation (*i.e.*, pearlite transformation) is not appreciably affected at 700 deg. C.

(4) The percentage of carbon in the eutectoid is lowered by molybdenum, the decrease being 20 points for each 1 per cent. of molybdenum present.

(5) A new phase appears, this being a double carbide above and below the eutectoid transformation.

(6) No graphite appears in iron-carbon-molybdenum alloys at carbon contents below the eutectoid concentration.

Translated into more practical language, this means that:—

(1) The melting point of cast iron is not lowered appreciably by molybdenum.

(2) The formation of a double carbide of iron and molybdenum is important as regards heat-treatment and physical properties, such as hardness and wear-resistance, and depth of hardening.

(3) The influence on the eutectoid composition is translated into more pronounced hardening on quenching, and in other directions also.

(4) Molybdenum tends to stabilise the carbides and therefore tends to prevent graphitisation.

(5) Molybdenum tends to remove hardness differences in castings of varying section.

Practical Points

This metal has a tendency to render cast iron sluggish, although experiences differ considerably. For this reason somewhat larger risers may possibly be required. These are also likely to be necessary because liquid shrinkage is increased to a certain extent, although here again experiences differ. Molybdenum also has a tendency to increase chill, and to counteract this many users take steps to keep the total carbon content as low as possible, thus producing irons of more uniform mechanical properties. These chilling tendencies are not, however, important in most instances, for, speaking quite generally, molybdenum is nearly always subordinate as an alloying addition to some other metal, such as nickel or chromium, or both. For higher percentages of molybdenum, namely, over 1 per cent., difficulty may possibly be encountered from chill, but in the amounts normally added to cast irons, little change in moulding and casting arrangements need be made, except in so far as are designed to meet special circumstances. Much appears to depend upon local conditions, so that it is not possible to give any very hard and fast rules, and the best procedure is that of determining those changes, if any, required by practical research in the foundry.

Simple Molybdenum Additions

It was Campion who first showed that 1 per cent. of molybdenum would increase strength and hardness, and Smalley in 1922 (*i.e.*, three years later than Campion) indicated that 0.1 per cent. of molybdenum has a refining action on the grain with only a slight increase in hardness. These results led to the suggestion that molybdenum might play the dual rôle of nickel and chromium, and it will be seen later how far molybdenum has come up to expectations. Among other men whose work in this field is of first importance, mention may be made of Piwowarsky, Smith and Aufderhaar, Kent Smith, Lorig and Dahle, Guillet and Ballay, Coyle, Hurst, Olsen, Cournot, Challansonnet, Portevin, McDougall and Schuck. Although many of their results are conflicting, there are, nevertheless, certain points of agreement, so that, considering the published data as a whole, the following general conclusions appear justified:—

(1) Molybdenum has a refining action on the graphite.

(2) There is a progressive increase in tensile strength up to 1.5 per cent. of molybdenum, and there is an increase also in both compressive strength and hardness.

(3) Transverse strength increases progressively with molybdenum content, although, when other alloying elements are present also, the influence of molybdenum is sometimes lessened. This will

be rendered more clear by reference to the summarised properties to be illustrated later.

(4) Shock resistance is generally improved and about 0.5 per cent. of molybdenum has been known to treble the Izod figure, although the increase is generally about double. In any particular grade of iron, however, there is clearly a limit in the improvement to be obtained, and further additions beyond that limit result in carbide formation which interferes. The improvements to be obtained by small amounts of molybdenum are derived mainly from its grain-refining tendency and from its influence on the size and distribution of the graphite flakes. Later this toughening tendency is opposed by the hardening tendency of carbide formation.

(5) While machinability may be improved up to 0.5 per cent., the increases in hardness which result thereafter cause a progressive decrease in machinability. These decreases become more rapid above 1.5 per cent. of molybdenum, and they are, of course, associated with the carbide-forming tendencies of this element.

(6) Growth characteristics are not appreciably affected when molybdenum is added in small amounts.

(7) Molybdenum does not show any tendency of itself to improve resistance to scaling, neither does it have any appreciable influence on resistance to corrosion.

(8) Molybdenum has no desulphurising tendency despite its high affinity for sulphur. It combines preferentially with the carbon present, and any benefit so far as sulphur is concerned is derived from the fact that molybdenum causes the sulphides to disperse in a more finely divided condition throughout the material.

(9) Molybdenum affects structures by tending to convert the pearlite matrix into sorbitic pearlite, thus increasing strength, both tensile and transverse, and increasing toughness also. The benefits are approximately progressive up to 1.5 per cent. of molybdenum, but above this amount structures similar to those of hardened steels are beginning to form and hardness rapidly increases in consequence.

(10) Wear resistance is improved by molybdenum additions, although it does not appear possible to give a figure to represent the increase in life which may then be expected.

These ten points summarise the chief benefits to be obtained from the use of molybdenum alone in cast iron. It is necessary, however, to draw attention to one trouble likely to be experienced, and it is that molybdenum has been known to form brilliant spots locally in the iron, these being associated with the carbides to give local hardness. These brilliant spots will cause trouble in the machine shop, but while the exact conditions for their formation are not yet known, a practical remedy has been discovered, and nickel in small amounts has been found to counteract this trouble completely.

The benefits obtained from molybdenum alone may appear small in view of the cost. Thus, a 0.1 per cent. addition, with molybdenum at 4s. 9d. per lb., works out at about 11s. per ton of cast iron made. Many of the benefits are not, however, readily assessed in terms of cash, but these apparently high costs can be countered successfully by additions of certain other alloying elements, notably manganese, nickel and/or chromium, more particularly nickel.

Now, although molybdenum cast irons are not resistant to oxidising conditions, they maintain their original strength on short-time exposure to temperatures up to 425 deg. C. Creep rates for molybdenum cast irons are also lower than those of either grey iron or high-test cast iron at the same load and temperature. The indications are, in fact, that irons containing 0.8 to 1.0 per cent. of molybdenum will be serviceable at temperatures up to about 700 deg. C. and sometimes over, and these irons have in fact been used successfully under these conditions, since the rate of growth is reduced from 8 per cent. to less than 6 per cent. in tests of 24 hrs.' duration. Despite these very definite benefits, however, molybdenum irons suffer the disadvantage of not being resistant to oxidising conditions, and this fact is likely to limit their applications in high-temperature service.

Heat-Treatment

It may be stated as a fairly well-recognised rule that if the full benefit is to be obtained from the use of an expensive alloy addition the iron so made should be capable of heat-treatment to give further improvements in properties. Molybdenum irons are indeed capable of improvement in regard to tensile strength, transverse strength, toughness and hardness by suitable heat-treatment, and this fact must be taken into consideration in assessing its value as an alloying addition to cast iron. In plain molybdenum irons it is necessary to add a fair proportion of molybdenum, seldom less than about 0.5 per cent., if substantial improvements in properties are to be sought by heat-treatment. In order to illustrate the degree of improvement which can, however, be obtained, mention may be made of an iron containing T.C, 3.50; Mn, 0.5; Si, 1.6, and Mo, 0.6 to 0.7 per cent. As cast, this iron has a tensile strength of 19 to 20 tons per sq. in. with a Brinell hardness of 220 to 225, but after heat-treatment by quenching at 850 deg. C. and tempering at 350 deg. C., the tensile strength is improved to 30 tons per sq. in., that is, by about 50 per cent., and the Brinell hardness increased to 350, that is, by nearly 60 per cent.

Nickel-Molybdenum Irons

It is inevitable that chief interest must centre around the nickel-molybdenum irons, although they cannot here be treated exhaustively. The development of the nickel-molybdenum cast irons has resulted from the fact that, while the plain molybdenum cast irons can give many of the properties, or combinations of properties, required by producers and users, the amount of molybdenum necessary is such as to render its use prohibitive in a large number of instances. The price of nickel is about one-third that of molybdenum, and it will thus be realised that three times the amount of nickel can be used without increase in total alloy costs. Hence, if it be found that 0.5 per cent. of molybdenum will give the properties demanded, one can, as an alternative, use 1.5 per cent. of nickel, at a cost of about 53s. per ton of iron produced. It is open to question whether heat-treating a 0.5 per cent. molybdenum iron will give properties and benefits comparable with those to be obtained from that nickel cast iron which is of equal alloy cost. However, this difficulty can be surmounted by combining the two elements in appropriate proportions and, indeed, further progress can be registered, for those combinations of the two elements which give the same total cost will give also properties definitely superior to the properties obtainable from either the nickel or the molybdenum when added alone.

It will be realised that in these irons the molybdenum must be regarded as subordinate to the nickel, and it is convenient, in fact, to regard molybdenum as intensifying the benefits of the nickel. These benefits are, as is known, towards increased strength, toughness, resistance to shock, more uniform distribution of the graphite, more uniform hardness, greater hardening power and greater depth of hardening. Molybdenum adds to most of these benefits, but at a certain cost as previously shown, so that from both technical and commercial reasoning there is a limit to the amount of molybdenum which can be added profitably to nickel cast irons.

It will also be clear that if the nickel is increased and the molybdenum reduced, the total cost need not necessarily be increased, but the properties obtainable both as-cast and after heat-treatment can be varied over wide limits. These facts are summarised in Table II. This table has been worked out assuming 100 per cent. recovery of the added element in each instance, but a practically theoretical recovery is only obtained in the case of nickel. Thus, the cost of losses in melting, alloying and casting, etc., must be added to the costs shown.

TABLE II.—*Alloying Costs.*

(Minimum increases per ton of iron, assuming 100 per cent. recovery of each metal.)

Composition.		Total alloy content. Per cent.	Costs.		Total cost of alloys.	Cost per 1 per cent. of total alloys.
Ni. Per cent.	Mo. Per cent.		Ni. Per cent.	Mo. Per cent.		
3.0	1.0	4.0	102/6	105/6	209/–	52/3
2.5	0.8	3.3	94/–	85/6	179/6	54/5
2.0	0.7	2.7	75/–	74/6	149/6	55/6
1.5	0.0—0.15	1.5—1.65	56/–	0 to 16/–	56—72/–	37—43/8
1.0	0.35	1.35	38/–	37/–	75/–	55/6
0.5	0.5	1.0	19/–	53/–	72/–	72/–
0.35	1.0	1.35	13/–	107/–	120/–	89/–
0.0	1.5	1.5	—	160/–	160/–	106/8

NOTE.—To these costs must be added that of the metals lost during alloying on the basis of over 99 per cent. nickel recovery, and 92 to 96 per cent. molybdenum recovery, depending upon the method of alloying adopted.

This table summarises the present position, and it shows also that the nickel-molybdenum irons of greatest practical utility having regard always to cost are those containing approximately 0.5 to 1.5 per cent. and 0 to 0.5 per cent. of molybdenum. It is within these ranges that most benefit is obtained for the money expended, and these irons are therefore likely to be the most frequently chosen. This table, furthermore, shows that special properties can be obtained but at greatly increased cost, which, however, is often justified by the additional benefits brought by heat-treatment. It will also be clear that if the ratio of nickel to molybdenum departs to any extent from the 3 to 1 ratio, the total alloying costs are disproportionately increased. When this happens, however, there are certain benefits to be derived from the increased molybdenum content, and these are chiefly to be experienced as regards improved wear resistance, as may be instanced by the fact that irons of this

type have been adopted by some motor-car manufacturers for brakedrums. Hence, these considerations may be summarised by saying that the simultaneous addition of nickel effectively helps in reducing costs to a minimum.

Properties

The properties of the nickel-molybdenum cast irons have been very widely studied from both the metallographic and practical standpoints. The general conclusions to be drawn from the researches undertaken are that molybdenum increases the hardness and power of hardening, but that when the nickel content exceeds 1 per cent., molybdenum does not have any very pronounced refining tendency. That responsibility is assumed by the nickel, and thus molybdenum has only a graphite-refining tendency when acting alone. Also, molybdenum aids nickel in its tendency to eliminate internal porosity, but while molybdenum is likely to bring local hardness, nickel additions effectively prevent this. Molybdenum is also claimed by some authorities to increase machinability in nickel cast irons, but according to others it decreases this property. Much appears to depend on the method of testing, and so, considering all the relevant facts, molybdenum may be stated to convey some benefit in this direction.

The nickel-molybdenum irons of most use contain nickel equivalent to either two or three times the molybdenum content, and irons are also available with equal nickel and molybdenum contents. Their chief uses are machine-tool beds, grey iron patterns, drier rolls for paper machinery, general machinery castings, and hot-water heaters. The compositions usually chosen for these applications are 0.75 to 1.5 per cent. of nickel with up to 0.35 per cent. of molybdenum. Two practical considerations may here be mentioned. It may sometimes be necessary to reduce the total carbon content to prevent the tendency to form chilled structures, and it may also be necessary to reduce the silicon content when the higher nickel percentages are adopted owing to the graphitising tendency of nickel.

The heat-treated nickel-molybdenum iron may contain up to 2 per cent. of nickel, with appropriate molybdenum additions designed to increase the depth of hardening. Very nearly the same results can, however, be obtained by chromium in place of molybdenum, and this substitution is likely to be advantageous on a cost basis. Shovel blades are made in this type of iron, plough points, and other components of farming machinery.

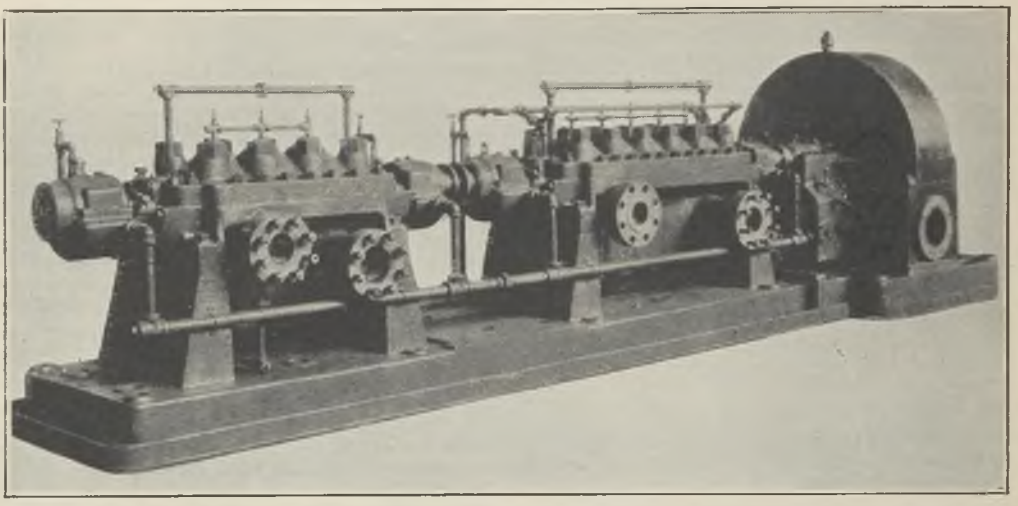


Fig. 2.—Boiler Feed Pump with Casing of High-Test Nickel-Molybdenum Cast Iron.

A good deal can also be claimed for nickel-molybdenum irons when used as drop-forging dies. These contain 0.6 to 2.5 per cent. of nickel and 0.6 to 0.8 per cent. of molybdenum. The 3 to 1 ratio is often here replaced by nickel and molybdenum in equal proportions, in order to secure greater surface hardness. All these irons are tough, as they should be for these purposes, but they are preferably only used when a small number of forgings is required. There are, nevertheless, instances on record where nickel-molybdenum cast-iron dies have compared favourably with steel as regards life; and it is, in fact, claimed that they are superior

to steel in certain specific instances, such as dies for optical glass.

High-strength irons produced by heat-treatment, either by annealing white iron or by the more usual quenching and tempering treatments, are most frequently made in nickel-molybdenum cast irons. Sometimes chromium is added also. These irons may contain up to 2.75 per cent. of nickel, and molybdenum must be no higher than one-third the nickel content if the optimum properties are to be developed. There are many applications for irons of this type, for they range in tensile strength from 25 to 40 tons per sq. in., and to mention but a few of these applications their use as gas-burner parts, pneumatic cylinders, compressor valve-seats, gears and bottle moulds may be recalled, their great advantage being that, when in contact with heat, they are structurally stable.

Fig. 2, reproduced by courtesy of the Mond Nickel Company, shows a boiler feed pump in a casing of high-test nickel-molybdenum cast iron. This iron was made from 80 per cent. steel scrap to keep down the total carbon content, 5 per cent. returned scrap, and 15 per cent. selected pig, the analysis of this iron being:—T.C, 2.62; Si, 2.38; Ni, 1.25; and Mo, 0.5 per cent. A high tensile strength of 36.7 tons per sq. in. was obtained in this iron, and it will be observed that the 3 to 1 alloying ratio has been maintained to develop the best combination of mechanical properties.

This example belongs to the class of irons known as "Ni-Tensyl," which, on account of their high strength and other valuable properties, are capable of replacing more costly steels. These irons are also adaptable to both light and heavy sections.

Fig. 3, also reproduced by courtesy of the Mond Nickel Company, shows another example of nickel-molybdenum cast irons, the particular iron illustrated containing T.C, 2.9 to 3.1; Si, 1.8 to 2.1; Ni, 1.35 to 1.55, and Mo, 0.4 to 0.6 per cent. These cylinders are for the hydraulic operation of sluice valves and are 26 in. inside diameter and 6 ft. 6 in. long. The iron was cupola-melted, using an extra high coke-bed and quick melting to keep down the total carbon content as much as possible, and the properties obtained were up to 35 tons per sq. in. in tensile strength with a Brinell numeral of 265 to 285.

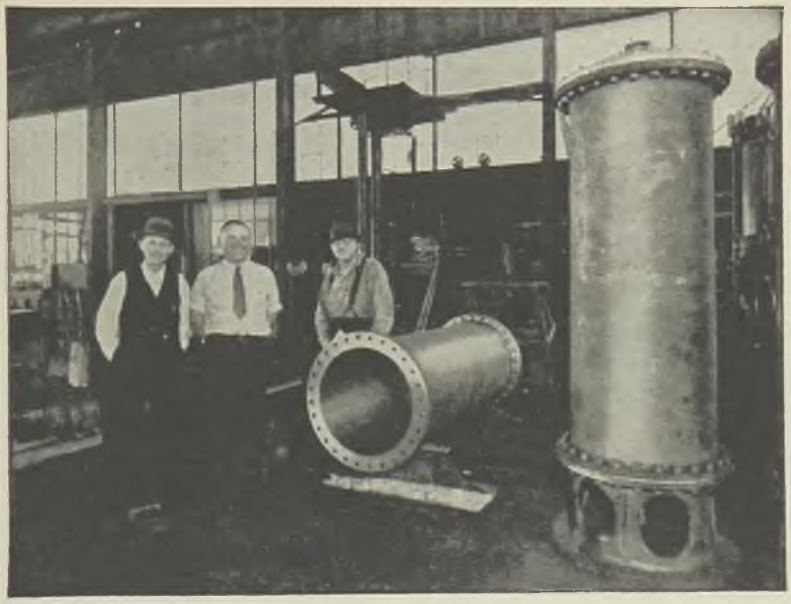


Fig. 3.—Cylinders for Sluice Valve Operation, cast in Nickel-Molybdenum Iron.

Chromium-Molybdenum Irons

Chromium increases the hardness of cast iron on account of its carbide-forming tendencies, but accompanying these hardness increases there is likely to be a certain loss of shock toughness, particularly when chromium contents begin to assume fairly large proportions. These harmful tendencies can be corrected in two ways: (1) by

addition of molybdenum, which, although also a carbide former, here increases the toughness, or (2) by additions of nickel, which, while it may or may not decrease the hardness, has a beneficial influence as regards shock toughness. In view of these facts, chrome-molybdenum irons are used where surface hardness obtained by chilling is required, one such use being tappets, where a tough material with a hard-wearing end surface is particularly suited to service conditions.

In the United States considerable use has been made of chrome-molybdenum irons for cylinder blocks and cylinder heads. These may contain up to 0.5 per cent. of chromium and a maximum of 0.4 per cent. of molybdenum, but other combinations have also been adopted with success. The influence of molybdenum on cylinder irons containing 0.5 per cent. of chromium has been examined carefully by a number of automobile manufacturers, and from the figures available the following average increases may be expected for every 0.1 per cent. of molybdenum added:—Tensile strength, 1 to 2 tons per sq. in.; transverse strength, 160 lbs.; Brinell hardness, 4 points, and resilience, 65 in.-lbs. These figures should be compared with those quoted for plain irons, when it will be seen that this combination of chromium and molybdenum is of special value where wear resistance is specially required.

Another widely-used chrome-molybdenum iron is that containing 0.35 per cent. chromium and an equal percentage of molybdenum. It gives a tensile strength of up to 22 tons per sq. in., transverse strength 2,700 to 3,200 lbs., deflection up to 0.300 in. and a Brinell hardness of 228 to 241.

The growth-resisting irons are not infrequently made from combinations of chromium and molybdenum, and they may contain up to 0.7 per cent. of chromium and up to 0.75 per cent. of molybdenum. Their selection is determined by their ability to resist surface oxidation, their ability to resist growth and changes of temperature, and their ability to maintain their strength and toughness at elevated temperatures. There are also cast irons suitable for this type of service in the nickel-molybdenum and nickel-chrome-molybdenum ranges.

Summary

An attempt has been made on the basis of the available data to show the trend of improvement likely to be obtained when molybdenum is added to various types of iron. Average figures obtained in this way are shown in Table III. These figures may possibly provoke discussion, because it is quite likely that entirely different results may have been obtained by individual users; but one fact is certain, and it is that the benefits to be derived from molybdenum additions to grey iron are not solely dependent upon molybdenum. This table illustrates this fact quite well, for it will be seen that the influence of molybdenum is dependent upon the type of other elements also added. Thus, the tendency to increases in hardness is least when chromium is present, and is greatest when nickel is present. This is due to the fact that, in chromium irons, molybdenum exerts a certain toughening action. The tendency towards increased transverse strength is greatest in the nickel-molybdenum combination, but the highest increases in tensile strength have been reported to occur in the chrome molybdenum cast irons. In the case of the nickel-chrome cast irons, it is difficult to assess the value of molybdenum in a similar way, and the average increases shown as regards transverse strength must be regarded as very approximate.

TABLE III.—*Average Increases due to* 0.1 *Per Cent. Molybdenum.*

Combination.	Tensile strength. Tons per sq. in.	Transverse strength. Lbs. per sq. in.	Brinell hardness numeral.
Molybdenum alone ..	0.75	175	5
Molybdenum with nickel	1.0	400	12
Molybdenum with chromium ..	2.0	200	2
Molybdenum with nickel and chromium ..	0.75	200 (?)	3—4

Possible Future Uses

It would not be a very difficult matter to compile a list of components which are now frequently made in molybdenum cast irons, nickel-molybdenum irons and nickel-chrome-molybdenum irons. It would be of no great value to emphasise the benefits of molybdenum for chilled rolls, for their use is now well established, and the reasons for choosing molybdenum cast irons for these applications are well understood. If progress, however, is to be made in the use of molybdenum cast irons, whether this element is used alone or in conjunction with other alloying metals, it is necessary first of all to grasp the essential facts concerning the possible benefits to be derived, and it is then necessary to seek out applications in which molyb-

denum is not being used and try to discover the reason or reasons why. In some instances the reasons are that the designer and manufacturer do not fully appreciate the value of molybdenum as an alloying element. Such men are rare, however, but it appears that the chief handicap of molybdenum is its price. Attempts have been made to show how this difficulty may be overcome to a greater or lesser extent by the simultaneous use of nickel, and it may thus be concluded that there are numerous applications where molybdenum is likely to prove of considerable advantage. Indeed, fifty applications come to mind immediately in which irons of this type could be usefully employed and in fairly large tonnage, and it is quite clear therefore that there is a big field available for exploitation.

DISCUSSION

Composition of Base Iron

Mr. Charles Cleaver, having expressed his great appreciation of the Paper, referred to some castings which had been illustrated, containing nickel and molybdenum, and in which scrap was used to the extent of 80 per cent. He asked for the composition of the scrap used. Mr. Cleaver commented that throughout the Paper there was no indication of the other constituents used in the various mixtures—the ratios of silicon and manganese, etc.—apart from the molybdenum, nickel or chromium. Again, in the case of the irons illustrated, if the addition of 0.1 per cent. of molybdenum increased the tensile strength by only 1 ton per sq. in., it seemed that the expense incurred to secure that increase of tensile strength was rather considerable. At the same time, the tensile strength of the alloy irons was given as 37 tons per sq. in.; and if the use of molybdenum had increased the tensile strength by only 1 ton per sq. in., the original irons must have been of very good quality indeed. Inasmuch as the alloy irons were very expensive, he asked if the scrap had a corresponding value, and to what extent it could be used.

Use in Alloyed Irons

Dr. Chubb said he had no further details of the nickel-molybdenum irons referred to; but no doubt the Mond Nickel Company, or Mr. McRae Smith or Dr. Everest could give Mr. Cleaver the details he required.

Usually the silicon and manganese contents of irons were not modified greatly when molybdenum was added; but it was necessary to work out the alterations to suit each particular type of iron being made. He agreed that an increase of 1 ton per sq. in. in tensile strength was not very much for an addition of 0.1 per cent. of molybdenum; but he had made the point at the beginning of the Paper that where molybdenum alone was added, the cost was somewhat prohibitive. When molybdenum was present in conjunction with nickel in the ratio given, the nickel usually brought most of the improvements obtained, and the function of the molybdenum was then to intensify its benefits in certain directions. The reason was that molybdenum divided itself between the carbide and the ferrite, so that its influence was determined by the type of metal or other alloying addition used. If the other alloy added with the molybdenum happened to be a carbide former, such as chromium, then the molybdenum could act by solution in the ferrite, and there was then likely to be an increase in toughness. If, on the other hand, the chief element present was one which did not form a carbide, as was the case with nickel, then the molybdenum stabilised the carbides and brought about increased hardness and transverse strength. This was a rather curious property of molybdenum, and a very valuable property if applied correctly.

It was quite permissible to use every bit of scrap from the alloy irons; but, of course, one must know how much molybdenum or other alloying element the scrap contained. It was sometimes stated that, because one could use all the scrap available, there must necessarily be 100 per cent. recovery of molybdenum. That was rather a thin argument, however, because there were always losses, but the fact remained that molybdenum came back through the cupola into the metal in the ladle with only a limited loss.

Reverting to his statement that the silicon and manganese contents of irons remained approximately the same when molybdenum was added, he said that they depended, of course, upon the percentage of molybdenum added, upon the particular iron used and upon the type of casting to be made. One could not put forward any hard and fast rule in that connection. Formerly one had to work to rather wide limits even in making cylinder head castings and other castings of that type. He appreciated that since 1930-32 the efficiency of foundry practice had improved, and irons were being made in which the elements were controlled to within very close limits, so that there would be no difficulty in ensuring any silicon or manganese content required. In the ordinary way, it could be said that, with additions of molybdenum up to 0.5 per cent., there need be little change in the silicon and manganese contents. Above that molybdenum content, however, one would probably require to make considerable adjustment, because the molybdenum was a carbide-forming element and, on that account, greatly increased the hard-

ness, so that sometimes it would be necessary to increase the silicon content to prevent chilling.

Use of Calcium Molybdate

Mr. P. A. Russell, B.Sc., asked what was the mechanism of the reduction of molybdenum from its oxide form in calcium molybdate, because a knowledge of that mechanism would help one to understand the use of calcium molybdate. He had used it very successfully in an air-type furnace, but he had never dared to use it in a ladle. From the Paper he had gathered, however, that provided sufficient time was allowed, it could be used successfully in the ladle, and he asked for an indication of the length of time that should be allowed.

Querying the author's reference to the use of larger risers, he said that in his own experience the use of larger risers for casting irons containing molybdenum had not been necessary; but possibly that was due to the fact that he used molybdenum only in irons which were originally of high quality, and in connection with which the risers used were already large.

Referring to Table III, showing the improved properties resulting from the addition of molybdenum to iron, he said he never liked to place much reliance on figures showing the results obtained before and after such additions were made to iron unless he was sure that he had a correct knowledge of the history. He asked whether the results given referred to exactly the same iron, with and without molybdenum, and of the same sectional thickness; he also asked whether the graphite was reduced in quantity as well as in size, because if the quantity of graphite was reduced, there was usually a reduction of size also.

Reduced Tensile but Increased Impact Strength

His experience of molybdenum in cast iron had been limited to nickel-molybdenum or nickel-chrome-molybdenum irons, and the increase of tensile strength resulting from the use of molybdenum, as claimed in the Paper, was not borne out by his experience. Indeed, he had found reductions of tensile strength when molybdenum had been added. He mentioned the case of two irons, from the same pour, with and without molybdenum; the tensile strength of the iron which did not contain molybdenum was 26 tons per sq. in., whereas that of the same iron to which 0.4 per cent. of molybdenum was added was only 24 tons. The impact strength had been improved very considerably as the result of adding molybdenum, and the Brinell hardness was increased. He could not agree, however, that the addition of molybdenum had trebled the impact strength of the iron. Test-bars were subjected to the single-blow impact test, of the form used by the British Cast Iron Research Association, and the impact strength of a nickel iron was improved from 10 to 12 ft.-lbs. by the addition of 0.4 per cent. Mo. The comparative figure for common iron was about 4 ft.-lbs. Therefore, he suggested that, whilst the impact strength of iron which contained molybdenum was treble that of ordinary common iron, it was not treble the impact strength of iron which was originally of high strength.

Early Charges and Sulphur Pick-up

Commenting on a statement in the early part of the Paper that, if one could not devote the whole blow of the cupola to molybdenum iron, one should run it first, he said he had found that to be a rather dangerous practice with nickel iron by reason of the affinity of the nickel for sulphur, tending to result in a high sulphur pick-up. He suggested that that might occur also in the case of molybdenum.

Discussing the final table shown by the author (Table III), indicating the improvements effected by adding 0.1 per cent. of molybdenum, he said he wished matters could be made as easy as they appeared in that chart. He asked whether the percentages of other elements added in the various cases were the same as the percentages of molybdenum; for example, did the statement "molybdenum with nickel" mean 0.1 per cent. of molybdenum plus 0.1 per cent. of nickel, and so on?

Finally, he complimented the author upon the Paper, and said it had encouraged him to go further in the alloying of cast irons.

The Via Media Taken

Dr. Chubb, replying, said that in order to decide what to include in the Paper he had examined a large volume of data from the United States, Germany, France and elsewhere, and had tried to work out, to illustrate the benefits to be secured, the tendency resulting from the addition of 0.1 per cent. of molybdenum. There were certain shortcomings in that sort of treatment, as Mr. Russell had pointed out. For example, when he had stated that 0.1 per cent. of molybdenum in a certain type of iron would result in a certain increase of transverse strength, he had meant that that was the order of increase to be expected no matter what was the nickel content of that iron. He was not surprised that Mr. Russell had picked him up on that point, because he appreciated that individual experiences were bound to differ. Indeed, if one compared the American, German and French research results it would be seen quite clearly that they were very often opposed to one another. For that reason it was very difficult to

assess the value of molybdenum in cast iron from the points of view of transverse strength, tensile strength, Brinell hardness, and so on, and all he had attempted to do was to give an idea of the sort of increase to be expected when a percentage of molybdenum was added.

He had visualised that he would be addressing people interested in the subject, who wanted to know what they could do by adding molybdenum, what were its limitations, and whether it would pay them to use it. Rather than give a long list of properties or details of research, he had confined his attention to general tendencies; and if he had made it appear to be rather simple, he had done so deliberately, because he did not wish his audience to be left with a lot of figures and a confused mass of ideas. It was not really so simple; if he had claimed an increase of 1 ton per sq. in. in tensile strength as the result of adding 0.1 per cent. of molybdenum, and if somebody else had claimed an increase of 2 tons per sq. in., or if a third user had said that no improvement was noticed, he would not be surprised. The results he had given were average results, taken from a large number of researches, and he believed they represented the situation fairly accurately.

The mechanism of the reduction of molybdenum oxide in calcium molybdate was not very clearly known. Molybdenum oxide itself could be reduced to metal by any reducing agent such as hydrogen, silicon, aluminium or carbon. Originally, carbon was the reducing agent used, but nowadays silicon and ferro-silicon were employed. He believed that in the cupola the conditions were such that carbon was the most active of the reducing agents present. There was not complete reduction, and some of the molybdenum oxide was not converted; but on an average one would get 95 to 96 per cent. of the molybdenum in the casting.

The use of larger risers when casting irons containing molybdenum was recommended on account of the fact that molybdenum tended to make the iron somewhat sluggish. They were used as the result of the experience of quite a number of American firms, but he had gathered that Mr. Russell had not found it necessary in all cases.

Mr. Russell said he had found no increase of shrinkage when he had added molybdenum to iron which had already a high shrinkage before molybdenum was added to it.

Influence on Graphite

Dr. Chubb, referring to graphite content, said that when molybdenum was added in small amounts the total graphite content was not affected appreciably. When the molybdenum content was above, say, 0.5 per cent., the effects of carbide stabilisation began to be felt, so that the total graphite content was progressively reduced as molybdenum content increased; and irons containing approximately 2 per cent. of molybdenum had their carbon very largely in the carbide form. Generally speaking, it could be said that molybdenum, in small amounts at least, made little difference to the total graphite content, but it had quite a pronounced influence on the distribution and size of the graphite flakes. The two photomicrographs which he had shown, indicating differences of structure, were of irons of exactly the same composition except in respect of molybdenum, and they were each cast in exactly the same way, the castings being of the same size.

As to the rather curious result mentioned by Mr. Russell, indicating that the effect of the addition of molybdenum was to reduce tensile strength, he could not quite appreciate how that could be explained, unless there were some other controlling factors. The figures given in the Paper, showing that the impact strength of iron was greatly increased when molybdenum was added, were provided by the Climax Molybdenum Company of America, who were producers of molybdenum; but it was not possible for him to confirm that because very little work had been done on that aspect of the subject. That tendency could nevertheless be anticipated on the basis of modern metallurgical theory. Quite a lot was being done, however, more particularly regarding the influence of nickel and chromium. He was not surprised that Mr. Russell had disagreed with the figures concerning the effect of molybdenum on the impact strength of irons; that fact served to show that the subject was somewhat controversial, that the results to be obtained were variable, and that a new user of molybdenum must not expect too much to begin with.

Size of Test-Bar Taken

Mr. McRae Smith, in congratulating Dr. Chubb upon his Paper, said that he had made under-statements rather than over-statements. Commenting on the point that, as shown by the figures obtained by the Climax Molybdenum Company of America, the impact value of iron had been trebled when molybdenum was added, he asked what size of test-bar had been used by that company in their tests, and what was the initial impact value of the cast iron without the addition of molybdenum. Reference had been made, he said, to the Izod bar; but presumably the test-bar used in the case mentioned was not the ordinary Izod bar as used for steel and which, if used for cast iron, might give only a fraction of the figure.

Recalling the use of the word "ductility" in the Paper, he asked whether the author had

actually meant ductility as the term was understood in respect of other materials, or whether he had been discussing rather a resistance to shock and comparing in that respect a moderately high-strength iron and a molybdenum cast iron or a nickel-molybdenum cast iron.

He was not at all happy with regard to the author's statement that total carbon should be kept at a low figure in molybdenum cast iron in order to reduce the tendency of the molybdenum to chill, because molybdenum was a carbide former. He asked for some further information, therefore, on that matter.

Dr. Chubb replied that he had not at hand the exact dimensions of the impact test-pieces used by the Climax Molybdenum Company, but he promised to supply the information to Mr. McRae Smith.*

* Dr. Chubb has since supplied the following information:—Specimens for impact tests on cast iron have been 0.79 in. square or 0.79 in. round, and with unalloyed cast iron the shock toughness is then found to be about 20 ft.-lbs. when broken in the Izod machine. In other instances test-pieces of 1.125 in. diameter have been employed, and specimens of these dimensions in nickel-molybdenum cast iron cannot be broken in the 120 ft.-lb. Izod impact tester. This fact clearly illustrates the exceptional properties to be obtained by adding both nickel and molybdenum to cast iron.

In the Paper the term "ductility" had been used in a rather more general sense than was usual when speaking of the ductility of steel; his use of the term was really meant to convey the meaning of shock toughness, as Mr. McRae Smith had suggested.

With regard to total carbon content, he had meant to imply that when that content was limited there was less likelihood of variable hardnesses in molybdenum cast iron; that the irons would be more uniform in hardness, and generally sounder. He believed that was quite a common experience amongst motor-car manufacturers in the United States—and he had obtained most of his information from the American technical Press and from users in that country.

Vote of Thanks

Mr. G. C. Pierce (Past Branch-President), proposing a vote of thanks to Dr. Chubb, commented that whereas he could have given a Paper of a highly academic nature, he had in fact dealt with his subject in a practical way which all could understand and appreciate.

Mr. V. Delport (Past Branch-President) seconded the vote of thanks.

London Branch

East Anglian Section

Paper No. 701

Some Notes on Making High-Duty Cast Iron

By J. H. WILLIAMS, B.Sc., F.I.C. (Member)

For all practical purposes, one may roughly attribute the advent of cast iron of high tensile strength to the period of the Great War of 1914-1918. Steel additions to cupola charges with the object of improving the strength of cast iron had, however, been made before that time, but the results were frequently unsatisfactory. As a result probably of these early experiments which proved so unfortunate, there exists even to this day a distinct distrust among many older ironfounders against the addition of steel to the cupola.

The author has a vivid recollection of the dismay and incredulity with which a suggestion to incorporate 30 per cent. of steel scrap in a cupola charge was received about 7 years ago by an executive in a fairly large foundry. It transpired that, at some date previously, a small quantity of steel (somewhere about 10 per cent.) had been added as part of a charge to a cupola with disastrous results. Since then, any scrap of steel had been religiously kept out of any charge. However, this foundry was persuaded to try once more the use of steel scrap under good melting conditions and obtained satisfactory results. There is no doubt that in the early days of experimenting with steel scrap or wrought iron in the cupola, considerable difficulties were encountered owing to poor cupola practice and the absence of sufficient manganese in the charge.

Many will also remember when the accidental addition of a piece of white iron to a grey iron charge was regarded as calamitous. Possibly this arose from difficulties which manifested themselves when common white iron formed an appreciable fraction of the charge. This was quite likely when the properties of white irons were not so well known as at the present time. The usual high sulphur and low manganese contents, combined with the "inherent property" of these irons to contain a high percentage of oxides in the form of a very finely divided silicate slime, may readily account for the unsatisfactory results and led to the conclusion that white iron of any class or in any quantity spelt ruination of the metal.

Lanz-Perlit Process

One may date the regular use of steel scrap to cupola charges to the post-war period when the Lanz-Perlit and the Emmel processes were introduced. It is interesting to note that Hurst read a Paper before the Lancashire Branch of the Institute of British Foundrymen on "Semi-Steel" in 1915, though he would probably modify some of his conclusions at the present time. About the same time, Hurst made a synthetic pig-iron from an all-steel mix.

McRae Smith, also some years ago, made a synthetic pig-iron in a cupola, with which he made castings direct, from an all-steel mix with 2 per cent. silicon added as briquetted 45 to 50 per cent. ferro-silicon and 1 per cent. manganese as briquetted carbon-free ferro-silico-manganese. The resulting iron contained 1.78 per cent. silicon and 0.87 per cent. manganese, so that the oxidation losses were low considering the nature of the charge.

When the author was in Sweden three years ago he noticed that the principal Swedish makers of malleable iron always melted down all-steel charges plus ferro-silicon and ferro-manganese additions. Their only complaints were the heavy oxidation losses in silicon and manganese on melting and the variability of those losses.

The Lanz-Perlit is a hot-mould process for making high-duty cast iron of about 20 tons per sq. in. tensile strength. Essentially it consists of adjusting the composition of the metal to the average thickness of the section and the mass of the casting, and pouring into a sand mould which has been heated to a given temperature, usually about 400 deg. C., which has been determined experimentally. The iron is low in silicon, so that if cast in ordinary cold moulds it would solidify in the mottled or even in the white form in the thin parts of the sections. Owing, however, to the slower and more equable rate of cooling throughout the light and heavy sections, all parts solidify with a close-grained pearlitic structure.

It is contended that the tendency for graphitisation in the thin sections is assisted by the hot mould walls being close together and

that the low silicon content modifies that reaction in the thick sections. In passing, it is interesting to note that E. Longden, on melting down charges of white pig-iron of the requisite composition for the Lanz process, frequently obtained mottled castings, but on "coming down," as he termed it, by charging into the cupola a grey iron with steel scrap to give the same composition in the molten iron, all the castings were grey and pearlitic. It is possible that some "inherent property" of the white pig-iron was responsible for the mottled castings. The advantage of the Lanz-Perlit iron lies in its good heat-resisting properties owing to the low silicon content; otherwise, as a method of producing high-tensile cast iron it would probably by now be out of date.

Emmel Process

The Emmel process has now gone or has been merged in later processes. It simply consists in using a high percentage of steel scrap in the cupola charges along with high-silicon pig-iron and common ferro-manganese or spiegel additions. The charges are run down under careful control of the cupola, but in spite of this the process was liable to give erratic results. The Emmel process employed very high percentages (60 to 80 per cent.) of steel scrap in the charge, but with improvements in cupola melting it was gradually discovered that iron with a tensile strength of 16 tons or 18 to 19 tons per sq. in., could readily be made with much smaller steel additions so that the wear and tear on the cupola lining was reduced. For instance, some 10 years ago, a foundry with which the author was well acquainted was easily obtaining 16 tons tensile strength from charges containing 30 per cent. steel scrap and the cast iron had 2 per cent. silicon and 0.8 to 0.9 per cent. manganese. With 40 per cent. steel scrap and the iron averaging 1.6 per cent. silicon and 0.8 to 0.9 per cent. manganese, the tensile strength rarely dropped below 18 to 19 tons. High tensile strength was therefore not gained by having an unduly low silicon content in either type. In both cases the total carbon ran out about 3.1 to 3.2 per cent., and phosphorus was moderately low at around 0.4 per cent. These factors, combined with good melting practice, were the primary ones in obtaining such good figures for tensile strength.

The recent report of the Cast Iron Sub-Committee upon the Properties of Grey Cast Iron may lead one to infer that irons of the highest strength, *i.e.*, those classed as Grade 3 (22 tons and over), require the use of special processes involving inoculation, superheating and so on, but such is not the case, as some foundrymen are probably aware. Admittedly these special processes ensure certainty and in general allow the metallurgist more latitude in his mixing.

Nickel Cast Iron

The author has obtained over 22 tons, tested by the 0.875-in. bar, by melting down steel scrap and white iron with silicon and manganese added in the form of silicon briquettes and carbon-free manganese briquettes. The white iron must be a refined iron, which the author prefers to make himself by melting down a good pig-iron and steel scrap with extra manganese and desulphurising with soda ash in the ladle. Ordinary white iron bought outside cannot be relied on. It may or may not serve the purpose. By this means the total carbon is reduced to 3.0 per cent. or more often less. One may come down to 2.6 per cent. total carbon with such charges, but this is rather too low, because with very low carbon trouble may be experienced from excessive shrinkage.

With carbon at 3 per cent. or less the influence of silicon, as is well known, has no appreciable effect on the tensile strength, although it affects the hardness and machinability, and it has been found that silicon can vary from 1.6 to 2.0 per cent. without the tensile strength falling below 22 tons. Greater certainty can be had by making a ladle addition of carbon-free ferro-silico-maganese. Again, a tensile strength of 22 to 24 tons can be readily obtained if 1.5 per cent. of nickel is alloyed with a suitable charge. For example, such an iron can be produced by melting down 75 per cent. steel scrap with 25 per cent. of close-grained grey pig-iron having, say, a silicon content of 1.2 to 1.6 per cent., adjusting the mix with ferro-silicon and ferro-silico-manganese and adding 1.5 per cent. nickel in the form of "F" nickel ingots. A typical analysis of the metal is as follows:—T.C, 2.78; Si, 1,98; Mn, 0.76; S, 0.117; P. 0.20; Ni, 1.42 per cent.

This metal has been run successfully in East Anglia giving 23 to 24 tons tensile, using Carron 1.6 per cent. silicon pig-iron. Close-grained low-phosphorus pig-iron, good steel scrap and careful melting are essential for success. The mix must be melted down steadily, neither too slowly nor too fast, and the most suitable height for the coke bed above the tuyeres may require a little experimenting.

Cupola Practice for High-Duty Irons

It is perhaps needless to remark that the cupola must be hot before bringing down the first charge of high-tensile iron. Either a couple of preliminary charges, say, one of common iron and one of steel-mix iron must be run through the cupola to heat it up, or the high-tensile iron may be made after the ordinary

work has been cast by draining the furnace, again making up the bed, and following with the high-steel charges. Both methods are satisfactory.

The best weight for the charges lies between 7 and 10 cwts. If more than one charge is required, say four 8-cwt. charges to be received in one ladle, the whole of the nickel is added to the first charge or may be divided between the first two charges. This is done to ensure obtaining the maximum yield of nickel, the last charges acting as washes through the coke bed. Incidentally, the same procedure is very useful for nickel-chromium cast iron, all the nickel and chromium being added to the first charge. Manganese, however, should be added individually to each charge.

It must not be forgotten that high-tensile cast iron has a limited range of freezing and is very easily oxidised; for these reasons it must be poured as quickly as possible. The molten metal can be thoroughly deoxidised by means of carbon-free ferro-silico-manganese, and MacPherran has recently recommended the addition of 3 lbs. of this alloy to 1,000 lbs. metal in the ladle. This de-oxidising agent has, however, been employed by a few foundrymen in this country for a long while. About 0.3 to 0.4 per cent. of ferro-silico-manganese may be added in pieces, the size of small shot, to the ladle, or better in the briquetted form to the charge in the cupola.

Nickel-Molybdenum Irons

Cast iron of very high tensile strength may also be made in a similar manner, by the use of combined additions of 1.5 per cent. nickel and about 0.3 per cent. molybdenum; but the author has had no experience of this alloy iron. Also, molybdenum is mainly added for the increased impact resistance it confers on cast iron, and its high price militates against its use simply for raising the tensile strength of cast iron.

Nickel-Chromium Irons

Nickel-chromium cast iron with total carbon around 3.0 to 3.1 per cent. also yields a high tensile strength of 24 to 26 tons per sq. in. A charge of 60 per cent. steel scrap with 40 per cent. refined white iron and remelts usually gives satisfactory results from a good cupola. Extra silicon and manganese must be added to adjust the composition. If the total carbon drops below 3.0 per cent., a proportion of close-grained grey iron can be incorporated in the charge. The nickel and chromium must be adjusted in the ratio of 3 to 1 in order to neutralise the hardening and embrittling influence of the chromium. Silicon should be maintained at about 2 per cent.

The nickel-chromium irons require great care to produce, as it is of utmost importance to obtain a uniform distribution of the chromium. It is not advisable to use ordinary ferro-chrome in lump form. Either the chromium should be added to the cupola charge as chrome pig-iron or chromium briquettes or to the ladle as powdered ferro-chrome. The carbon-free grade is best for ladle additions in spite of its higher cost, as it seems to give a more homogeneous mixture.

The combination of chromium with nickel is, however, unnecessary for the purpose of obtaining 22 tons tensile cast iron, as the same result may be obtained more easily and cheaply from a nickel iron.

In all the above cases, the alloy additions of silicon, manganese, nickel and so on, required to adjust the charge to the requisite composition, have been added to the cupola. Nickel may be added in the form of "F" nickel shot to the stream of metal at the cupola spout, but it is much better to add it directly to the charge in the furnace, because one obtains a more homogeneous solution and no heat is lost by the addition of a cold metallic substance to the molten metal. The loss is very small as nickel undergoes no oxidation. The only slight disadvantage is the tendency of nickel to absorb hydrogen and pick up a little sulphur.

The author has had no experience in making very heavy castings in high-duty iron, but in a Paper published in the Transactions of the American Foundrymen's Association in 1937, MacPherran states there are no foundry reasons which limit the size of the castings produced and his firm (Allis-Chalmers Mfg. Company, Milwaukee, Wis.) have made them up to 37 tons in weight. One would imagine, however, that the number and size of the heads required to compensate for the heavy shrinkage would require some thought, and the cost of removing them would be somewhat expensive.

Inoculation Processes

Of the special processes involving inoculation, the Meehanite and the Ni-Tensyl are the best known. In the Meehanite process a high percentage of steel scrap is incorporated in the charge, which is adjusted to the correct composition for silicon and manganese and a final addition of silicon is made to the ladle in the form of calcium silicide to yield a dense, pearlitic grey iron.

The Ni-Tensyl process similarly employs a high percentage of steel scrap along with a close-grained pig-iron, with which a certain proportion of silicon in the form of a high-silicon pig-iron or silicon briquettes is added. Ferro-manganese or manganese briquettes are also added to

run the high steel-mix and increase the manganese content of the charge.

Nickel is added either to the charge or to the ladle, but again it is better to incorporate the nickel in the charge. On tapping, the remainder of the silicon required is added to the stream of metal at the spout. In subsequent runs a small proportion of remelts is added to the charge to use up the foundry returns of nickel cast iron.

A very dense cast iron with small graphite flakes is thus obtained which has a tensile strength of 22 to 26 tons, mainly depending on the total carbon content, and this strength can be improved by suitable heat-treatment. The great advantage of the processes involving inoculation is the certainty with which one can obtain tensile strengths of 23 tons and over. Processes in which the total alloy additions are made to the cupola charge require much greater care and attention. As in all high-duty irons, silicon may vary between wide limits without much effect on the tensile strength, but it is advisable to keep the manganese content above 0.8 per cent. in view of the inevitable sulphur pick-up.

In casting, good heads are essential in view of the shrinkage, and almost invariably the moulds must be thoroughly dried; in some instances, however, this is not essential.

The production of high-duty iron demands good cupola practice, and any well-designed cupola which is worked with due care will yield satisfactory results. Owing to the large quantity of steel scrap in the charge, the air-blast must be very carefully adjusted; excessive oxidation will occur if the blast is too great, and will give rise to a black frothy slag.

Shifting of the constituents of a charge is a common fault; for example, ordinary so-called fist-sized pieces of ferro-silicon are very apt to trickle down from a higher to a lower charge, and lumps of ordinary ferro-chrome seem to find their way into any charge and invariably leave a trail through succeeding charges. It therefore follows that care should be taken in the selection of the components of the charge, particularly in regard to size and relative melting points. In adding the components of the charges to the cupola, it is customary to add the steel scrap first, followed by the pig-iron and remelts together with the alloy additions. Recently it was suggested to the author that the steel scrap should be added last, but, though this procedure has been tried several times, no material improvement in the resultant iron has been noticed by this inversion of the customary order. No doubt the order of charging is comparatively immaterial where the bulk of the mix consists of steel scrap.

In conclusion, the author would like to emphasise that, in the production of any high-tensile cast iron, as much, if not more, consideration should be given to the materials, *i.e.*, the iron, the steel scrap and alloying elements, as well as to the chemical composition of the final cast iron. In other words, one must choose irons which have good "inherent properties" even for melting down and preparing a synthetic white or grey base iron. The use of de-oxidising agents in the preparation of high-duty cast iron is also to be greatly insisted upon. In most cases the addition of a good de-oxidiser makes at least 10 per cent. difference to the strength of the iron.

DISCUSSION

Mr. G. Hall said that, as a practical foundryman, he greatly appreciated the way the lecturer had dealt with the subject. Mr. Williams had spoken about the importance of high tensile strength, and in every Paper to-day on high-duty cast iron this high strength was always stressed. He agreed with Mr. Williams that iron of 18 to 20 tons tensile strength was very nice to make and rather appealed to most foundrymen; iron of 22 to 24 tons was quite another proposition and involved considerable alterations in normal foundry working.

Lanz-Perlit iron was produced in an ordinary foundry with just a few additions and perhaps more care in controlling the cupola, but not necessarily with a quantity of instruments. He had seen cupolas worked for Lanz iron without any instruments except a water gauge. They had never made a point of getting over 20 tons as there was no object in doing so; irons of 14, 16 and 18 tons were quite easily obtained from the cupola without any additions whatsoever. To-day one had to add nickel, chromium and other alloying elements to produce high-duty cast iron, which was very costly. The speaker did not consider high tensile strength to be so important as the production of good wearing and good heat-resisting cast irons.

Cupola Control Essential

Mr. Williams, replying, said he hoped that in referring to the Lanz and other processes he had not given the impression that they required an excessive amount of cupola control with the use of elaborate instruments. It was necessary, however, in all processes for making high-tensile iron to exercise a certain amount of control to ensure that the furnace was neither under- nor over-blown, and for that purpose a blast volume meter was very useful.

With regard to the Lanz-Perlit, it was a very good process for producing heat-resisting cast iron, and was made by some firms without any instrumental control of the cupola. It was easy to get 20 tons tensile by the process, but not so

easy to exceed that figure. The other methods outlined in the lecture rendered the production of high-tensile iron over 22 tons more certain. In ranging over a wide field, he had mentioned a method of making high-duty iron without any of the usual alloy additions, such as nickel, chromium and molybdenum. The use of nickel and nickel-chromium simplified the process and eliminated any uncertainty. The cost had to be considered, but if it enabled one to get away with the job, this was of secondary importance.

Simplification Desired

Mr. J. L. Francis agreed with Mr. Hall that complications and special tackle in the foundry were to be avoided as far as possible, but he thought it a big point with these high-duty irons that special equipment was unnecessary. There was no point in securing high strength unnecessarily, but some of the newer types of alloy iron did widen the field for ironfoundry products, and thus help in the securing of business which had been slipping away gradually to the steel founder, the fabrication people, and even to the non-ferrous founder. Apart from the actual increase in strength, the introduction of alloys into cast iron had produced material with new properties, and in this respect the cost of the alloy additions was justified.

The Lanz process was a pioneer process, and at the time it was introduced was a very big step forward. A maximum of 20 tons tensile was about the limit for this particular process, chiefly because the abnormally slow cooling which was necessary to produce machinable castings occasioned rather coarser structure of the graphite flakes.

Incidentally, the whole of the range of processes which had been introduced at any time for the production of high-tensile iron had, in some shape or form, taken steps to control the carbon in the iron, especially graphite, as it was the graphite which lowered the strength.

Another point in connection with alloy additions to cast iron was that they gave a much more uniform structure throughout different sectional thicknesses, and where one had to make castings to withstand internal pressure, this was a great advantage. Castings made without the alloy might show leakage of water and were scrapped. In this case the cost of the casting and its machining was lost. Often a few shillings spent on alloy additions would prevent such loss of time and money.

Manganese-Sulphur Ratio

Concerning manganese, it occurred to him that Mr. Williams had not mentioned that the manganese-sulphur balance had been definitely stated by Norbury as 1.72 times the manganese plus 0.3 per cent., which was a safe minimum ratio. As to the addition of the alloys, he personally, wherever possible, preferred to make additions to the ladle, probably because his experience lay in that direction. One might have to add it to the charge where the conditions called for high percentages.

Nickel was an advantageous alloy to use; it gave a good range of properties and it was "fool-proof," because it did not adversely affect other irons which one did not want alloyed, whereas chromium was a powerful hardening element and might give rise to trouble if it found its way into material where it was not required. Molybdenum additions were not more expensive than nickel, because molybdenum was more active, and one part of molybdenum was equivalent to three parts of nickel, so that for equivalent additions the cost worked out about the same.

In introducing alloys, the charge should always be adjusted so far as silicon content was concerned. Another method for the production of high-duty iron was the duplex, utilising one cupola melting white iron and one melting grey iron, and by mixing the two molten metals in various proportions one could obtain a range of irons which had different properties from those obtained by melting white and grey iron together.

Mr. Williams was pleased to hear what Mr. Francis had said about the relative cost of molybdenum. He quite agreed that the foundry people had a good opportunity to recover some of the business which had been taken from them by the steel founders. He was not quite so sure about the sulphur-manganese balance propounded by Norbury. Theoretically, this ratio of manganese to sulphur should be quite satisfactory, but much depended on the form in which the manganese was added and the rate of melting. Numerous cases were on record where the iron/iron-sulphide eutectic had separated in the presence of a large excess of manganese; McNair* had mentioned a case where this eutectic had segregated out from 0.07 per cent. sulphur in the presence of 0.82 per cent. manganese.

Mr. H. H. Shepherd, proposing a vote of thanks to the lecturer, said foundrymen seemed to have advanced a very considerable way in foundry practice, and also in metallurgical practice, but he noticed the use of the term "semi-steel" persisted. He suggested its elimination and substitution by the phrase "ferro-steel." The making of malleable iron from an all-steel mix was undesirable from the practical point of view, and experimenters should be discouraged.

* Proc. I.B.F., Vol. XXVII, pp. 543-562.

Tensile Strength

On the question of tensile strength, he felt that, despite all the advance registered in connection with the physical properties, people still judged cast iron by its tensile strength. It was possible to produce very high-tensile irons, but they were useless. Tensile strength in itself was not a criterion of the iron. If there had been sufficient attention given to phosphorus in the past there would have been considerable room for a cheap and good tensile iron.

He had stated repeatedly that he believed the inoculated type of iron would be the iron of the future, and he had also expressed the opinion that with a white-iron base and a proper system of inoculation one could produce almost any type of casting.

Some of the aluminium-molybdenum irons had very good properties. These alloys appeared to be very expensive, but when one took into account the use they could be put to, the expense was quite justified. He then proposed a vote of thanks to Mr. Williams.

Influence of Phosphorus

Mr. Williams said he had no pretension to being an expert on malleable iron, but had referred to the matter because it seemed to be the practice in Sweden, where they had to melt white iron to adopt the practice of using steel with additions. Possibly one of the reasons they had trouble was because they tried to melt too fast. He agreed with Mr. Shepherd with regard to the transverse test of iron, and that frequently this was of much greater importance than mere tensile strength. On the question of phosphorus, he disagreed with Mr. Shepherd; no doubt the idea of a low phosphorus content might be overdone, yet in many cases a phosphorus content of 0.8 per cent. was a useful ingredient so far as wear was concerned. On the other hand, it did lower the transverse test and, in pressure-tight castings, was very apt to lead to porosity. In high-tensile cast iron, where one was aiming at strength, a low phosphorus content was essential. With regard to molybdenum, he did not stress its use, because he did not think it was required for producing a high-tensile cast iron, but it was useful for giving a high impact test.

Meeting Competition

Mr. T. R. Reavell (Norwich), who seconded the vote of thanks to Mr. Williams, complimented the author on his ability to explain metallurgical matters so lucidly. Information of this nature was usually given in such a way that it was not easily understood. The iron foundry industry was feeling the competition of the steel founder, and, in the case of his firm, it was losing orders for certain types of work where they called for steel. It had to adopt new measures, and by alloy additions it was now able to produce iron with over 22 tons tensile, and as a result the firm had recovered quite a lot of business and, moreover, had received orders for castings that were originally made in steel.

Mr. Williams thanked his audience for the generous reception accorded to his Paper.

Paper No. 702

Making a Large Lathe Bed

By WILLIAM Y. BUCHANAN (Associate Member)

The casting to which the author proposes to devote this Paper is a lathe bed of constant cross-section in varying lengths; the usual is 33 ft. long, but in some cases 40 ft. when it is jointed in two sections. In all 97 castings were made in the manner about to be described, and all the data referring to metal composition and structure, etc., are based in the first 81 castings.

Method of Pattern Construction

As the casting outlined in Fig. 1 must be machined and highly-finished from end to end of the slides or shears, it must naturally be cast with this side down, although the casting is always machined on the other side as well. The general construction of the pattern is a strong box-shaped body on which the facings are mounted and the draft of the pattern is made to suit casting the shears down.

Draw bars are fitted in convenient positions in the pattern sections, and these are best fitted so that they can be either removed temporarily or made permanently below the top of the pattern, as they may, and usually do, foul the bars of the top part unless their relative positions are carefully measured before ramming up the pattern.

The facings on the sides and projecting parts of the bed shears are made loose and screwed so that they can be slackened during ramming up to allow the bed to be drawn. The long print on the bottom of the pattern serves to allow the setting of the body cores. For the purpose of camber the pattern might best be partly sawn through at intervals throughout its length and fitted with removable wedges, so that it could be bent readily; but this is not done here, as the casting is wanted in a great variety of lengths and various pieces are normally used, in which case the uniform cambering of the pattern is difficult.

The pieces actually available are the head end-piece, which is 14 ft. long, and eke piece, 12 ft., 8 ft., 6 ft. 5 in., 4 ft., and 1 ft., and sometimes four pieces are used to make up the length. These short pieces are difficult to arrange in a smooth continuous camber.

The colours which have been in use for some thirty years are *orange* for machined surfaces, *red* for the as-cast surface, and *black* for core prints. The author is unaware whether the British foundrymen intend to recommend pattern colours in the same way as the American foundrymen have done. The standard colouring would be helpful in the case of most firms undertaking outside work, and indistinct marking is often the cause of mistakes. The pattern is split so that, when in position for ramming, the base section at the head end can be removed to facilitate ramming at that part.

Moulding Box

Although some foundries might mould in a three-part box and lift it into the stove for drying, this casting is made in a long permanent box in the floor and dried with portable driers. The box itself is 110 ft. long, 5 ft. 1 in. wide and 4 ft. 7 in. deep at one end, and 3 ft. deep for the remainder of its length, as shown in Fig. 2, and is made with a permanent ash bed. The intention at first was to make the top parts and drill them with 3-ft. centres between the snugs for bolting to the box, but it was found much more convenient to clamp and wedge the top parts, which allowed their unrestricted movement.

The original method was to use a box to take the longest pattern and work one bed at a time, but the use of the very long box has many advantages for this class of casting, as, for example:—

(1) If the box is not in use (that is, the whole box or any part of it), it can be filled up and the space used for other moulding on the floor level, such as closing machine-moulded jobs, as is regularly done.

(2) Several long beds or a number of short ones can be moulded at one time. The maximum number so far is six jobs at one time.

(3) Where a number of castings are wanted off the pattern under consideration, the delivery time can be greatly improved by making an extra set of facings for the pattern. By moulding and drawing the pattern, then fitting the extra facings, moulding can be begun on the second bed while the finishing of the first is going on, so there can be the first drying, the second finishing, and the third moulding, and then the first cast, the second drying, and the third finishing, and so on in a steady

sequence. In this way, for beds 30 ft. long, the rate of casting is three per fortnight.

The box was made level with the floor, and the "wings" or small frame to give the increased depth necessary at the head end was made loosely, so that it can be fixed and clamped at any position along the box.

Box Top Parts

The top parts are made in convenient lengths of 9 ft., 6 ft. and 12 ft., and the bow portion is made detachable. Although covering 6 ft., 9 ft. and 12 ft. respectively, the top parts are actually 1 in. shorter so as to allow 1 in. space, which in closing the mould is filled in with an oil-sand core. This method is preferable to laying-in pieces of round rod to chill the metal and ramming up with green sand, as this tended to chill the hard type of metal used rather heavily and caused a decided mark on the casting.

Moulding

The ash bed is first laid in and rammed in position about the level of the bottom of the tie bars of the box, and covered with straw and sand, then firmly rammed. After the first bed has been cast, this part of the mould becomes permanent. Having rammed and levelled the sand in the bottom to the required height, the first operation is to prepare the bottom of the mould to receive the pattern, and this includes the laying of the camber. To do this, 3-ft. straight edges are placed across the bottom of the mould at intervals of 4 ft. from one end to the other. Then, using a string, the heights of these short straight edges are adjusted to give full camber in the centre, say $1\frac{1}{8}$ in., and varying to nil at the ends.

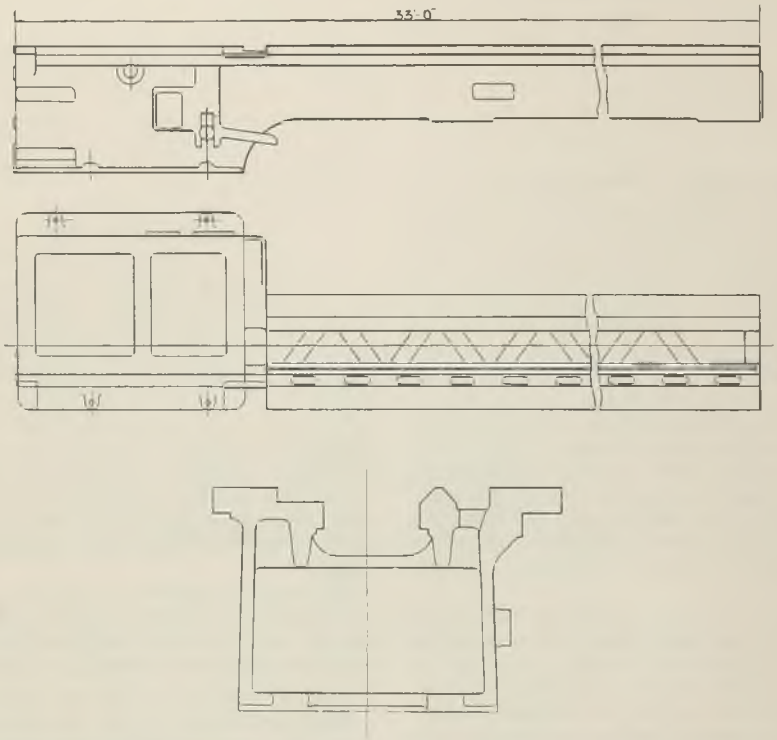


Fig. 1.—Side Elevation, Plan and Section of Lathe Bed Casting.

The short straight edges are secured at their correct height and the sand is rammed between them and struck off level, so that the camber is actually put down in a series of short straight sections altering at intervals of 4 ft. The short straight edges are then drawn and the holes filled up and levelled. The pattern is placed in the correct position in the box and the impression of the bottom prints made by bumping the pattern. Then several stakes are driven down the sides of the pattern before it is removed, so that it can readily be returned to the correct

position for ramming. Long straight edges are next laid in position along each side of the impression of the print and the sand is swept out to the correct depth. The straight edges and boards are all strengthened along the working edge by strips of $\frac{1}{8}$-in. thick metal.

Where several pieces of pattern are used, it is best to use a string to set the straight edges and measure out the print. The pattern is then lowered into position and the stakes removed.

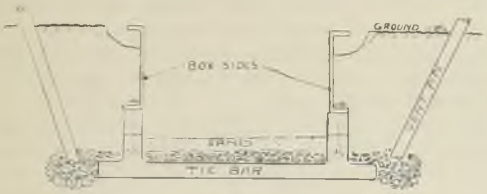


Fig. 2.—Construction of Moulding Box.

A board is placed at each end of the pattern and rammed in this position to remain there till the pattern is drawn. Weights of about 10 cwts. are placed on the pattern to spring it down to the bottom, and all is now ready for ramming up.

Ramming

The bed course is first pin-rammed and then flat-rammed using a fairly high-moisture sand to get hard ramming, as the mould is liable to strain in this position.

For the front side, the first course is 5 in. rammed to 3 in., and the first row of straight irons is put in to support the sand above the projecting part of the shears. The second course is 4 in. rammed to $2\frac{1}{2}$ in., followed by the second row of straight irons to about the centre of the fillet. These two rows of irons are put within $\frac{1}{4}$ in. of the pattern.

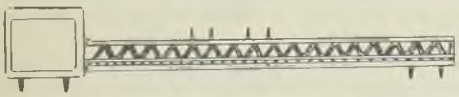


Fig. 3.—Showing an Unusual Method of Dealing with Side Camber.

The third and fourth courses are 6 in. ramming to $4\frac{1}{2}$ in., each followed by rows of straight irons to within $\frac{3}{4}$ in. of the pattern, and the last course $4\frac{1}{2}$ in. ramming to 3 in. brings the mould up level with the top of the pattern. For the parting $1\frac{1}{2}$ in. is swept out to get down to the bottom of the round.

The ramming up of the back is similar except that the first course of 5 in. rammed to $3\frac{1}{2}$ in. brings the straight irons up to centre of the fillet above the projection of the shears, and this is followed by three courses at 6 in. rammed to 4 in., and finishing with $4\frac{1}{2}$ in. ramming to 3 in. Here again $1\frac{1}{2}$ in. is swept out to form the correct parting line.

Facing sand is used for about $1\frac{1}{2}$ in. from the pattern face, and the remainder is floor sand mixed on the spot. The parting is then made with a layer of wet parting sand, and the top parts are placed in position and staked for future registration. The vent pins are placed in position by the markings on the pattern and the centre and end gate-pins placed by measurement. The top parts are then rammed up by careful pin-ramming round the bars and finally finished by heavy flat-ramming. The vent-pins and gate-pins are then loosened and withdrawn and the holes blackwashed. The top parts are lifted off and turned over for finishing. The sand is carefully repaired round the top facings and sprigged round the gate holes and at the bow of the pattern, where the air and metal are liable to rush up during filling.

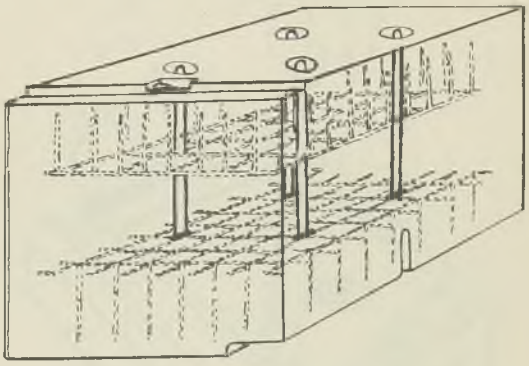


Fig. 4.—Contruction of Head End Core.

Where the top-parts together are longer than required to cover the pattern, the extra length is left unrammed. The operation is completed by blackwashing with swabs, dusting on plumbago and sleeking and the removing to the stoves. The pattern is next slung by the crane, rapped, and slowly drawn, leaving the facings in the mould. An extra set of facings can be screwed on the pattern and the next bed proceeded with. Meanwhile, the mould is repaired and sprigged round the facings and all along the bottom of the mould, *i.e.*, the face of the shears. The mould is then blackwashed, and plumbago liberally applied and sleeked on to give as good a finish as possible.

Side Camber

Cast normally, the side camber on a bed of this type would be considerable—probably $1\frac{1}{7}$ in. in 33 ft., and as already explained the usual

method of putting the camber on the pattern is not convenient when the pattern is in a number of pieces. The method used is to anchor the casting securely to the box and prevent any distortion during cooling. Blocks of cast iron are rammed up at a level with the shears, *i.e.*, on the first ramming course, with one side against the box and the other about 6 in. from the pattern. A piece of wood about 2-in. square

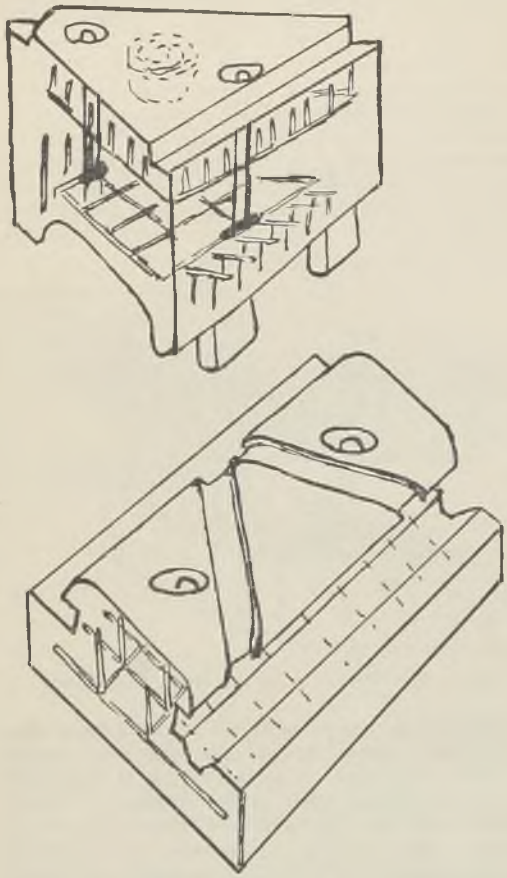


Fig. 5.—Body Cores, Top and Bottom.

is placed between the block of metal and the pattern, and this is tapered to draw inwards and so leave a projection on the casting which will bear directly through the block on to the moulding box. The bulging side is anchored in the centre by four of these suitably placed, and on the other side the ends are anchored. (Fig. 3.)

This method is now the usual practice and turns out a casting within about $\frac{1}{8}$ in. of the pattern shape. It is also quite flexible in that the number off, distance apart, and position of these metallic buffers can be varied at will. In drying the mould cast-iron plates are used for covering the mould, and some of these plates have suitable openings through which the heated air can be blown. After claying up the spaces between the plates the mould driers are placed, one in the centre, one near the tail end, and the other just outside the head end.

The ends are closed with cast-iron plates so as to leave openings for gases to escape at the lowest point. Under the centre and tail-end mould driers, a short cast-iron pipe is used to direct the hot air down past the sides of the mould, then allowing it to escape parallel to the mould length only.

In drying, the head-end and centre driers are put on for 18 hours, to be followed by the head and tail-end driers, for 9 to 12 hours. It was found best to have these mould driers made with screw-controlled dampers which allow a fine degree of adjustment. The lower dampers can

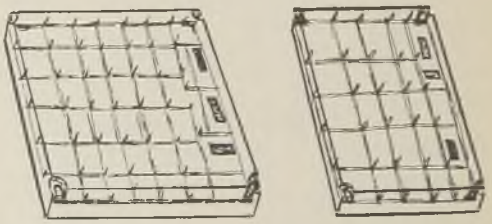


Fig. 6.—End Cake Cores.

only be used for kindling, *i.e.*, all air goes over the fire or the mould will be burnt. The dried core in the head end is covered with paper and wet loam to protect it from over-drying. These driers burn about 20 lbs. coke per hr. and are fired regularly every $1\frac{1}{2}$ hr. The cost of drying a 33-ft. bed is for fuel 12s. 4d. and for electricity 1s. 4d.

The system of recording the exact time of each fire and checking the weight of fuel is the best control of firing that can be had. It might be worth while to install pyrometers in the air stream, but the existing scheme works perfectly with the screw dampers, which were made on request some four years ago. The danger of "burning" the mould was always due to lack of control of the small push dampers and the liability to shift during working.

Head-End Core

The core box is open top and bottom and is rammed up in the normal casting position. The lower grid is cast with four lifters spaced suitably, and the bars of the grid form $4\frac{1}{2}$-in. squares with 9-in. and 7-in. "dabbers," as shown in

Fig. 4. The metal in this grid and the frame is of the usual D-shape, 1 in. broad by $1\frac{1}{4}$ in. deep. The sand is carefully rammed up to about half-height, and the frame put in with "dabbers" upwards. This frame has bars forming 8-in. squares at the ends and 6-in. squares in the centre, and, unlike the lower grid—which has dabbers to every square—has dabbers only round the side, 6 in. long and 5 in. apart.

The ramming is continued to the top and the centre filled in with ashes. The box is then

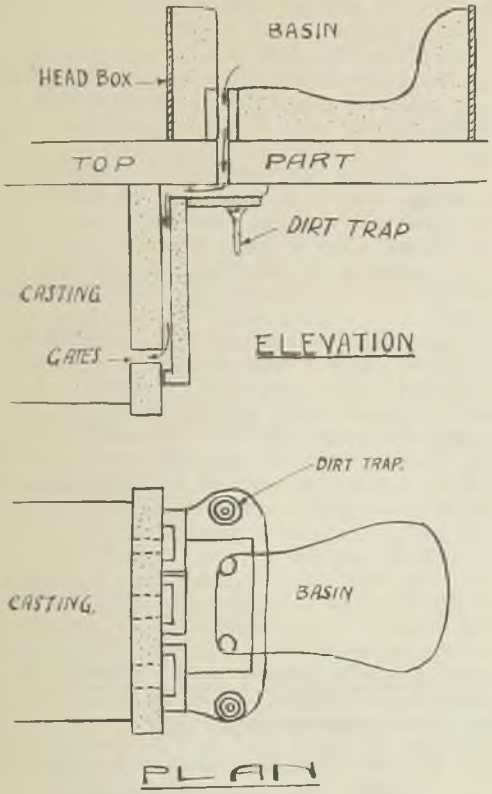


Fig. 7.—Method of Gating and Position of End Cake Cores.

loosened and taken away, and the core finished and sprigged along the fillets and on the edges of the prints. The core is then suspended and sprayed with blackwash and finished by painting over, using a flat brush. It is removed to the drying stove and dried two nights at a temperature of 600 deg. Fah. (315 deg. C.) maximum, no drying being carried out during the day.

Body Cores

The body core was at first split vertically, *i.e.*, put in as one core, but the method of using two cores illustrated in Fig. 5 was found best for many reasons.

The top half is rammed up with a grid and frame as shown in Fig. 5. The grid has two 9-in. lifters and $4\frac{1}{2}$-in. dabbers on one side above the plugs. A single straight iron is rammed up on the opposite side to strengthen the projection on that side. The frame is of similar shape and has $4\frac{1}{2}$-in. dabbers, and is rammed up in the core with the points upwards. An ash vent is put in the centre of the top face and the core is sprigged along the fillets and on the plugs and projection on the opposite side.

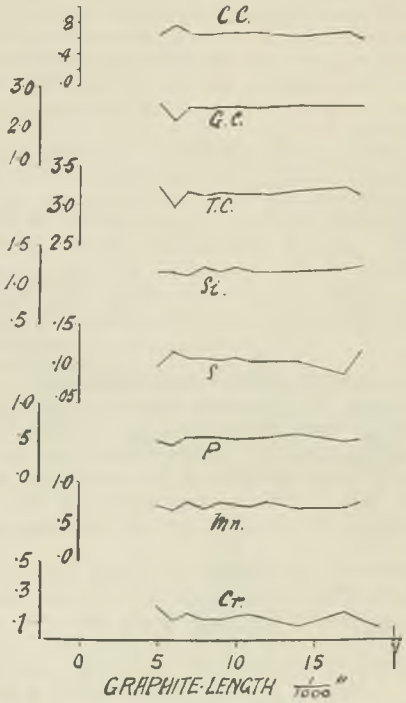


Fig. 8.—Relation between Graphite Length and Analysis in 81 Castings.

Every alternate body-core top-half is turned the opposite way in the mould and is exactly the same, except that it has no plugs projecting from the lower side. These cores are vented through the top part of the mould. Longer cores are used at head- and tail-ends, shaped to finish off square. These are, however, essentially the same as far as coremaking is concerned.

The lower core (Fig. 5)—referred to as the bottom print core—is made in standard lengths of 23 in., with the one at the head end 3 ft. long. The grid used has two 7-in. lifters and

two rows of "dabbers" 6 in. long. These cores are sprigged on the edges and fillets, and, in addition, those nearest the gates at the tail end are sprigged along the flat faces along which the metal runs. These cores are vented through the bottom into a clearance in the bottom print, which is vented direct to the ash-bed.

End Cake Cores

These cores, shown in Fig. 6, are used to form the ends of the mould, and are made 6 in. thick and 4 in. thick, through which are cut the inlet gates. They are made by jolting in an open top box which carries the facings on the end of the bed. The head end core is 6 in. thick and has a grid covered with 5-in. dabbers and 5-in. lifters. Spaces are left in the grid for the gates, and the pins are located by measurement. The tail-end cake core is 4 in. thick and has 3-in. dabbers and three 3-in. lifters.

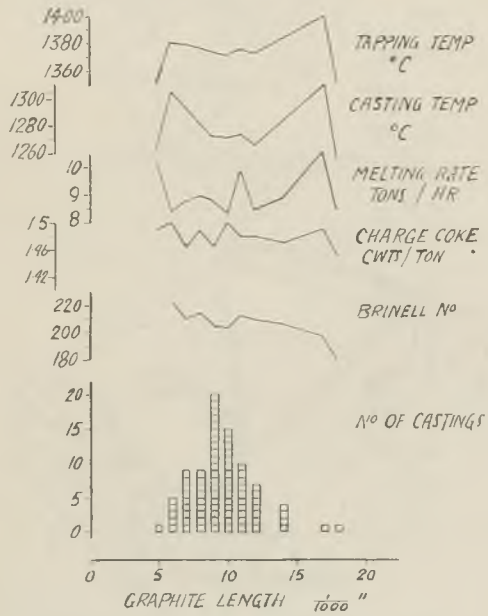


Fig. 9.—Relation between Graphite Length and Melting Conditions, Brinell Hardness, etc.

Closing

The head-end core is laid in first, then the lower body cores are butted to this in succession towards the tail end. Careful alignment of these cores is essential, as they form part of the contour of the slides, or shears. These bottom cores are set on a light loam stamp and vented direct to the ash-bed. The body cores are set from the head end onwards and are secured by chaplets, the height being fixed by the same stick as that used to sweep out the parting.

After examining from end to end through the open ends, the cake cores are placed with the gates in the correct position so as not to cause the metal to strike the mould on the cores. The upright cores which form the down gates are placed in position, loamed up and rammed in position, taking care to wedge the bottom tightly from the solid sand and using convenient plates to take the pressure. After ramming to near the parting, a dry-sand cake is placed in position to take the force of the metal dropping from the down gates from the basins. The space between this dry cake and the top parts is $1\frac{1}{4}$ in. Dirt pockets are placed at the sides of the dry cake, as shown in Fig. 7.

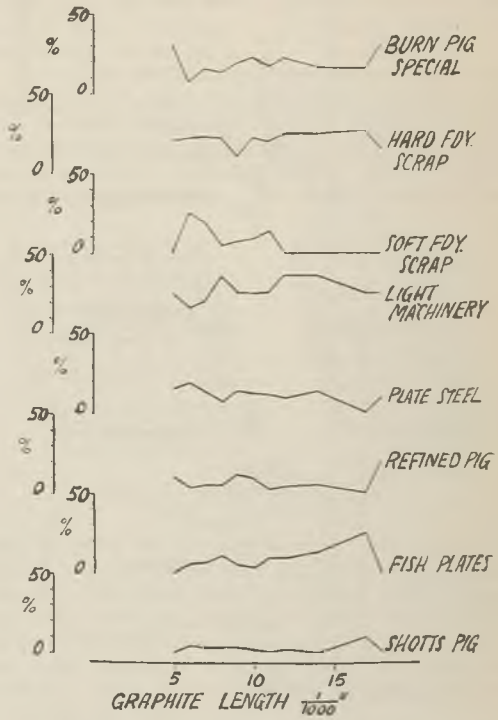


Fig. 10.—Relation between Graphite Length and Type and Percentage of Raw Materials in Cupola Charge.

Loam stamps are placed round all core vents, round the mould sides, and also round the gate areas at the parting. The top parts are brought over and tried on, dropping whitening down the gates and vents before lifting off again in order to test the position of the down gates and vents.

The stamps are trimmed off, the vents filled in with loose green sand, and the mould finally examined for any trace of detached sand, for which purpose a small electric lamp on a long tube is used.

Having replaced the top-parts, the making-up of the risers and pouring basins is begun. Hollow cylindrical cores are carefully placed in position, so as to extend the down gate from the top-part up to the level of that required for the bottom of the basin. The head box is placed in position, and the basin rammed up and cut out to shape such that both end basins have the down gates close to the side of the basin to prevent swirling of the metal during pouring. The centre gates are built up in the same way, but a long trough basin is used to take in the gates on either side of the mould. This basin is filled from the adjacent bay by means of a suitable runner, which is kept dried ready for the purpose. The down gates in this basin are plugged with stoppers until the basin is well filled, and then the flow of metal is released, as it would otherwise be difficult to keep up the metal level.

The four risers on the head end are made up to the required height with a series of square cast-iron frames in the usual way. Six extra risers are taken off the body section of the mould. These are cut back from the facings situated along the top of the casting, and brought up through the top part to the required level. Their function is to help to free the mould of air which tends to become trapped during rapid filling. Heavy cast-iron weights in the form of long bars are laid along the sides of the top parts after clamping securely and the intervening space rammed up. Without this precaution the metal is very liable to get out at the parting. Four weights of about a ton each are placed on the top parts as an additional safety measure, and these to some extent prevent straining of the top parts in the final filling stages.

Gate Dimensions

The gates at the head end consist of three rectangular inlets, $2\frac{7}{8}$ in. by $\frac{7}{8}$ in. at the casting, fed by uprights 4 in. by $\frac{5}{8}$ in. Those at the tail-end consist of two measuring $2\frac{1}{2}$ in. by $\frac{7}{8}$ in. and one 2 in. by $\frac{3}{4}$ in. The first two are fed by a single upright 9 in. by $\frac{3}{4}$ in. and the other by an upright 4 in. by $\frac{5}{8}$ in. The centre gates consist of one each side of the centre.

Rate of Casting

This casting is best cast quickly, and the rate used for those referred to is 6 tons per minute. The object is to cover the bottom and fill the shears as quickly as possible, but, as there is a relatively light section above this, with rapid filling the metal is certain to rise too quickly toward the top and may strike the top of the mould with considerable force.

The use of three ladles is preferred to, say, one large ladle collecting all the metal, as this cannot give such uniform cooling conditions. With three ladles and a continuous tapping system the metal can be conveniently collected and cast with not more than 20 or 30 deg. C. difference in temperature. By starting all three ladles together and allowing one to empty early, the rapid filling of the lower heavy section can be accomplished with a somewhat slower filling of the lighter upper sections of the mould.

If this rate be not checked towards the end a small quantity of metal is shot up to the roof, which, although it does no harm to the mould, is very annoying to those who have to be near.

Lifting

The bed is usually cast at 4 p.m. Next morning the top parts are lifted off and the gates broken off and the centre part only covered with hot sand. Then the casting is lifted in the afternoon of the following day. A typical sequence is: Cast, Tuesday, 4 p.m.; gates broken, Wednesday, 10 a.m., and lifted, Thursday, 2 p.m.

Precautions and Possible Defects

The inspection and standard of quality required seem to go far beyond what is usually expected in foundry work. A small surface defect in the shears which could not possibly interfere with the usefulness of the casting would cause rejection on the grounds of appearance alone.

As is well known, a percentage of defective castings accompanies all foundry work, but it is highly desirable that this percentage confines itself to something less important than the casting herein described. The defects to which this casting is liable may be listed as follow:

(1) Chaplets becoming dislodged and falling into the shears, where they may appear in the machined surface.

(2) Inferior coating on chaplets causes gas holes. Only the best coatings of pure tin have been found suitable, and the quality of this coating is checked by analysis.

(3) Defects due to detached sand during closing.

(4) Scabs due to incomplete drying. As stated elsewhere, these do not appear due to expansion in normal circumstances.

(5) Burning of the mould sides results in bad surface defects accompanied by washing.

(6) Washing may occur under the gates along the shears if the sand is not hard rammed and

of good dry strength. This defect is guarded against by sprigging along the entire length of the shears.

(7) Scaling of blackwash is a source of dirt inclusions on the casting surface. This is usually due to weak sand condition or faulty blackwash mixture, and is largely eliminated by the use of a proper mixing machine to replace the old method of mixing by hand in an open tank.

(8) Gas holes may result along fins formed by excessive clearance on the partings, which may be aggravated by lack of fluidity in the metal after casting, and also by low temperature.

(9) Low Brinell hardness, which is fatal with some inspectors. This can only be overcome by control of tried and proved composition, casting and melting conditions.

(10) " Open " machined surface which can occur even with good Brinell hardness. This is controlled to a large extent by the form and quantity of graphite in the iron.

(11) Chilled edges are an ever-present source of possible trouble. These might be largely eliminated with the fins, as a much harder iron can be used where there are no fins.

(12) Lack of machinability due to the presence of pro-eutectic cementite. This may result from a fairly small excess of chromium over the low percentage required with low-silicon, low-carbon iron.

Use of Chills or Denseners

It should be noted that no chilling is done on the surface of these beds, and the hardness obtained by the proper composition and melting conditions has a very high uniformity in heavy sections. A casting made in this way is much less subject to strains; distortion is more uniform on machined surfaces even if the camber does not turn out as expected.

Metal Control and Composition

Besides the regular analysis of samples taken from each ladle, a test-piece is cast on the shears and of the same thickness as the shears, so that the conditions of cooling will be the same. This test-piece is planed down with the bed so that the surface of the machined test-piece will be the same depth below the casting skin and have the same structure. The test-piece is numbered before leaving the foundry and when cut off is sent to the laboratory. On this the Brinell hardness is checked and the micro-specimen cut from the machined surface. The micro-specimen is numbered on the reverse side and, after examination, filed for reference.

Since the degree of closeness of the machined surface is directly affected by the size of the graphite flakes, the actual measurement of these is made in order to give some numerical value to this property. Thus, to say that the 81 castings represented in the graphs have an average graphite length of 6.8 thousandths of an inch gives a definite idea of the size of the minute cavities made in the surface during machining, since the pieces of metal when torn out break away along the graphite plates.

A surface which would be described by the machinist as open, is associated with graphite length of 50 thousandths and often with free ferrite. The figure taken for each micro-specimen is the average of 10 measurements. The method, like many others, may be unreliable on a small number of cases, but if carefully done on a large number, as in the data under consideration, gives useful conclusions. Since the closeness of finish is the most sought-after property, the other data have been graphed against this in order to show, if possible, which conditions or sets of conditions favour small graphite size.

In the case of the chemical analysis, as in the others, the points on the graph (Fig. 8) are the averages of all the castings having the same graphite size. It will be seen that the graphs are remarkably flat and that graphite size within the range found is independent of composition, that is, of course, provided the composition is controlled to close limits. The majority of castings will be observed to have graphite less than 11 thousandths in length, with one at 5 thousandths which may be accounted for by the slight excess of chromium; but for general conclusions it may be best to neglect single cases.

The Brinell hardness is seen from Fig. 9 to fall as the graphite size increases, which can be readily accepted. A lowering in the percentage of coke charge per ton of iron during melting appears to be accompanied by a drop in casting temperature and an increase in graphite size, which may support the theory that high melting temperature re-dissolves graphite more completely than low melting temperature. The type and percentage of raw materials may be expected to have some effect on this graphite size.

From Fig. 10 it will be seen that there is a tendency to increased graphite size with increased steel and with remelting the same material, but on the whole they seem to have balanced one another out very well. It should be remembered that all of these factors operate at once and that the object here has been to prevent variation as far as possible and to maintain as small a graphite size as is possible, consistent with avoiding the other physical defects which may occur due to metal conditions which

are unsuitable to good foundry practice by carrying this pursuit too far. Also, this group of castings covers a period of 3 years, with its varying market conditions, etc. However, it may be said with some satisfaction that the 97 castings referred to had none of the defects listed or described, and they might be modestly called good castings.

DISCUSSION

Coring and Blocking

Mr. R. D. Lawrie said he had no experience of making lathe beds, but he would like to express his appreciation of the Paper Mr. Buchanan had presented to the meeting. Remarking on the fact that Mr. Buchanan had based his Paper on observations on 81 castings, Mr. Lawrie said that, had he been in the author's place, he would have adopted standardised methods in order to cheapen production, *e.g.*, coring out the sides of the mould, but he added that he noted that had already been done to some extent.

Mr. Buchanan replied that he had applied coring and blocking-out very extensively to increase production rate to such an extent that the drying equipment now represented a bottle neck. There had been ample scope for it on the other castings; *e.g.*, small beds were split and dumped up in halves up to 9 ft. long, but he thought it would be more expensive to set cores along the sides and would not leave a very good surface, owing to the joints of those cores. The adoption of standardised methods was difficult in this case, as the firm usually got small numbers of castings, and they were wanted in different lengths.

Testing Chaplets

Mr. Ross said that Mr. Buchanan's experience with chaplet coatings confirmed his own experience of defects due to chaplets.

Mr. Buchanan said he had found a good coating on the chaplet to be important in the making of these castings. He regularly tested chaplets by melting off some of the coating with a clean gas flame and effecting an analysis on the small bead of metal thus obtained. The method readily showed the difference between a pure tin coating and a cheaper type. Several cases of defects were found when pure-tin coated chaplets could not be obtained and cheaper coated chaplets had to be used temporarily.

Casting Methods

Mr. Marshall doubted whether the mould could be efficiently dried for 13s. 8d. with coke at 33s. per cwt. He wondered whether Mr. Buchanan, when using three ladles, had experienced trouble due to dirt, especially when one of the ladles was emptied earlier than the others. He also asked if the wash of metal in the mould when using a ladle at each end had any influence in causing dirty castings.

Mr. Buchanan assured Mr. Marshall that efficient drying was obtained, and added that mould-drier fire-boxes had been modified as regards grate area. Inefficient drying would certainly result in a defective casting. There was a tendency for dirt to be trapped if the metal was cold, and this was a trouble which had to be overcome in his earlier experience. In allowing one ladle to be emptied before the others, the head of metal did not allow dirt to get into the casting.

Core Mixtures

Mr. Little asked if Mr. Buchanan had ever used a copper addition to prevent chilling at joint fins; in his own experience he had found 1 per cent. helpful. He suggested that the coke/iron ratio used by Mr. Buchanan was too low and likely to lead to trouble. He asked the author for details of the core mixture used.

Mr. Buchanan said he had not used any copper addition, as he found it unnecessary. He confirmed that with under 1½ cwts. coke per ton of iron he got the best possible conditions of melting. This figure was readily obtained in his Balanced-Blast cupola. The core mixture in use at present he gave as floor sand with under 1 per cent. Colbond and no other additions. This gave the following average figures:—Green strength, 4 lbs.; permeability, 73, and dried strength, 100 lbs.

In reply to Mr. McManus, Mr. Buchanan said that the runner box used was a plain type with no special provision for dirt trapping. The small dirt traps shown in the sketch probably did not do much good, but were an old-established practice which he had not attempted to alter.

Final Straightness

Mr. Hurst was specially interested in the methods Mr. Buchanan had adopted to ensure that the beds would be straight. His experience was that, after rough machining, there was a tendency for the casting to distort, due to the release of casting strains; accordingly, he thought it necessary to leave such castings to season for some time before final machining.

Mr. Buchanan said the method of preventing side camber on this casting was new as far as he was aware; it was unorthodox but completely successful. The castings were still rather warm when taken to the dressing shop; in fact, ⅜ in. of camber came out actually during cooling. In all cases referred to, the castings were straight when cold, and no signs of twisting were ob-

served on rough machining. Also, the castings referred to were in the shops over a year before despatch, and often over 7 months before commencing to assemble the machine with the present rate of production in the foundry.

Mr. Ballantine (Branch-President) congratulated Mr. Buchanan on the excellent Paper he had submitted, and expressed the most sincere thanks and appreciation of the members. Referring to the model lathe-bed pattern, he remarked the design of the cross webs seemed to him to be poor.

Mr. Buchanan said that triangular-shaped cores were more troublesome than square cores, but there was no doubt of the marked superiority of the diagonal design, and the extra trouble in making was in the end amply justified. He concluded by saying that he was indebted to John Lang & Son for permission to put this Paper before them.

Scottish Branch

Falkirk Section

Paper No. 703

Production of Castings from Shell Patterns

By JOHN CAMERON, Junior (Associate Member)

It is only proper, for anyone setting out to present a Paper such as this, to define the scope of his remarks, even if it is only to prevent him from straying too far from the immediate subject of the production of castings from shell patterns to the larger subject of the production of castings in general. Thus, by "shell patterns" is meant any patterns which leave their own cores, or, alternatively, a pattern which does not incorporate the use of cores made from a separate corebox.

For the actual production of castings, exactly the same plant is required as for other types of moulding, namely, sand, a moulding box and a pattern whose outer surface is a facsimile of the object to be produced, and whose inner surface forms the shape of the core. In a centre such as Falkirk, which is very closely associated with the pipe trade, the majority of soil and rainwater pipe connections will all be made from shell patterns, and it will be realised that the skill of the individual moulder is the deciding factor where the moulding principle is so well-known.

Sand

Sand is a material which up to a few years ago was taken almost entirely for granted. If a certain fault started in the casting, such as scabbing, a certain empirical remedy was applied, and by a system of trial and error the trouble was eventually removed. Now, however, we are in a much more happy position regarding the sand. A regular series of tests typified by Table I has been developed. These can be simply and effectively used in any foundry, and cover green strength, dry strength, permeability, grain size and moisture, and it is known that if the sand gives certain figures on these tests, then good clean castings, free from scabs, blowholes and misruns, can be reasonably expected. Personal experience shows that a sand conforming to Table I gives very good results for the average run of castings produced at the author's

Fig. 1.—Interceptor Traps made with Shell Patterns.

foundry. The permeability figure is probably higher than that generally found in the Falkirk district, due to the higher average weight of the castings therein produced, and this figure is reflected in the grain-size distribution of the floor sand. The raw sands used are Avenuehead rock sand, Erith loam, and a synthetic sand formed from burnt core sand, bonded with Colbond. The new core sand is a wind-blown sea sand from Irvine, and, provided that reasonable care is exercised to maintain the fines at a certain figure, this sand gives very good results.

Fig. 2.—The Same Principle Applied to Anti-Flooding Ball Valves.

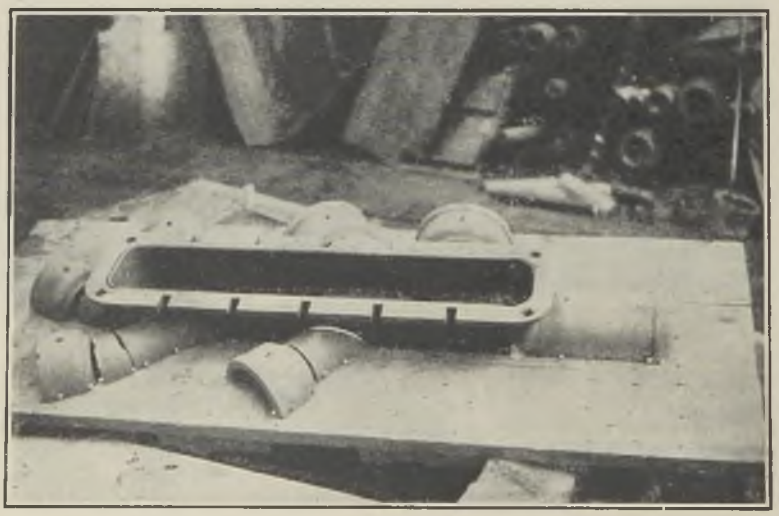


Fig. 3.—A 6-in. Inspection-Pipe Shell Pattern.

Moulding Boxes

The question of moulding boxes for this type of work is very difficult, as a system has arisen in the trade of having a box for each separate

pattern. Where there is little chance of a change in design of the casting, this system has undoubted advantages, as bars may be specially shaped, and everything formed just to fit the pattern and no more, but, unfortunately almost everything changes sooner or later and the boxes have to be scrapped. A personal prejudice is in favour of using simple forms of moulding boxes, carefully thought out as regards length, width and depth, which will cover the entire range of regular lines of castings, and at the same time allow a suitable box to be selected to make that inevitable special, which always just fails to fit a box designed solely for a particular line of castings.

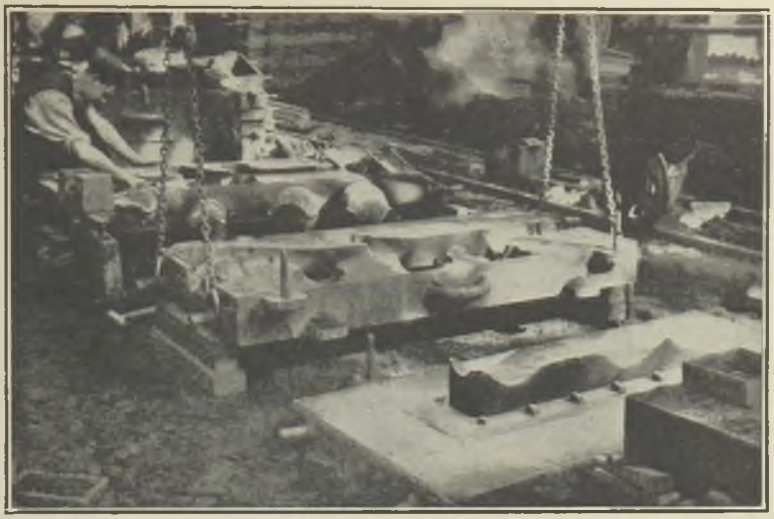


Fig. 4.—Inspection Pipe Moulds ready for Closing.

Fig. 5.—Top Half of the Core for a 4-in. Flanged Bend 8 ft. 6 in. long.

The result of a system of a box per pattern

can be seen in almost every foundry producing light castings, where the box yard generally exceeds the moulding shop in area, and is filled with piles of scrap iron which would be far better in the furnace than slowly rusting away waiting for the day when they may be called on to make half a dozen castings, then returned to the yard.

Shell patterns, owing to the fact that they make or leave their own core, pre-suppose hand moulding, and not only hand moulding but skilled moulding. For this reason the standard of accuracy demanded of a machine pattern is not so essential, and frequently the skilled moulder produces a perfectly shaped casting from what would look to the outsider to be a pile of scrap. This remark does not refer to the castings which it is now proposed to illustrate and describe; they consist mainly of special drain castings which have been supplied in the ordinary course of trade during recent years.

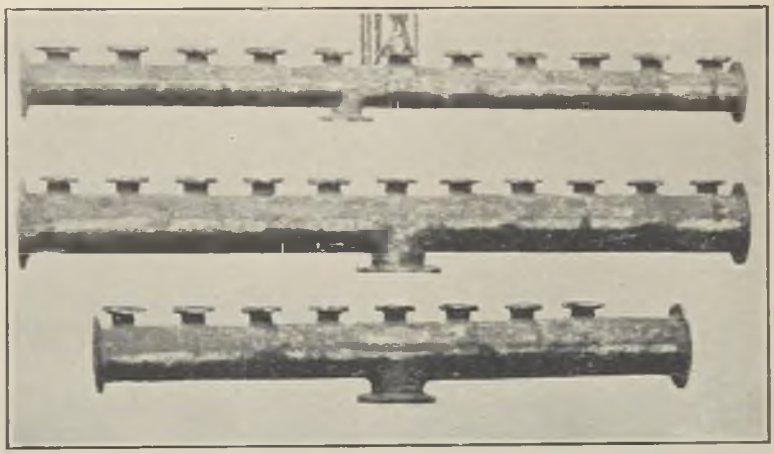


Fig. 6.—Three Flanged Headers made by using Rigid Cast-Iron Corebars.

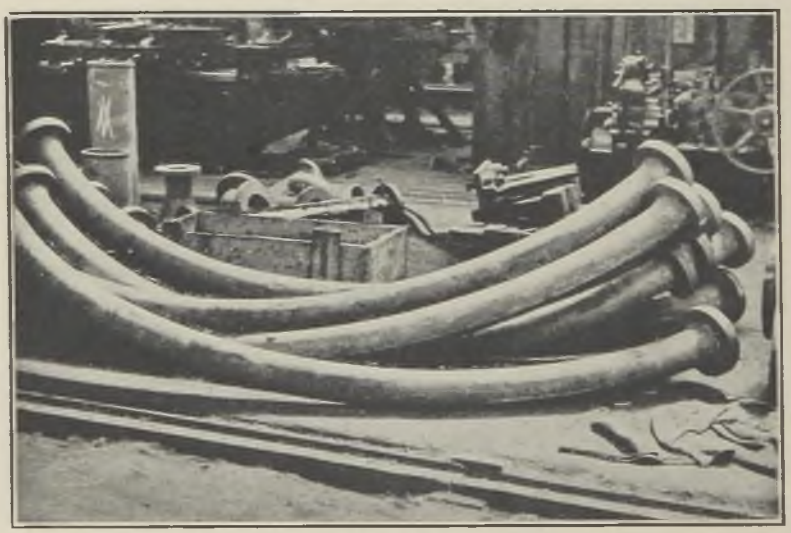


Fig. 7.—Long Flanged Bends made in Meehanite Metal.

Special Drain Castings

Fig. 1 shows a 6-in. interceptor trap with a 6-in. back inlet and a 4-in. reverse clearing arm. This casting is in regular production, and therefore is made from a whole pattern; this pattern can clearly be seen between the two halves of the box, while in the foreground lies the finished core, the whole mould being ready for closing. Fig. 2 illustrates the same features, but this time the subject is a 4-in. anti-flooding ball valve.

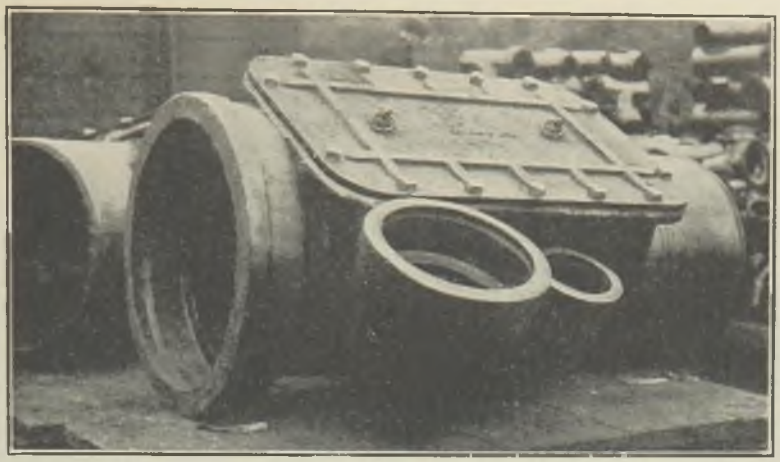


Fig. 8.—An 18-in. Vertical Inspection Pipe for Earls Court Exhibition Drainage System.

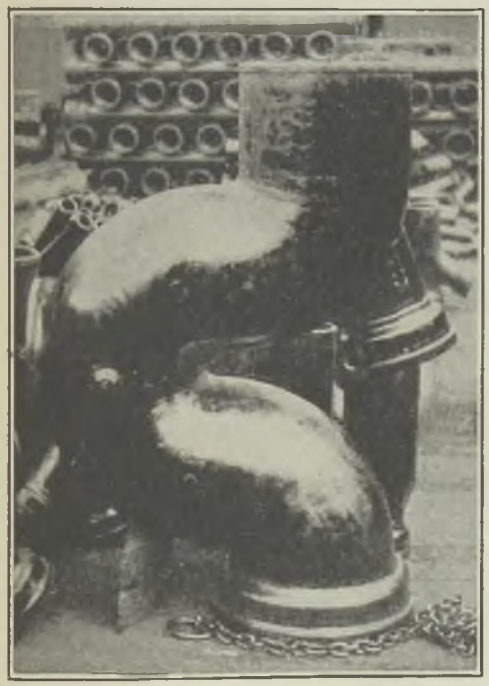


Fig. 9.—An 18-in. Interceptor Trap for Earls Court.

Again, a whole pattern is used, but here, owing to the shape of the casting, balancing arms have to be employed to keep the heel of the core from moving during casting. Reference to the design of core bars will be made later on.

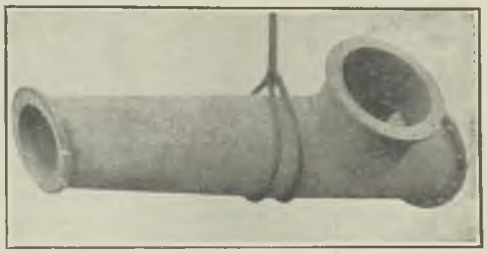


Fig. 10.—A 30-cwt. Green-Sand Casting made from Shell Pattern.

Temporary Patterns

From these two examples of castings produced from permanent shell patterns, the subject passes to examples of types produced from temporary or "pieces" patterns. After seeing a few examples of this type, no one will have any difficulty in understanding the meaning of a "pieces" pattern, and Fig. 3 shows the pieces pattern for a 6-in. inspection pipe. The various pieces are held in position on the board by a few

nails, and this whole pattern probably only took an hour to assemble and fit together. The moulding processes are clearly seen in Fig. 4, which shows the mould ready for closing. Three-part boxes are used for these "one-off" castings; they are usually poured through runners at each end, and use is made of the ubiquitous cotton thread, without which no connection-moulder seems to be happy.

Fig. 5 shows the making of the top half of the core of a 4-in. flanged bend, 8 ft. 6 in. long. These castings are tested usually to 100 lbs. per sq. in., but frequently at much higher pressure, so that it is essential to have the core mathematically concentric with the body. This can be done either by the use of a considerable number of studs or chaplets, thus increasing the risk of leakage in the finished casting, or by eliminating chaplets altogether, using one stud, and designing the corebar to give the maximum rigidity combined with strength.

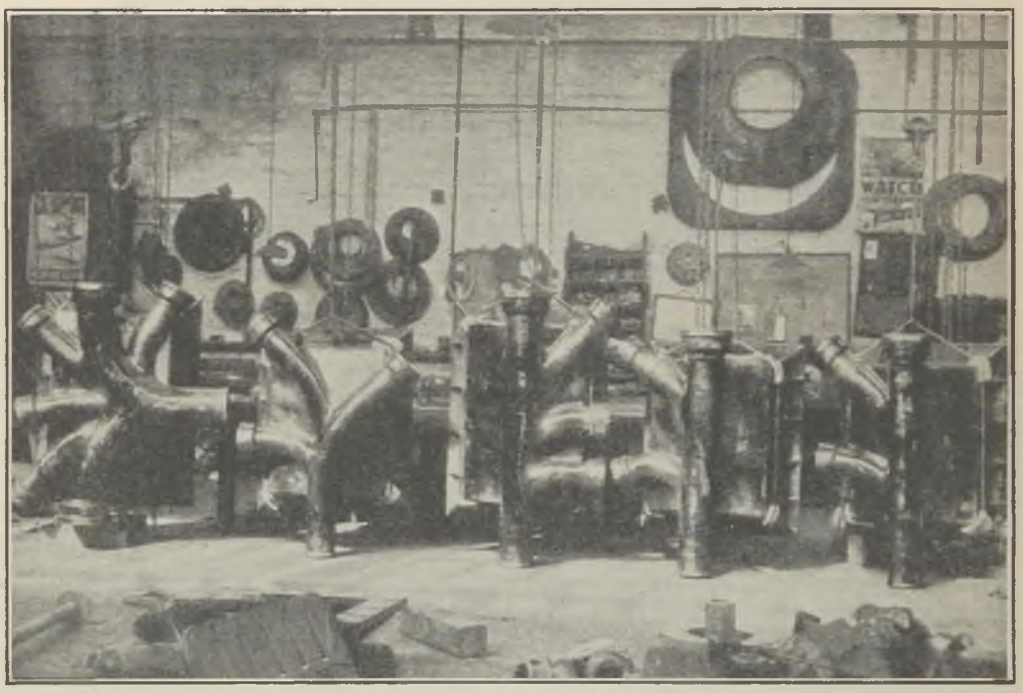


Fig. 11.—Special Manhole Bottoms for the Bank of England.

Cast-Iron Corebars

It is surprising how few moulders realise the valuable physical properties of cast iron, particularly its rigidity, when they are making corebars or grids. A corebar should always be made as deep and as narrow as possible for the centre or main part, and use made of short lateral webs with toes on them for holding the sand both on the top and bottom halves of the core. Such a core iron is a rigid structure and resists bending in a vertical plane. This directly affects the number and strength of the studs required to hold the bar down, and also directly influences the chances of a good casting. A heavy, shallow half-round bar is only a nuisance in a foundry, has a very small degree of rigidity, and frequently weighs twice as much as a bar in which a little care and knowledge of the properties of cast iron have been used during manufacture.

This question of the weight of corebars is especially important to-day, when every founder must keep cost down to a minimum. The reaction, "I can't risk a casting for the sake of saving a few pounds weight in the core iron," is unwarranted. It is suggested, however, that thought be given as to how by skill the strength of the core iron can be increased by a reduction in its weight. In the author's foundry, the yield of castings has slowly increased from 62 to 68 per cent. at present, in spite of a reduction in heavy pipes cast, and it is certain that an appreciable part of this increase is due to the

realisation by the moulders of the fact that a heavy corebar is not necessarily a rigid bar.

Fig. 6 illustrates three flanged headers, part of an order for an oil refinery. The top casting is 8 in. bore by 13 ft. 6 in. long, and has eleven 4-in. flanged branches on one side; the centre casting is 12 in. bore by 13 ft. 6 in., and the bottom casting 12 in. bore by 10 ft. 6 in. long. All these castings were made in green sand, metal ¾ in. thick, rigid corebars were employed and there were no defective castings. The test pressure was 150 lbs. per sq. in., and "pieces" shell patterns were used. All the branches were moulded on the parting, and particular care was taken to relieve the sand at the back of each end flange after casting. The normal contraction on these long castings is 1⅝ in., and if this precaution be not taken, one can expect to find one end flange torn off on opening the box next morning.

Fig. 12.—Close-up of the left-hand Casting in Fig. 11.

It is now proposed to deal with a small flanged connection, which, in addition to having a side branch, has a few bosses and hinge lugs top and bottom. With thoroughly skilled pattern-making there is no limit to features of a special nature which can be added to a "pieces" pattern of this type with the greatest of ease.

Long Flanged Bends

The successful production of long flanged bends such as are shown in Fig. 7 calls for the very highest degree of skill from the moulder. These particular castings are complicated by the fact that they are cast in a high grade of Meehanite metal with a strength of over 21 tons per sq. in., and a phosphorus content under 0.1 per cent. They are subject to working conditions calling for complete absence of leakage at a pressure of 350 lbs. per sq. in. at a temperature of 300 deg. C. Naturally, chaplets or nails have to be reduced to a minimum; in this case only one was used in each casting. The corebar has to be as rigid as possible; this is helped in these castings as they are 5 ft. radius from flange to flange, so the bar comes out without having to be broken. It is also very important to fill these moulds steadily and evenly, and with this end in view eight ingates were provided on the parting; these ingates are fed by two downgates, and care is taken to throttle the metal flow before it enters the mould to avoid high velocities and the risk of sand washes. It must always be remembered in the production of castings, particularly in green sand, that all the iron has to flow down the gate before it enters the mould; consider then, the care with which the mould is finished, often in places where only a few pounds of molten iron may flow, compared with the scant attention often given to the gates which are the medium of conveying several hundredweights of metal from ladle to mould.

Table I.—*Properties of Pipe-Connection Heap Sands.*

Moisture	Per cent.	9.4	8.5
Apparent density	.. ..	1.6	1.57
Green strength ..	Lbs./sq. in.	3.6	4.0
Green permeability	.. ..	39	38
Dry strength ..	Lbs./sq. in.	17.5	25
Dry permeability	.. ..	78	—
Loss on ignition ..	Per cent.	5.5	6.1
Clay	,,	5.0	4.0
Sieve Test.		Per cent.	Per cent.
Left on 30	.. .. ..	4	6
,, 40	.. .. ..	4	4
,, 60	.. .. ..	6	6
,, 90	.. .. ..	36	38
,, 120	.. .. ..	20	20
,, 200	.. .. ..	14	12
Through 200	.. .. ..	16	14
		100	100

Figs. 8 and 9 illustrate two large 18-in. castings supplied for the main-drainage system at the Earls Court Exhibition building in London. Fig. 8 is an 18-in. inspection pipe with a 9-in. and a 6-in. vertical socket branch on the left-hand side. This casting was moulded in green

sand and from a "pieces" pattern in a three-part moulding box. The moulding was complicated by the fact that the sockets of the vertical branches had to be in exact positions relative to the main bore of the chamber, and the patternmaker thus could not just finish them off flush with the flange round the opening; also the sockets had to be correct to British Standard sizes internally and externally. Block cores were used to take out the internal groove on the vertical sockets.

Fig. 9 shows an 18-in. intercepting trap with a 9-in. clearing arm. This casting is nothing like so complex as the previous inspection pipe, but both castings are out of the ordinary as regards size, and for this reason alone very special care was taken during their manufacture.

Fig. 10 shows what is perhaps one of the

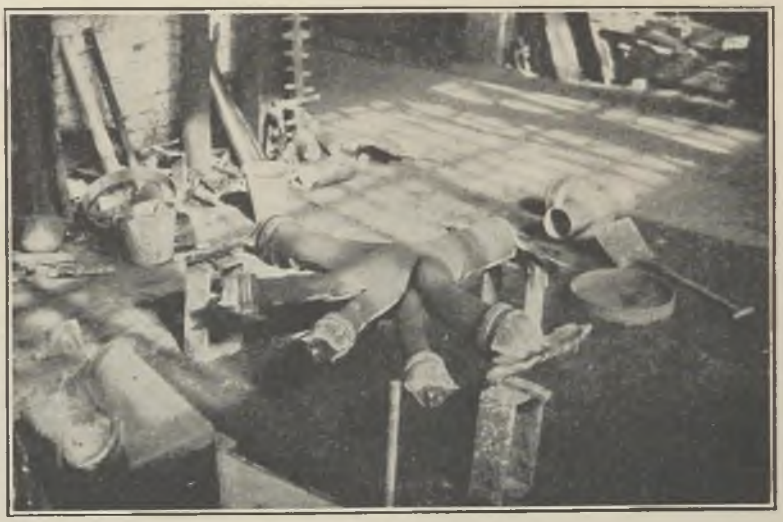


Fig. 13.—Core for Job illustrated in Fig. 12.

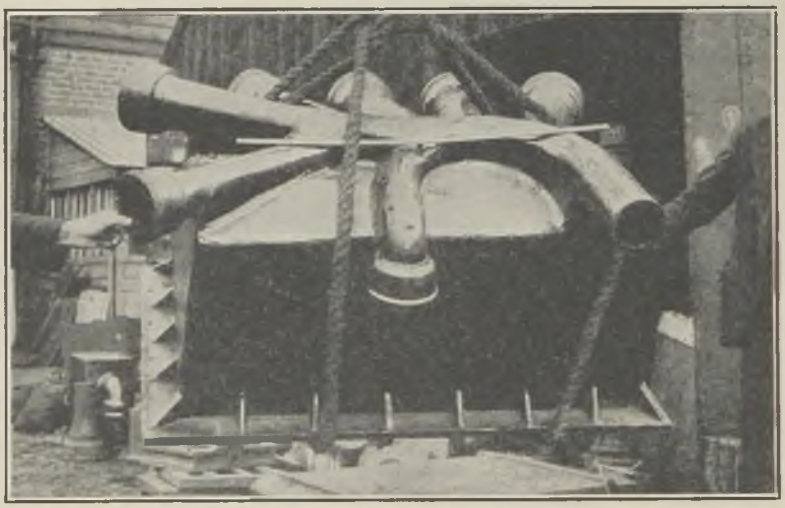


Fig. 14.—Deeper Casting than that in Fig. 12, carrying a Vertical Socket.

largest green-sand pipe castings the author's foundry has produced. It was for a local colliery company and weighed around 30 cwts. The main bore tapers from 24 to 18 in., with a 24-in. branch, and all flanges were to template. It is quite a nice little casting to have produced from a "pieces" shell pattern.

Bank of England Manhole Bottoms

The next few illustrations relate to the moulding of a number of special manhole bottoms which were cast in connection with the rebuilding of the Bank of England head office. Fig. 11

Fig. 15.—Mould Ready for Closing.

shows the inside shape of five of these castings after the top flanges have been machined and the shaped waterways at the bottom of each can just be discerned. The size of these manhole bottoms varied from about 3 ft. 6 in. square by 2 ft. deep to 24 in. by 18 in. by 6 in. deep. With each bottom were cast several eke pieces having simple sockets cast on at definite points to catch drains coming in at higher levels. Some complete units were over 30 ft. deep. Usually the main outlet spigot was 6 in. dia. with several 4-in. branches, but in the smaller units 4 in. dia. was used throughout. The left-hand casting is shown in detail in Fig. 12, and it will at once be observed that only two of the sockets are on the same level. The invert of each 4-in. socket is different, only small on two of them but quite considerable on the others. This casting is quite shallow, but some were much deeper, and the top flange and the flanges of the various ekes had to be machined to bring the sockets accurately to predetermined positions so that the setting of a core in such a casting as this was a most particular and exacting piece of work.

Fig. 13 shows the core just prior to its being put back into the box. The varying levels of the core branches can easily be seen. The core-iron was made by inverting the pattern board on a level sand bed, and establishing the various levels of each branch. These branches were then levelled off and the shape of the bar fingered out inside the pattern impression. Where levels varied, such as in this casting, the lower arms were covered over with strips of paper, and sand heaped on top to resist the fluid pressure while casting the core iron.

Fig. 14 shows another rather deeper casting, with a vertical socket to help to worry the moulder. It will be observed that the varying inverts of the sockets are again present. Exactly the same moulding procedure was followed with this type of vertical socket as with the 18-in. inspection pipe, and a separate block core used to form the groove inside the socket. In Fig. 15 is shown the box ready for the top part being closed on; the core is very clearly shown, but, unfortunately, from the side opposite to the vertical branch. Wooden ekes, such as shown, are often used to give the right depth of the mid-part, but very great care must be exercised when putting on the top part to avoid "off the twist" castings, or, worse still, a crush. No bars can be used in the mid-part when moulding such a casting; instead, in order to hold the sand firmly in place, several holes are drilled on each side and short bars of iron jammed in. The projecting ends of several of these bars are shown in the photograph. Beyond the mid-part can be seen some of the pattern. This illustrates the general construction employed, the main part being built up of wood, with the bottom flange fixed on, and loose iron pieces placed on to form the top part.

Paper No. 704

Principles of Gating and Feeding

By A. M. CAMPBELL (Associate Member)

This is a subject of great controversy, as opinions have been formed and re-formed, and one foundryman's experience has clashed with another's, until one begins to realise that there can be no question of orthodoxy, but rather a question of the sensible application and recording of past experience with different types of castings, due consideration being given to the physical properties of the metal cast.

The practices which are to be described may cause further controversy, but they are examples in cast-iron and non-ferrous alloys which have been found entirely successful in personal experience.

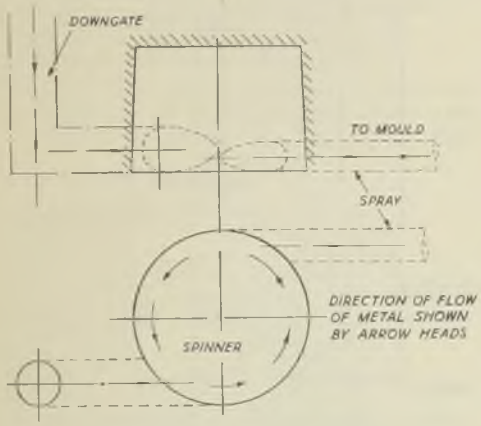


Fig. 1.—Spin Gate.

Fundamentals

First of all, certain fundamentals in gating and rising must be adhered to. These are:—

(1) To decide the type of gate which is best suited and most convenient to use on the type of casting, or kind of metal being considered, *i.e.*, whether drop gate, bottom-poured gate, or a combination of both.

(2) The correct size and shape is of next importance, as they govern the speed of filling; consideration should be given to the relation between the cross-sectional area of the main gate and the sprays taken from it. Personal experience suggests that the main gate cross-sectional area should be 50 per cent. greater than the total cross-sectional area of the sprays taken from it, this extra allowance being made to take care of any flash which may form.

(3) In order to ensure clean metal entering the mould, the use of dirt or slag traps may be necessary. There are several different forms of these traps.

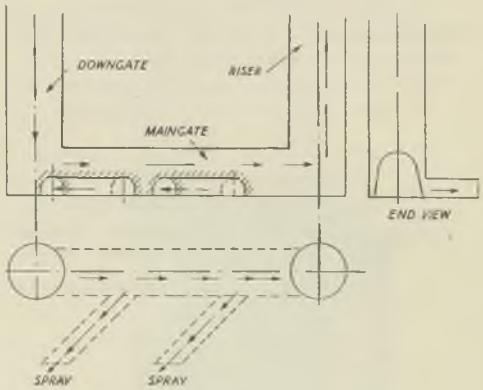


Fig. 2.—Bypass Gate.

Cross-sectional area of Downgate is 50 per cent. greater than Maingate, and total cross-sectional area of sprays is 50 per cent. less than Maingate.

Types of Gates

Fig. 1 shows the spin gate, so constructed that the metal from the downgate swirls in the spinner and the motion given to the metal causes the dirt to rise to its centre, allowing a clean stream of metal to pass to the spray. Fig. 2 shows the bypass gate, in which type of gate a riser is connected to the downgate by a channel from which the sprays are cut at a tangent. The flow of metal from the sprays is against the flow of metal in the downgate, which is an important factor. In the direct trap gate shown in Fig. 3, a dummy riser is placed between downgate and spray for the retention of any dirt in the metal. The dirt can only be retained if the relation be-

tween the downgate and spray is correctly proportioned.

(4) In feeding, the first consideration is the

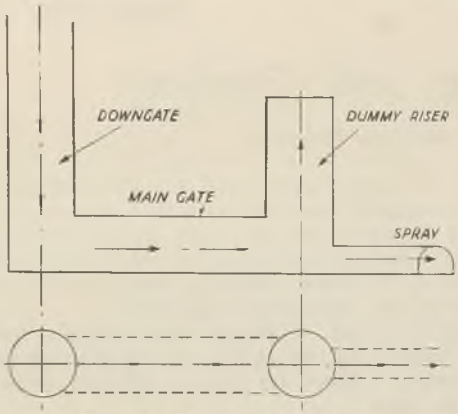


FIG. 3.—DIRECT TRAP GATE.

Cross-sectional area of Downgate is 50 per cent. greater than Maingate, and total cross-sectional area of sprays is 50 per cent. less than Maingate.

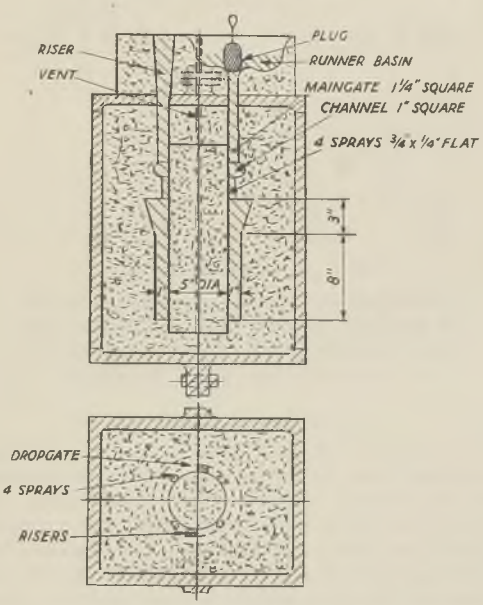


FIG. 4.—TYPICAL DROP GATE FOR SMALL WORK.

kind of metal to be cast, on account of the variation in liquid shrinkage of different metals. For example, in cast iron the shrinkage is considerably less than in steel, high tensile bronze or Monel. One should bear in mind that all castings must be considered from the angle of the heavy section which will be formed, and adequate risers located at places found by experience as suitable for avoiding shrinkage cavities. Of course, these parts may sometimes be too inaccessible for risers to be taken from them, and in such cases chills or denseners must be used. Finally, the casting temperature plays an important part from a feeding point of view, but this depends to a greater or lesser extent on the kind of metal cast.

Application to Cast Iron

Fig. 4 gives an example of the successful method employed for the running and feeding of a 5-in. diameter cored liner. This is an example

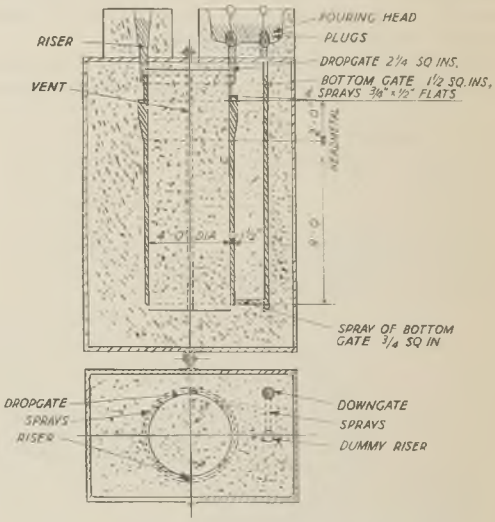


FIG. 5.—TYPICAL USE OF COMBINED DROP AND BOTTOM POUR GATES.

of the drop gate which is properly balanced. On this length of liner a 3-in. head is employed to overcome shrinkage, and also to receive any dirt which may have found its way into the mould. Note, however, the safety precaution of plugging the main gate in the pouring head, which is first filled with metal before the plug is removed. If this pouring head is maintained full, all dirt should be trapped on the surface of the metal. The drop gate is so arranged that metal on entering the main gate is diverted by means of a channel cut in the circumference of the top print, thence through the communicating sprays to drop perpendicularly into the mould.

Fig. 5 illustrates the gating of a large liner using a combination of the drop and bottom

gates. The drop gate, being the same as in the example of the small liner, needs no further explanation. The additional gate, however, is

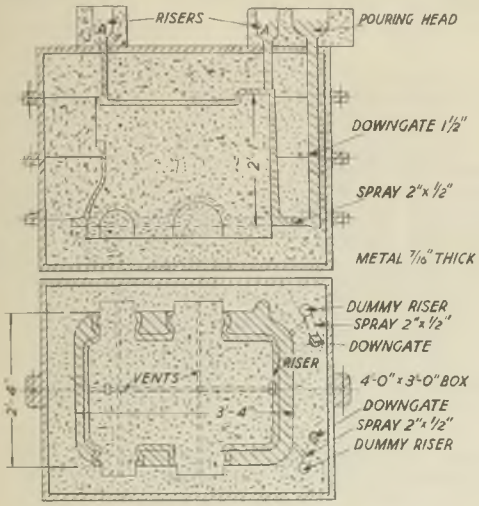


Fig. 6.—Balance of Gates. There are 2 Sprays of 2 sq. in. total area and 2 Downgates of 3 sq. in. total area.

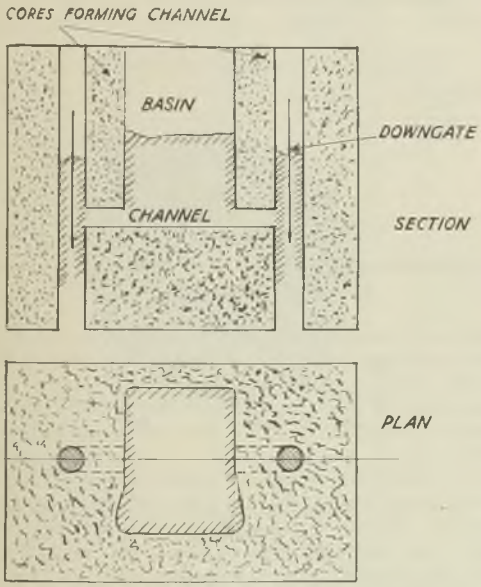


Fig. 7.—Section and Plan showing Formation of Skimmed Runner Box.

bottom run and formed on the by-pass principle. It is a medium whereby a small amount of metal is admitted to the mould by plugging the drop gates as shown, forming a cushion on which to receive the bulk of metal admitted by the series of sprays. This cushion effect protects the bottom of the mould from the shock it would receive if the bottom gate were omitted. In moulds of abnormal depth, the use of the combined drop and bottom gate is good practice.

Fig. 6 shows the use of the bottom gate with dirt trap and skimmed pouring head as applied to a gearcase. Two downgates both run from the one pouring head, a single spray being taken from each and run to the bottom flange, thus ensuring quick covering of lowest part of mould and reducing the likelihood of scabbing to a minimum. Risers as shown in Fig. 6 are suitably placed for feeding purposes.

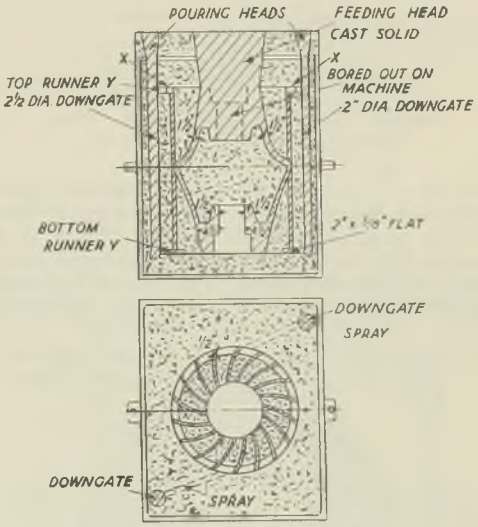


Fig. 8.—Large Pump Rotor.

The skimmed pouring head, as shown in Fig. 7, is constructed by using cores grooved to form a communicating channel between the downgate and the basin. These cores are rammed in position. The head box is then stoved and dried with the mould and placed in position prior to casting. The head is kept well filled and only clean metal can enter the downgate. The trap provided at bottom runner takes care of any dirt which may possibly enter the downgate at the commencement of pouring.

Application to Monel Metal

Monel Metal is an alloy of 65 per cent. nickel, 32 per cent. copper, 0.5 to 1.0 per cent. manganese, and 0.5 to 3.0 per cent. silicon. Care must be taken in casting this material on account of its high liquid shrinkage and high pouring tem-

perature (1,560 deg. C.). In practice the production of castings is more or less similar to steel. The sand for cores and moulds must be highly refractory and ample feeding heads

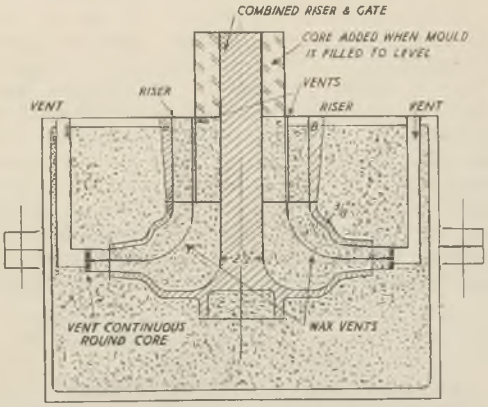


FIG. 9.—MOULD FOR 14-IN. DIA. EXTRACTION PUMP IMPELLER.

allowed to overcome shrinkage troubles. Gates and risers require careful consideration, as every casting is a problem in itself. There is no general rule to be followed for gates and risers, but the high contraction ($\frac{1}{4}$ in. per ft.) must be taken into account. Sprays are made pro-

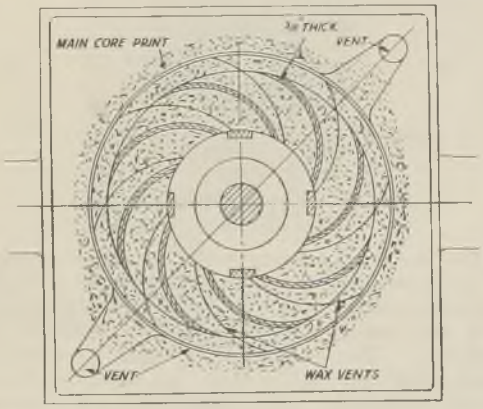


FIG. 10.—PLAN OF PUMP-IMPELLER MOULD SHOWN IN FIG. 9.

portionately greater than those used for similar castings in cast iron, this proportion being in the region of 50 per cent.

The method of feeding and gating a large pump rotor in Monel Metal, shown in Fig. 8, was adopted after some unsuccessful attempts had been made using a drop gate on the boss in centre of mould. The centre boss is about $1\frac{1}{2}$ in. thick, and the hubs at top and bottom about $4\frac{1}{2}$ in. thick. To these 18 blades of $\frac{1}{2}$-in. section are attached and shaped as shown in plan.

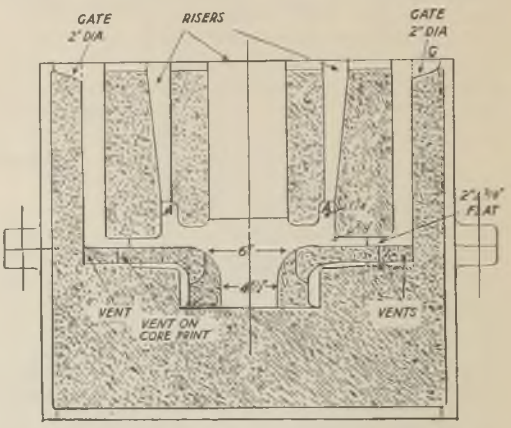


FIG. 11.—SECTION OF MOULD FOR FEED PUMP IMPELLER.

There are two stay ribs about $1\frac{1}{2}$ in. by $\frac{1}{2}$ in. at the top and bottom of the blades as shown at XX.

The varying thickness of metal caused unequal balance of cooling, which was further aggra-

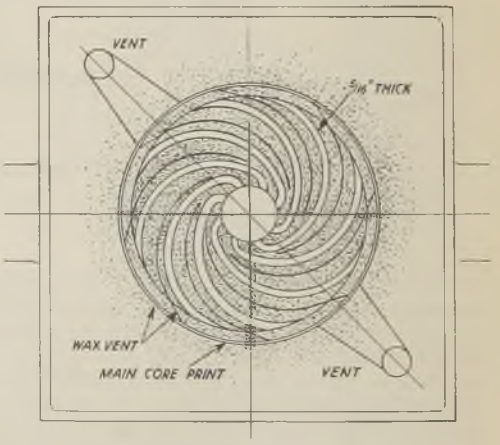


FIG. 12.—PLAN OF MOULD FOR FEED-PUMP IMPELLER.

vated by the position of gate; for example, when cast in the hub, the casting cracked due to uneven cooling on contraction. To overcome this defect, top and bottom running at the stay ribs, *i.e.*, at YY was used; this more even heat distribution overcame the unequal heat balance. The riser provided for feeding is of the same

diameter as the boss on the casting. The riser is cut off before machining.

On every Monel casting a patent refractory (black in colour) is used to cover all feeding heads after casting. This refractory helps to keep the feeding head liquid, thus preventing the formation of shrinkage cavities.

Figs. 9 and 10 show the section and plan of a turbine extraction pump impeller mould. This impeller is fairly uniform in section, the eight blades being $\frac{3}{8}$ in. thick. The top and bottom shrouds are also $\frac{3}{8}$ in. thick. The heaviest section is the centre boss, which is $2\frac{1}{2}$ in. thick. As this casting is machined all over, great care has to be taken in arranging gates and risers,

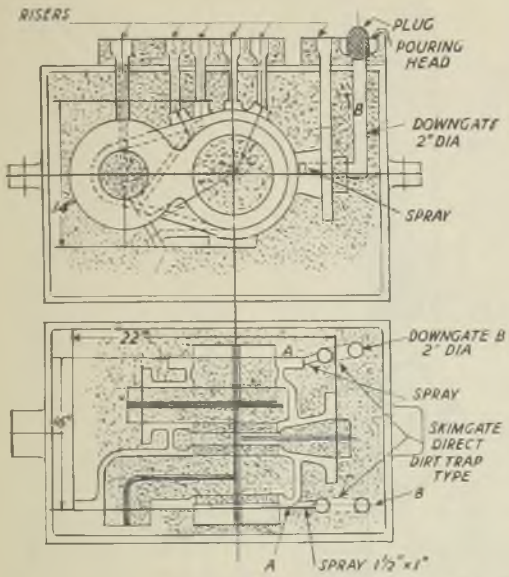


Fig. 13.—Mould for Valve Body with $\frac{7}{16}$-in. Metal Section.

and providing ample vents to ensure soundness. However, this example is straightforward and is typical of normal production with Monel Metal. A combined gate and riser is used down the centre of the boss. This arrangement is used for two reasons: (1) because it is the point which gives quickest access to all parts of the mould, including the blades, and thus is ideally located for gating, and (2) it is the heaviest section of the casting, and thus the part most requiring adequate feeding. Risers are also taken from top of packing ring diameter for feeding purposes as shown at BB.

Turbine Feed Pump Impeller

Figs. 11 and 12 show an example of another type of impeller to be cast in Monel Metal. In this case the centre boss is about $4\frac{1}{2}$ in. diameter spreading out to 6 in. diameter where it joins the shroud. There is a further thickness of metal attached to this shroud for the packing

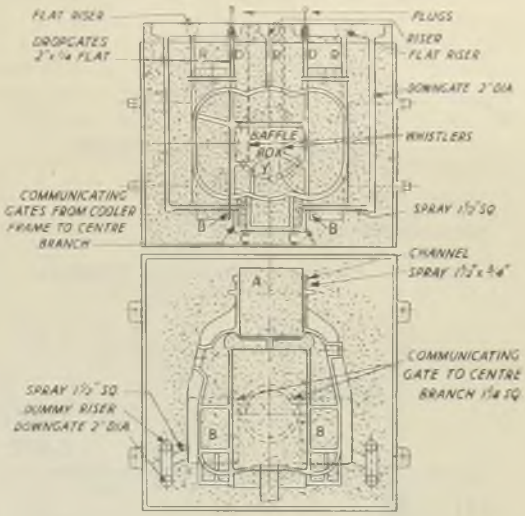


Fig. 14.—Mould for De-aerator Casting, in 8-ft. Square Box.

ring as shown at AA in the sectional view (Fig. 11). The blades of this impeller are only $\frac{5}{16}$ in. thick, while the shroud is $\frac{5}{8}$ in. and the packing ring $1\frac{1}{4}$ in. thick. There is an extremely heavy section of metal at the boss.

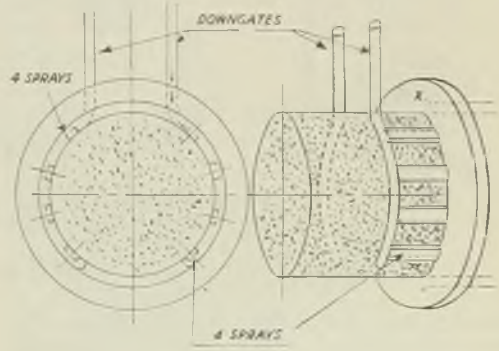


Fig. 15.—Arrangement of Sprays for De-aerator Casting.

If cast in the normal way as shown in the previous example of the extraction pump impeller (Fig. 9), shrinkage would occur at this heavy section. In order to overcome this the method of moulding was reversed so as to obtain risers over the centre boss and from the packing

ring, as shown. Further, to avoid cracking and to give a more even heat distribution, two side gates cut at the parting were used; this arrangement gives direct access to all the blades, and has been found to be the most successful method of casting this type of impeller. Two hand ladles are required to cast these impellers at points GG (Fig. 11). The sprays used are of rectangular section 2 in. by $\frac{3}{8}$ in., while the downgate is 2 in. diameter.

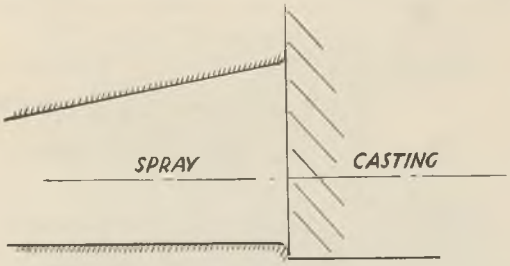


Fig. 16.—Shape of Sprays for Gunmetal.

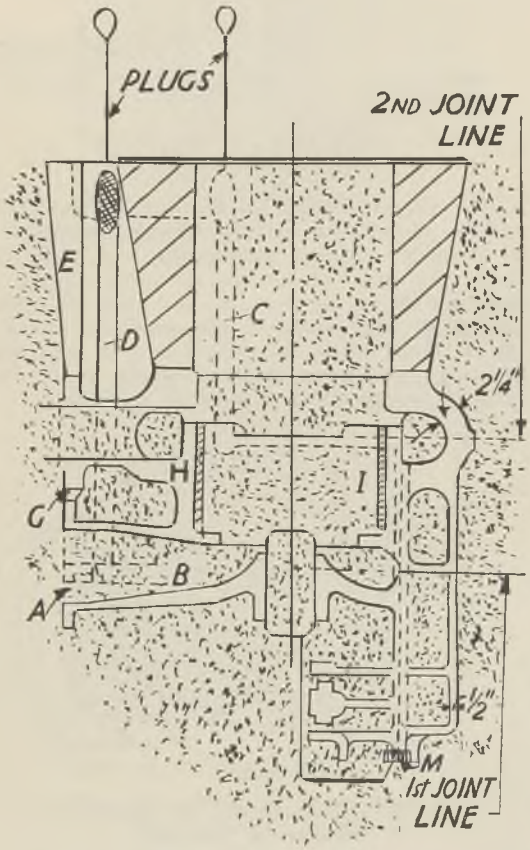


Fig. 17.—Mould for High-Tensile Bronze Pump Casing.

Gunmetal

The examples given under this heading were cast in Admiralty gunmetal of the following approximate composition:—Copper, 88; tin, 9.5 to 10; zinc, 1.8 to 2; and lead, 0.5 per cent. max. In dealing with the gating and feeding of this alloy, the main points for attention are:—(1) The sprays should be larger in area generally than required for cast iron; and (2) while risers are necessary to deal with liquid shrinkage in some cases, feeding is more or less regulated by the casting temperature.

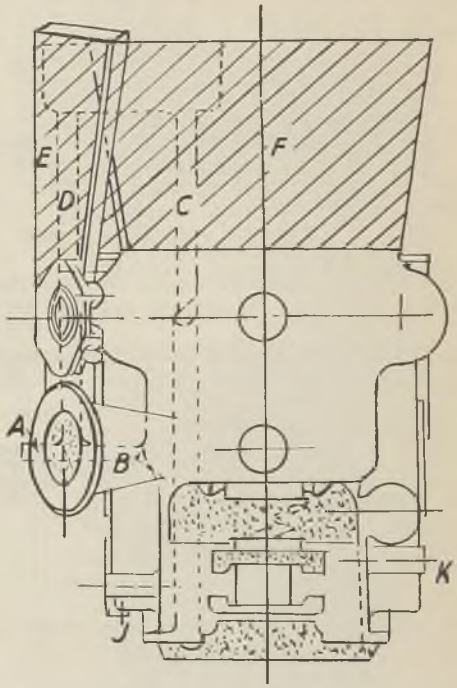


Fig. 18.—Representation of Pump-Casing Casting.

There has been ample evidence of shrinkage cavities due to too low a casting temperature. There is a wide divergence of opinion as to the correct casting temperature, due possibly to the fact that various authors have in mind different kinds of castings and different foundry conditions. In the examples given the casting temperature range of the metal was 1,180 to 1,220 deg. C. This temperature range has been found most satisfactory for the author's type of work.

Gunmetal Valve Body

Fig. 13 shows the section and plan of a valve body, fairly uniform in section. The manner in which this body is gated will serve to illustrate a clean and successful method which is typical of normal production in gunmetal and can with modifications be applied to numerous types of castings. As shown in Fig. 13, the metal enters the mould through flanges AA by two in-gates BB of the direct dirt-trap type, correctly proportioned, ensuring a flow of clean metal to the mould. Risers taken from the casting at the points shown overcome liquid shrinkage, feeding being governed by correct casting temperature.

Gunmetal De-Aerator

Fig. 14 is a plan and section of a mould for a large gunmetal de-aerator casting weighing approximately 2 tons, and of $\frac{7}{16}$ in. average thickness. On account of its size and section, the gating had to be considered very carefully, more particularly since internally the casting had a baffle box attached by ribs to the external contours of the casting. Arrangements had to be made to get the hot metal to this box as well as provision for casting the outside contours. The following arrangement was found to give satisfaction by avoiding a mis-run. Provision was made for casting with two ladles, one on either end of the mould. At A, Fig. 14, on the main core print, two channels were cut and each was fed by a main gate. Eight sprays were taken off these channels and entered the mould at flange X (Fig. 15).

These main gates were $2\frac{1}{2}$ in. diameter, while the sprays were $1\frac{1}{2}$ in. by $\frac{3}{4}$ in. At BB (Fig. 14), at the other end of the mould, and entering stools at the bottom of the mould, a further two main gates were placed, each having a spray which entered the stool at the flange. These gates were 2 in. diameter, while the sprays taken off

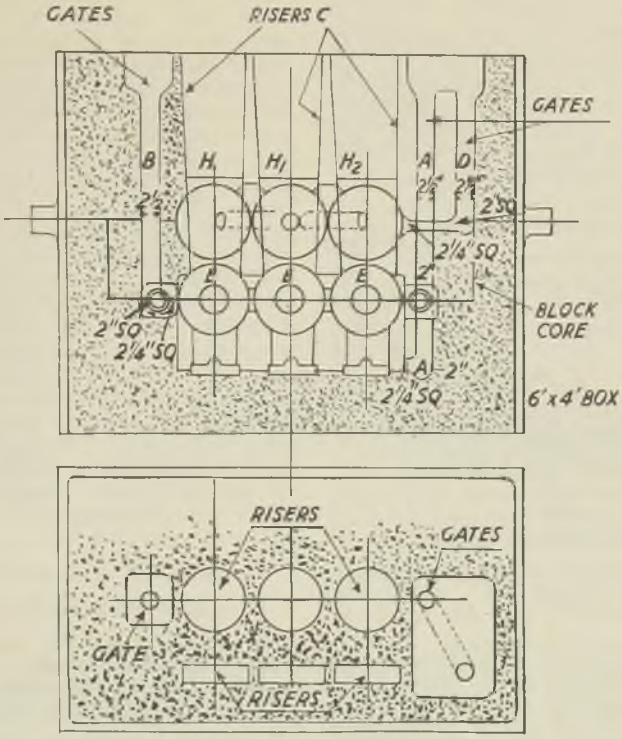


Fig. 19 (bottom).—Top Box Plan of Mould for High-Pressure Pump.

Fig. 20 (top).—Mid-Section of Mould.

were $1\frac{1}{2}$ in. square. Note arrangement of by-passing the metal to a dummy riser in order to ensure cleanliness.

This arrangement did not succeed in getting the metal to the bottom of the mould, and it would have risen in the mould about 1 ft., and then tumbled back into the cooler branch, which is at the bottom of the mould, and might have caused cold shut. To avoid this the stool flange nearest this branch was connected by two sprays, as shown at CC, Fig. 14. These sprays were $1\frac{1}{4}$ in. sq. By this arrangement, immediately the stool flange became full of metal, it was by-passed to the bottom of the mould. Finally, on top side of the mould four drop gates were used at DD, as shown in Fig. 14. These were so arranged to pass down the metal thickness of the top stools, which, in turn, was connected by ribs to the baffle box internally.

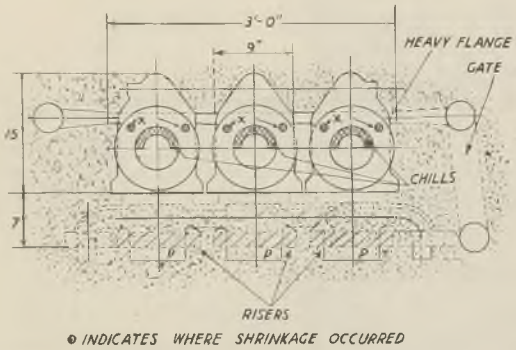


Fig. 21.—Plan-Section of Mould for Pump Casting.

On casting, these gates were plugged, and gates at A and B started first. When it was judged that the metal had risen in the interior of the mould to the bottom side of the baffle box, *i.e.*, at Y (Fig. 14), these plugs were removed and hot metal allowed to drop on to the rising metal. These gates were 2 in. by $\frac{1}{4}$ in. Risers were taken off as shown at positions R, R, R, and whistlers, as shown by arrows in Fig. 14, in the box core to assist in eliminating any chance of an air lock in that portion of the casting.

High-Tensile Bronze

The alloys from which examples are given under this heading are made up approximately as follow:—Copper, 54 per cent.; zinc, 40 per cent.; iron, 1.7 per cent.; aluminium, 2 per cent.; and manganese, 2.8 per cent. The tensile strengths in the as-cast condition are in the region of 38 to 42 tons per sq. in., with an elongation of 20 to 28 per cent. This alloy has an extremely high liquid shrinkage, and on this account heavy risers or feeding heads are required. Gating has to be such that as little turbulence as possible occurs when casting. This turbulence causes the formation of zinc oxide which, like sand, is highly refractory, and forms an inclusion to the detriment of the casting. Sprays, therefore, must be situated at the lowest point of the casting and shaped as is shown in Fig. 16 to obviate "fountain" effect. Casting temperature is also important for the same

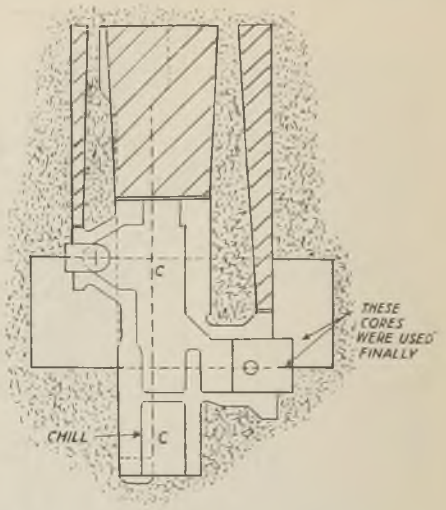


Fig. 22.—Cross-Section of Mould for Pump Casting.

reason as with gunmetal. The most satisfactory casting temperature range for this metal, in the author's experience, is 980 to 1,020 deg. C.

High-Tensile Pump Casing

Fig. 17 shows a section through the assembled mould and cores of a turbine pump casing in high-tensile bronze. This pump has an oil box with bearing attached to the main pump body. The average section is about $\frac{1}{2}$ in., while the pump itself varies from 2-in. to $3\frac{1}{2}$-in. section. On account of the high shrinkage of the metal the pattern was made so that the heavy pump sections were on the uppermost portion of the mould. The oil box was arranged at the bottom.

A gate C was formed as shown in Fig. 17 (section of mould) and Fig. 18 (view of finished casting) and stepped down gradually from the second to the first parting, finally to enter the mould by a spray at the flange in the bottom

of the oil box at M. This gate was 2 in. in diameter. After stepping down the first parting it was reduced to $1\frac{1}{4}$ in. diameter, while the spray was 2 in. by 1 in., opening out to $2\frac{3}{4}$ in. by $1\frac{1}{4}$ in. A further gate D was stepped down through the second parting to the first and finally two sprays were taken at a tangent to the lower portion of the pump body, as shown at A and B, Fig. 18. This gate was $2\frac{1}{2}$ in. diameter to second parting, then stepped down to $2\frac{1}{4}$ in. diameter, with two sprays 2 in. by 1 in., increasing to $2\frac{3}{4}$ in. by $1\frac{1}{4}$ in.

The total depth of casting was about 3 ft. 6 in., and a head of 2 ft. was found necessary, as shown at F in Fig. 18. In addition, a riser was taken from the discharge branch as shown at E. This branch was, in turn, connected to the suction branch immediately below, as shown at G. This overcomes the high shrinkage which occurs after casting. When casting, both main gates were plugged until the runner head was filled. While still pouring, the plug on the downgate C was withdrawn and the metal allowed to rise in the mould to the first parting. When this was judged to be the position, the second plug for gate D, Fig. 18, was withdrawn and metal allowed to enter sprays A and B, and casting was continued until the head was filled. About 2 tons 10 cwts. of metal was required to cast this pump—35 cwts. for the pump and 15 cwts. for head and risers. The gates were stepped as described in order to have as little turbulence as possible. In addition to the feeding heads described, denseners (or chills) were necessary to overcome shrinkage at points H and I, Fig. 17, and J and K, Fig. 18.

Three-Throw Pump and Valve Box

Figs. 19 to 22 show the top box plan, mid-section, plan-section, and cross-section of a three-throw pump and valve box which was cast in high-tensile bronze. Originally, this casting was made with cores, as shown in Fig. 21, directly through the cylinder and valve with chills as marked at the heavy flange side of the cylinder, to overcome the shrinkage which occurred at the junction of the metal between this flange and the cylinders, *i.e.*, X, X, X.

One gate was stepped down to the bottom of this heavy flange, as shown at A, Fig. 20. This gate was $2\frac{1}{2}$ in. diameter, and stepped down at parting to 2 in. diameter with a spray in flange 2 in. square opening to $2\frac{1}{4}$ in. square. A second gate B was stepped down to the top end but at the opposite side of this heavy flange, and was also $2\frac{1}{2}$ in. diameter, with 2-in. square sprays opening to $2\frac{1}{4}$ in. square. A third gate D was taken to the parting, thence direct to the valve box flange, and this was also $2\frac{1}{2}$ in. diameter, with 2-in. square sprays opening to $2\frac{1}{4}$ in. square. Risers were taken off flanges E, E, E, whilst the valve box and main heads were taken from top of cylinder, *i.e.*, H, H, H (Fig. 20).

Originally the section varied from $\frac{1}{2}$ in. to $2\frac{3}{4}$ in. at the junction of the cylinders and heavy flange at the bottom of casting as cast. When the casting was made by means of centre cores, Fig. 21, and chilled as previously described, trouble was experienced with shrinkage at points X, X, X all down the junction of the cylinder and the heavy flange. To overcome this, these centre cores were finally removed and the casting made solid, with the exception of the pipe connection core as shown at P, P, P. By so doing the shrinkage trouble was overcome and successful castings were obtained which withstood 2,500 lbs. per sq. in. water pressure. This casting finally required 3 tons of metal to cast, care being taken that the temperature was in the region of 1,000 deg. C.

In conclusion, the author desires to thank the directors and foundry management of G. & J. Weir, Limited, for affording him the facilities to produce and publish this Paper, and also to Mr. Fred Howell for his help in preparing the sketches for reproduction.

DISCUSSION

The Chairman (Mr. Evan J. Ross) said that they would realise why Mr. Campbell had been awarded the John Surtees Gold Medal for his Paper. He had dealt clearly with all the theories of gates and risers and the applications to practical work. He was to be congratulated on the Paper and on the manner of its presentation.

Mr. J. Longden said the author had tried to correlate all theories to principles. They often heard statements of practice without reference to principles. Nearly all the illustrations were of special types of castings, and many particularly concerned non-ferrous work. These examples were exceedingly useful. In reference to cast iron the author had stressed the value of the trap gate, but the speaker doubted whether it was advisable in all applications. There was one principle with which he agreed in regard to the relative gate area, *i.e.*, the ingate should be 50 to 75 per cent. of the downgate area. He thought, however, that in green-sand work there would be too great a cutting action where the metal impinged on the mould. Mr. Campbell had very properly drawn attention to the necessity, in non-ferrous work, to arrange for the opening of the gate to avoid turbulence. Mr. Longden had been very interested in the remarks on making runners and the method of by-passing

runners, but he noticed in some of the illustrations that the ingates were cut from the runner at a very awkward angle to the casting. In one case the ingate gave the metal impact on the opposite side of the flange; but probably that was a mistake in drawing.

The Chairman said that he had had Mr. Campbell's experience in regard to the light castings industry, where it was paramount to get clean castings. He sketched several types of runner which he had used with success. He agreed with the author that the downgate must be greater in area than the runner.

Mr. Campbell thanked Mr. Longden for his kindly criticism, which was what he wanted. He himself was only a very young member; it was somewhat of an ordeal to read the Paper, and little did he realise that he could speak to the old and experienced members on such a subject.

The Chairman said that the members had been delighted with the Paper.

West Riding of Yorkshire Branch

Paper No. 705

Alloy Cast Iron

By H. A. MacCOLL, B.Sc. (Member)

Recent years have seen the development of cast irons whose properties, mechanical and physical, show a remarkable improvement on those of the pre-war and early post-war period. Turner's "Lectures on Iron Founding," published in 1911, contains the following statement:—"The tensile strength of cast iron usually varies from about 4 to 16 tons per sq. in.: the average for common iron is about 7 tons, and for selected brands about 11 tons." As late as 1925 Thompson[1] cited the figures given in Table I.

TABLE I.—*Strength of Cast Iron.* (Thompson.)

Properties.	Bad.	Average.	Very good.
Tensile strength. Tons per sq. in.	5	10	15
Crushing strength ,, ,, ,,	30	40	50
Transverse strength. Cwts., on section 1 in. broad and 2 in. deep at 3-ft. centres	18	28	38

The latest B.S.I. specification, B.S.S. No. 786, however, gives the figures in Table II. These figures have been adopted as representative of:—*Grade* 1.—High-quality engineering iron, made by ordinary processes, possibly including the use of steel and refined pig-irons. *Grade* 2.—The highest grade of engineering iron produced as above, but including alloy additions. *Grade* 3.—Irons made by special processes such as superheating or inoculation.

TABLE II.—*Tensile Requirements for High-Duty Cast Iron. B.S. Specification* 786.
(Tons per sq. in.)

Bar.	Grade 1.	Grade 2.	Grade 3.
0.875 in.	15	18	22
1.2 in.	14	17	20
1.6 ,, ...	13	16	19
2.1 ,, ...	12.5	15	18

Consideration of these figures illustrates the extraordinary progress of the last few years, particularly when the fact is borne in mind that the figures in the specification do not, of course, represent the maxima obtainable.

Cast iron is, and always has been, a popular material with the engineer; but, whereas in the past such popularity was due to the low cost, easy casting properties, and machinability of cast iron, to-day it is a material which merits notice by virtue of its mechanical properties, whilst retaining its other attributes.

In the past cast iron has been criticised, admittedly with a certain measure of justification, as an unreliable material. Such criticism has been associated with the well-known fact that cast iron is affected, more than any other material, by differences of section. The chart[2] shown in Fig. 1 is an attempt to convey some idea of the tensile strength to be expected in different section sizes from plain unalloyed irons. The shaded zone illustrates the effects of varying cupola practice and the character of the charge, lower silicon irons following the top curve and softer irons the lower curve. It should be noted that the two classes of iron approximate to the same strength in the light sections, but differ considerably as the thickness increases.

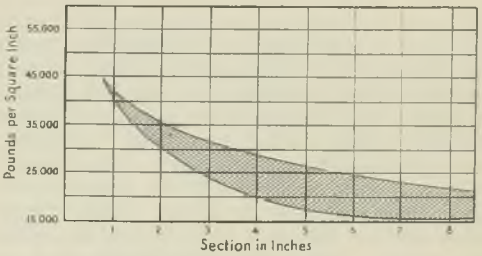


FIG. 1.—EFFECT OF SECTION SIZE ON TENSILE STRENGTH OF GREY IRON. (CLIMAX MOLYBDENUM CORP.)

From the engineer's point of view, such a state of affairs is highly undesirable, and test-bars are of little consolation, because even if one casts a series of test-bars of varying section, the rate of cooling of the test-bar may bear little relation to the cooling rate in the corresponding section of the casting, and it must be remembered that it is the rate of cooling which determines the structure, and hence the mechanical properties. In consequence, as the requirements of the engineer have become more stringent, he has turned his attention to other

materials such as steel, and, more important from the founder's standpoint, he has, in many cases, abandoned castings in favour of built-up and welded parts. There is little doubt that the sudden realisation that cast iron, hitherto unchallenged for general engineering construction, was in danger of being superseded for high-duty work, contributed in no small measure to the almost feverish research activity of the last few years.

In order to appreciate the development of alloy cast irons, it is necessary to have some conception of the problems which confronted the ironfounder. Cast iron is a complex material containing a variety of individual constituents, each possessing its own specific properties; hence, if the changes induced by the addition of alloying elements are to be understood, a knowledge of the primary constituents and their characteristics is essential, and the section of the Paper which follows is included in the hope that it will clarify the later portions for the non-metallurgist.

Constituents of Cast Iron

Experience shows that the majority of cast irons contain four main constituents, namely, graphite, ferrite, pearlite and phosphide eutectic, the last three constituting a metallic matrix, interspersed with flakes of the graphite. A fifth constituent is cementite, which only exists in the free state in white irons, or those portions of a grey iron casting which have been subject to rapid cooling, and those become "chilled."

If the microstructure of a grey iron is examined, the graphite will be observed as a series of curved and elongated plates, varying appreciably in size and distribution throughout the sample. Relatively, irons of this type are invariably brittle, not so much because of the brittleness of the graphite itself, but because of the thorough manner in which the continuity of the ductile matrix is destroyed by the graphite particles. The size of the graphite flakes is a function of the rate of cooling, slow cooling tending to give gross flake size, thus weakening thick sections. The distribution is also of the greatest importance, as it has been shown that small flakes, badly distributed, may result in an iron which is weaker than a corresponding iron in which the flakes are larger, but more evenly distributed.

Pearlite

The main constituent of the matrix is pearlite, which is the eutectoid of iron and iron-carbide, and consists of alternate plates of iron, known metallographically as "ferrite," and of iron-carbide, known as "cementite." Some irons show a well-laminated pearlite, but in others the laminations may vary considerably in size. The pearlite in a cast iron is similar to the pearlite of a steel, with the exception that the ferrite component might more aptly be termed silico-ferrite, since it contains silicon in solution, and the percentage of carbon in the pearlite, which is approximately 0.9 per cent. in plain carbon steels, is lowered by the presence of the other elements which in cast iron are present in much larger quantities than in steels.

The strength of a cast iron is due, almost entirely, to the pearlite, which may be taken as having a tensile strength of 50 to 70 tons per sq. in., with an elongation of 15 to 10 per cent., the variation being accounted for by the differing degrees of fineness of the pearlite laminæ. The weakening effect of the graphite flakes will now be apparent if the above figures are compared with those given earlier. In this connection Bardenheuer and Zeyen[3] consider that the strength of a cast iron, whilst influenced to a certain extent by the nature of the matrix, is controlled predominantly by the size and distribution of the graphite flakes.

Ferrite

Ferrite only occurs in the free state in irons of a fairly high silicon content, due to the action of silicon in inhibiting carbide stability, whereby cementite is transferred into its constituents, graphite and ferrite. It consists of "alpha" iron containing silicon in solution, and may be taken as having a tensile strength of about 20 tons per sq. in., with an elongation of 40 per cent. These figures, as in the case of pearlite, will be modified considerably in the presence of graphite.

Phosphide Eutectic

The remaining constituent of normal grey irons is the phosphide eutectic, which is composed of ferrite and iron phosphide. It is a hard, brittle, constituent of negligible tensile strength, and must be considered as a weakening influence in the matrix. With sufficient phosphorus present, the eutectic is found as a network structure, and under these conditions high tensile strengths have been obtained, which is quite contrary to the results obtained with similar structures in other alloys. No convincing explanation has yet been advanced for this anomaly in the case of phosphoric irons, and whilst this effect has been observed by many investigators, it should be taken that, for the general run of irons in the foundry, other things being equal, the lower the phosphorus, the higher will be the strength.

The most useful feature of the eutectic is its low melting point, which varies from about 950 to 985 deg. C. The phosphide eutectic contains 10 per cent. by weight of phosphorus, and hence

one-half per cent. of phosphorus in the iron means 5 per cent. eutectic in the iron, from which it will be realised that small changes in the phosphorus content will be reflected quite markedly in the fluidity.

Cementite

Cementite is the carbide of iron, Fe_3C. As already mentioned, it is not a normal constituent of grey irons under normal rates of cooling. Its importance lies in the fact that, under rapid rates of cooling, it is preserved, giving a cementite-pearlite structure, instead of the normal graphite-pearlite matrix. Since it is intensely hard, the presence of cementite is always accompanied by machining difficulties.

Having reviewed, in brief, the structural components of normal grey cast irons, it should be clear that the production of irons of superior quality, may be approached by:—(*a*) Improving the properties of the matrix and/or controlling the quantity, size and distribution of the graphite flakes, and (*b*) developing irons with new structural constituents possessing enhanced properties.

The question then arises as to how these eminently desirable objects are to be attained. The answer lies in the introduction into the metal mixture of alloying elements, and, in connection with the production of fine graphite, the employment of superheating, or the process known as inoculation.

EFFECT OF SPECIAL ELEMENTS

It was only natural, when considering the question of suitable alloy additions for cast iron, that attention should have been directed to the elements which have proved so successful in the production of alloy steels, and the period from about 1925 onwards has seen a veritable spate of Papers and articles recording the influences of nickel, chromium, molybdenum, vanadium and copper, whilst developments have also been made in connection with one of the normal constituents of iron, namely, silicon.

It has already been suggested that the production of high-strength irons may result in the appearance of entirely fresh structural constituents, and, as this actually happens under certain conditions, it will be necessary to consider the nature and properties of these newcomers to the structural make-up of cast iron. They are austenite, martensite, troostite and sorbite, and will be recognised as the constituents found in heat-treated steels.

Austenite

Austenite is the name given to the solid solution of iron and iron carbide, which is formed when steels and cast iron first solidify, and which, under normal conditions of cooling, becomes saturated with one or the other of its constituents, resulting in deposition of ferrite or cementite, breaking down ultimately to pearlite around 700 deg. C. The change from austenite to pearlite should, in theory, be capable of suppression by quenching, but it is found that this does not hold in practice even with the most drastic quench, and although a certain amount of austenite is produced, it is always accompanied by martensite. However, the addition of certain alloy elements, albeit in appreciable quantities, enables one to obtain austenite even "as cast." The reason for this is that the alloy elements either depress the temperature of the austenite-pearlite change to below ordinary temperatures, or lower the rate of cooling necessary to suppress the change. On examination austenite is found to be a relatively soft, ductile material, and is non-magnetic, which makes austenitic cast irons of importance in the electrical industry. Under the microscope it is a white featureless constituent, typical of a solid solution of the "alpha" variety.

Martensite

Martensite is the constituent which is produced when the austenite of a normal steel is quenched. Opinions regarding the nature of martensite are many and varied, but the general consensus of opinion is in favour of regarding it as a solid solution of iron carbide and "alpha" iron, as compared with austenite which is a solid solution of iron carbide in "gamma" iron. Its notable characteristic is its intense hardness. Under the microscope it often shows a well-developed needle-like or acicular structure. It is obtained "as cast" with alloy additions slightly less than those required to produce austenite.

Troostite

This may be regarded as a transition stage between the finest form of pearlite and martensite. It is produced by mild quenching or by alloy addition, and is seen under the microscope as a black featureless constituent. It is generally accepted as a colloidal solution of iron carbide in iron.

Sorbite

Sorbite, sorbitic or granular pearlite possesses the best all-round mechanical properties, combining the greatest toughness for a given tensile strength. It represents a transition stage between troostite and pearlite, where the colloidal carbide of the troostite has commenced to coalesce, but the resulting granules still remain just unresolvable under the microscope. This is true sorbite; the term sorbitic pearlite is applied when the particles *are* just resolvable, but both terms are used rather loosely.

Having considered the nature of these new constituents, to which frequent reference will be made from now on, the general effects of the common alloy elements are found to be as follow.

Nickel

Nickel has received more attention than any of the other special elements. The first systematic research was carried out by the famous French metallurgist, Leon Guillet,[4] in 1907. Guillet demonstrated the now well-recognised graphitising action of nickel, and its ability to induce the austenitic condition when present in large quantities in a cast iron. However, the potentialities of his work, and those of other pre-war investigators, appear to have been ignored, and it was not until the middle twenties that renewed interest in nickel became apparent. Early English workers include Donaldson,[5] and Andrews and Hyman,[6] whose work was concerned mainly with problems of heat resistance; the chief English investigations have been those of Hanson and Everest who have published many Papers,[7 8 9 10 11 12 13 14]. German work has, in the main, been due to Piwowarsky and his co-workers,[15 16 17], whilst a tremendous amount of work has been carried out in the U.S.A. by Merica, Wickenden, Vanick and others.[18 19 20 21].

TABLE III.—*Mechanical Properties of Nickel Cast Iron* (Everest.)

Material: T.C, 3.30; Si, 2.08; Mn, 0.96; S, 0.10; P, 0.18 per cent.

Test-bars.	A 20	A 21	A 22	A 23
Nickel content. Per cent.	0	0.699	1.12	1.84
Ratio GC/T.C. Per cent.	81.5	81.8	81.4	81.2
Transverse:				
Max. stress. Cwt. ..	25.36	25.52	26.68	24.58
Deflection. Inch ..	0.37	0.40	0.43	0.37
Modulus of rupture .. Tons per sq. in. ..	33.65	33.87	35.38	32.60
Tensile. Max. stress. Tons per sq. in. ..	12.74	13.09	13.32	13.25
Brinell hardness:				
1 in. sect. ..	192	197	199	207
½ in. ,, ...	192	199	210	217
¼ in.	299	229	229	235
⅛ in.	229	235	235	241

Note.—Transverse tests on I.B.F. "M" bar, 1.2 in. dia. 18-in. centres. Tensile tests on bars 0.798 in. dia., machined from lower end of transverse test-bars.
Hardness tests on standard step bars.
Each result is the mean of two or three determinations.

Broadly speaking, the effects of nickel on the structure of cast iron may be summarised as follow:—The first small additions tend to harden the matrix, and as the quantity increases graphitising action becomes apparent, whilst the pearlite changes progressively through the sorbitic and martensitic stages to austenite; coincident with these changes a general refinement of grain size occurs.

Since the properties of the martensitic and austenitic high-nickel cast irons are only of service in special cases, the bulk of the development work in nickel cast iron has been devoted to the production of irons containing up to 3 per cent. of the added element. The structural changes induced by such additions have just been mentioned; translated into practice they confer the following advantages:—(*a*) Equalisation of properties in sections of differing thickness, due to the graphitising action of the nickel in preventing chill in the thinner sections; (*b*) superior strength and wear resistance, due to the grain refinement and hardening of the matrix.

TABLE IV.—*Mechanical Properties of Nickel Cast Iron.* (Everest.)

Material: T.C, 3.4; Si, 1.56; Mn, 0.49; S, 0.099; P, 0.74 per cent.

	M 0	M 1	M 2	M 3
Nickel content. Per cent.	0	0.5	1.13	2.08
Transverse:				
Max. stress. Cwt. ..	22.16	23.48	21.10	20.84
Deflection. Inch ..	0.258	0.283	0.238	0.242
Modulus of rupture. Tons per sq. in. ..	29.4	31.1	28.0	27.6
Tensile strength. Tons per sq. in. ..	15.45	14.99	14.4	13.7
Brinell hardness:				
1 in. sect. ..	217	—	228	231
½ in. ,, ...	228	—	228	228
¼ in. ,, ...	235	—	241	255
⅛ in. ,, ...	269	—	269	262
Drill hardness	108	—	137	109

It has just been indicated that addition of nickel to a grey cast iron will result in higher strength, but the strength increase obtained by a simple nickel addition is small, and not sufficient in itself to warrant the extra cost. Tables III and IV, taken from one of Everest's Papers,[7] show the effect of nickel additions up to 2 per cent. on a motor cylinder iron, and an iron for heavier engineering practice. It will be noted that in the first table, the strength increase is of a very small order, and that in the second table a decrease is shown; at the same time, whilst the effect of the nickel on the tensile properties is inconclusive, the equalisation tendency is apparent from the hardness figures. However, the graphitising action of nickel being

established, it was logical to suppose that more noticeable effects might be obtained if the silicon content of an iron was reduced coincident with the introduction of the nickel, and further experiments were conducted to this end. Using an automobile cylinder iron as a base material, Hanson[10] obtained the results shown in Table V, which demonstrate quite conclusively that by altering the composition of the base iron to suit the nickel addition appreciable increase in tensile strength can be obtained.

Experience since the publication of this work has shown that the optimum effect is attained when each part of silicon is replaced by two to three parts of nickel.

It is, of course, well known that enhanced strength may always be obtained by the simple expedient of reducing the silicon content of a given iron, but the advantages of achieving this result by the use of nickel will be seen from a study of Figs. 2 and 3.

Fig. 2 shows the tensile strength, hardness and extent of chill in three step bars. Considering B it will be noted that the strength may be increased either by reducing the silicon, giving bar A, or by reduction of silicon, and addition of nickel, giving bar C, but whereas simple reduction of silicon results in enhanced strength at the expense of considerable increase in chill, the alternative method has secured even better mechanical properties, whilst maintaining the chilling tendency at the same level. Fig. 3 illustrates control of chill by silicon and nickel respectively, and it will be seen that, whereas reduction by silicon is accompanied by marked decrease in tensile strength, the figures for the nickel irons remain approximately constant. The hardness figures demonstrate clearly the equalising action of the nickel. In the thick section (1 in.) the variation on the silicon bars is 90 points against 24 points for the nickel bars, whilst the variations between the thick and thin sections ($\frac{1}{8}$ in.) are 93, 30 and 58 points for the silicon bars, against 58, 28 and 21 points for the nickel bars. Consideration of these Brinell figures indicate that a large stride has been made towards the removal of the inequalities in mechanical properties in differing sections, which, in the eyes of the engineer, provide an argument for not using cast iron. It should also be noted that the Brinell figures in the nickel bars remain throughout at a higher level than the silicon bars, indicative of a tougher matrix and better wear resistance.

There remains the important question of machinability. If hardness be increased by a reduction of silicon, the tendency to chill in the thin sections is increased, and in many cases the result will be that, when the silicon is reduced to the lowest permissible figure which will allow easy machining of the thin sections, it will be found that the hardness is insufficient in the heavier sections. In such circumstances, the influence of nickel in increasing the general overall hardness is of particular value (Fig. 4). Space limitations preclude further considerations of the effect of nickel on machinability, and ample literature on this aspect is available.

So far, the advantages claimed for nickel additions have been from the engineers' standpoint, but nickel can also be a good friend in the foundry. By virtue of grain refinement and matrix hardening, nickel assists greatly in the production of pressure tightness and general elimination of porosity, draws, etc. In reading through the literature available, the author has

TABLE V.—*Effect of "Balanced" Nickel-Silicon Content on Mechanical Properties.* (Hanson.)
Material: Automobile Cylinder Iron, T.C, 3.2 to 3.3; Mn, 0.9; Si, 0.10; P, 0.18 per cent.

Ni. Per cent.	Si. Per cent.	Transverse tests.*		Tensile strength.† Tons/sq. in.	Brinell numbers (step bar).			
		Load. Cwts.	Mod. of rupture. Tons/sq. in.		1 in.	½ in.	¼ in.	⅛ in.
0	2.0	25.36	33.65	12.74	192	192	229	229
0.7	2.0	25.52	33.87	13.09	197	199	229	235
1.12	2.0	26.68	35.38	13.22	199	210	229	235
0‡	1.3	—	—	—	228	250	364	340
0.93‡	1.29	26.6	35.3	16.84	212	228	242	251
1.84‡	1.35	28.0	37.4	16.70	225	241	251	286
1.22	1.42	29.46	39.0	18.5	226	232	273	292
1.12	1.44	28.43	37.6	20.5	228	230	250	386

* Transverse tests on standard I.B.F. "M" Bars.
† Tensile tests, pieces cast 1.2-in. diameter and tested 0.9 in.
‡ Carbon rose to 3.40 per cent. in these irons.

found that these claims are fully substantiated by the experience of actual users of nickel as revealed in the discussions following the presentation of many Papers. Attention is drawn to this point because many people who have not

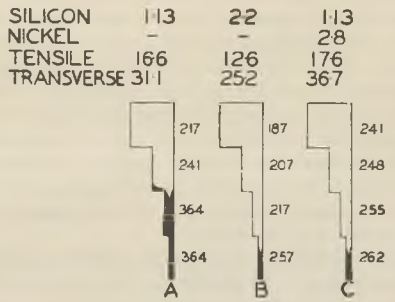


Fig. 2.—Step Bar Tests showing Influence of Ni and Si on Cast Iron.

had personal experience of alloy additions are sceptical of claims advanced as the result of experiments on a laboratory scale.

The foregoing constitutes a brief outline of the properties to be expected from grey irons

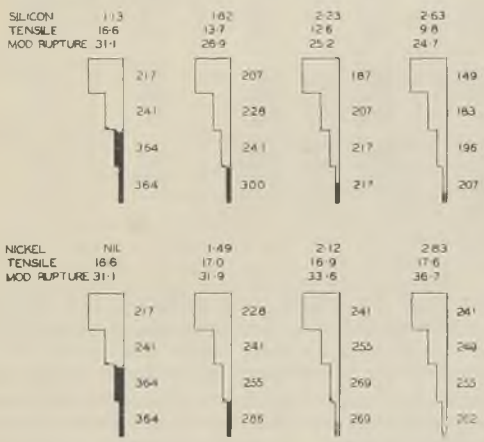


Fig. 3.—Control of Chill by Nickel and Silicon.

to which simple and "balanced" additions of nickel have been made.

Chromium

Additions of chromium to cast iron have also been the subject of intensive research. Chromium may be regarded as the antithesis of silicon, for it is essentially a carbide promoter and stabiliser. If silicon is taken as having unit tendency to promote the formation of graphite, then the tendency of chromium to the same end may be considered as – 1.2. Work by Keep[22], Campion[23], Smalley[24], Piwowarsky[25] and others has shown that additions of chromium up to 0.5 per cent. in conjunction with silicon contents of 1 to 2 per cent., result in increases in the tensile and transverse strengths, and the hardness. As might be expected from the anti-graphitising action of chromium, even additions of under 1 per cent. will render the iron unmachinable if the silicon content be low, and in this connection Pfannenschmidt[26] found that with silicon contents of 1.5 and 2.3 per cent. the limiting additions of chromium which could be made whilst preserving machinability were 0.4 and 0.7 per cent. respectively, for sand-cast bars $1\frac{3}{16}$ in. diameter.

Chromium exists in chromium cast irons as a double carbide of iron and chromium in the pear-

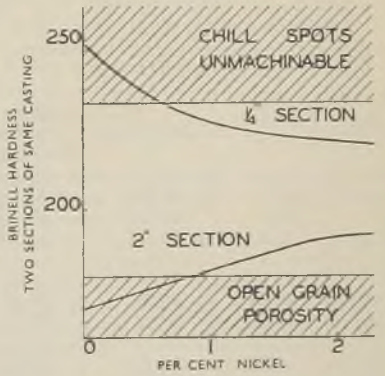


Fig. 4.—Showing Influence of Nickel on Brinell Hardness of Cast Iron.

lite. This double carbide is very much more stable than the plain cementite, particularly at elevated temperatures; consequently chromium irons find important application in the heat-resistance field. Donaldson[27] has studied the effects of chromium additions up to 0.9 per cent., at which figure he obtained complete stability even after 200 hrs. at 550 deg. C.; at the same time the specimens showed complete resistance to growth, contractions being observed instead. In actual practice, however, plain low-chromium irons have a limited application, their use being confined to wear resisting irons and irons of moderate heat resistance.

Another group of plain chromium irons exists in which chromium contents of 15 to 35 per cent. are used in conjunction with carbon contents as low as 1.8 per cent. As in the case of the low chromium irons, these high alloy irons are used for wear- and heat-resisting work.[28]

Although, as indicated, the uses of plain chromium irons are limited to certain specific fields, chromium is a very valuable alloying element when used in conjunction with other additions. The most popular combination is that of nickel and chromium, which will be considered next.

TABLE VI.—*Effect of Nickel and Chromium on Cast Iron.* (Hanson.)

Material: Automobile Cylinder Iron, T.C., 2.9 to 3.0; Mn, 0.85; S, 0.10; P, 0.17 per cent.

Ni. Per cent.	Cr. Per cent.	Depth of chill on ⅛-in. step.	Brinell hardness.				Transverse test on standard "M" bar.		Tensile strength. Tons per sq. in.	
			1 in.	½ in.	¼ in.	⅛ in.	Max. load. Cwts.	Mod. of rupture Tons/sq. in.	1.2-in. bars.	0.875-in. bars.
nil	trace	0.5 in.	199	213	228	241	28.15	37.3	15.3	19.4
1.02	trace	trace	210	217	335	241	26.93	35.7	16.8	18.8
1.10	0.27	trace	228	231	238	241	28.27	37.5	18.6	20.5
1.14	0.414	0.35 in.	230	238	258	269	28.15	37.3	18.0	22.45

Nickel-Chromium Irons

Chromium hardens iron by virtue of promoting carbide formation; consequently, as in the case of silicon and nickel, a "balanced" nickel-chromium addition may be used with advantage, as is shown in Table VI. The nickel will harden the matrix and so also will the chromium, but the graphitising action of the nickel will resist the chilling tendency of the chromium, since it is found that this characteristic of nickel is preserved unaltered in the presence of the chromium. Hence, an iron of greater toughness is obtained without sacrifice of machining properties. It should be mentioned here that experience has shown that, in the case of pressure castings, superior results are obtained by simple nickel addition and reduced silicon content. In one of their Papers, Hanson and Everest[11] suggested that the ratio of nickel to chromium should be varied according to the quantity of chromium added. Their suggestions are shown in Table VII. Later experience has shown that, in general, two or three parts of nickel to one part of chromium prove quite satisfactory. As regards actual quantities of these elements, British practice appears to favour the retention of the chromium at about 0.5 per cent., with a total carbon of about 3.2 per cent. and a manganese content of 0.7 per cent., the nickel and silicon being varied to suit requirements. Typical recommendations are set out in Table VIII.

TABLE VII.—*Suggested Ratios for Nickel-Chromium Additions to Cast Iron.* (Hanson.)

Chromium added.	Nickel : Chromium ratio.
Less than 0.2 per cent.	3 to 1
0.2 to 0.3 per cent. ..	4 to 1
0.3 to 0.4 per cent. ..	5 to 1

TABLE VIII.—*General Recommendations for Nickel-Chromium Cast Irons.* (Bur. Inform. on Nickel.)

——	T.C	Si	Mn	Ni	Cr
For medium sections ..	3.2	1.6	0.7	1.25	0.5
For heavy sections ..	3.2	1.0	0.7	1.25	0.5
Hard grey iron.. ..	3.3	1.2	0.8	3.0	0.5

American practice tends to the use of slightly higher values of nickel and chromium, approximately the same total carbon, and a reduction in the manganese to 0.6 per cent. or less. Typical analyses are shown in Table IX.

TABLE IX.—*Typical Analyses and Applications of Nickel Chromium Cast Irons.* (A.F.A. Handbook.)

——	T.C.	Si.	Mn.	Ni.	Cr.
Light automobile cylinders	3.3	2.1	0.6	0.75	0.3
Heavy automobile cylinders	3.3	1.85	0.65	1.5	0.6
Light forging dies* ..	3.3	1.5	0.6	1.5	0.6
Heavy forming dies* ..	3.0	1.25	0.6	2.75	0.8
Brake-drums	3.25	2.0	0.65	1.5	0.6
Light cylinder liners ..	3.25	2.0	0.6	1.5	0.6
Caustic pots	3.3	0.7	0.5	1.5	0.6
Clutch plates	3.3	2.1	0.65	1.25	0.4
Permanent moulds ..	3.25	1.75	0.6	1.55	0.6

* Heat treated.

Molybdenum

The use of molybdenum has increased extraordinarily during the past few years, particularly in the U.S.A. When added to cast iron, molybdenum passes partly into solid solution in the ferrite, and also forms complex carbides, but this latter tendency is small compared with chromium. These effects are reflected in a

strong sorbitising effect on the matrix. Additionally, there is a decided refining action on the graphite, accompanied by superior distribution.

The effects on the mechanical properties are shown in Fig. 5, which shows the influence of increasing molybdenum content on four base irons. It will be noted that the additions are more effective when added to a low-carbon base. It should also be noted that the hardness does not rise proportionally with the increase in strength and thus introduce machining difficulties.

One of the most striking effects brought about by additions of this element is the remarkable "mass effect." Steelmakers are well aware of

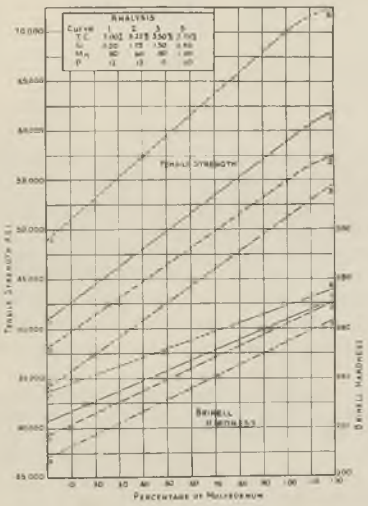


Fig. 5.—Effect of Molybdenum on Tensile Strength and Hardness.

this propensity, and it has proved no less successful in the case of cast iron. Fig. 6 shows the Brinell hardness taken across the feeder head of a hydraulic ram, and the extraordinary uniformity will be noted. The analysis of the iron was T.C, 2.96; Si, 1.46; S, 0.102; P, 0.128; Ni, 0.61; Cr, 0.23, and Mo, 0.58 per cent., and whilst the nickel-chromium addition may have been a contributory factor, the major influence must be credited to the molybdenum.

The transverse strength is also improved by molybdenum additions for the same reasons as the improvement in tensile strength and hardness; the deflection is also raised. Experiments show that the transverse strength of an ordinary grey iron (T.C, 3.31; Si, 2.27, and Mn, 0.65 per cent.) may be raised by as much as 9 cwts. by addition of 0.5 per cent. Mo, the deflection increasing from about 0.225 to 0.325 in.

From the point of application in the foundry, molybdenum additions offer important advantages. The element may be added satisfactorily in the ladle, and since the amount to be added is small, the metal is not cooled to any appreciable extent. A wide variation in properties can be obtained, according to the extent of the addition, which means that one base iron may be used to satisfy several requirements. Finally, molybdenum reduces "patternmaker's shrinkage," which minimises contraction stresses and the consequent risk of cracking and tearing.

Molybdenum finds its greatest use in combination with other alloying elements. Popular combinations are Cr-Mo, Mn-Mo, Ni-Mo, and

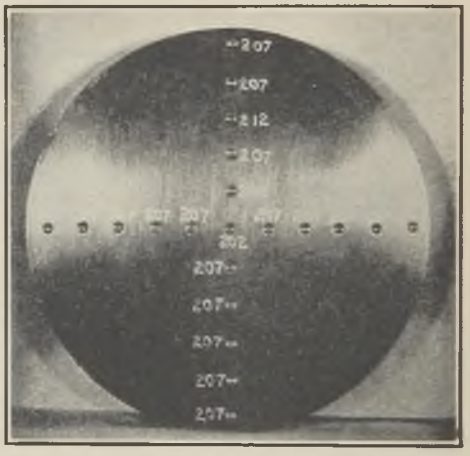


Fig. 6.—Section of a $6\frac{1}{4}$ in. Round Bar showing Uniform Hardness.

Cu-Mo. Combination with nickel appears to produce the maximum beneficial effects on the physical properties. This effect combines high tensile strength, transverse strength and deflection, with intermediate hardness and outstanding machinability.

Although virtually unknown in 1929 except for use in chilled rolls, its use, so far as the U.S.A. is concerned, is practically universal for castings of high strength requirements. Strengths of twenty tons are easily obtainable with hardnesses of under 300 Brinell. Applications include motor-vehicle and diesel castings, dies, pressure and machine-tool castings, and gears. Some typical analyses are set out in Table X.

It may be thought that the information given suggests that molybdenum is the founder's "philosopher's stone," but the author finds that British information concerning this element is

comparatively scarce compared with that available in the case of nickel and chromium, and this opportunity has been taken to emphasise the potentialities of molybdenum. British Papers available include work by Smalley,[29] West,[30] Hurst,[31] and others.

Vanadium

The effects of vanadium have been studied over a prolonged period. The earliest reference the author can trace is a Paper by Smith[32] in 1909, since which time some thirty or more other Papers have appeared. British workers include Norris,[33] Hatfield,[34] Donaldson,[35] Campion,[36] Hurst[37] and Norbury.[38] Germany is represented by Piwowarsky,[16] Bardenheuer and Zeyen,[39] Pfannenschmidt[26] and others, whilst a notable worker in this field has been Challansonnet[40 41 42] in France. It is, however, in the U.S.A. that vanadium irons have been in regular production for many years, and numerous Papers have appeared in the technical Press of that country.

Vanadium is the most powerful of the carbide-forming agents. The effects on the matrix parallel those of chromium; at the same time, there is a marked tendency to improve the graphite as regards both flake size and distribution. Vanadium also exerts a well-recognised deoxidising effect, accompanied by degasification, which is reflected in better transverse strength.[26]

The general effects on the mechanical properties are as follow:—Hardness is increased; as little as 0.1 per cent., when added to an iron with a total carbon of 3.1 per cent. and a silicon content of 1.8 per cent., will raise the hardness 15 to 20 points. The larger differences occur in the thicker sections, thus giving the much sought equalisation. The change in tensile strength, when added to plain irons, is roughly proportional to the increase in hardness, but when added in conjunction with other elements the tensile strength rises more rapidly than the hardness. As an example, a strength increase of 10 tons per sq. in. can be obtained with an increase of 75 points Brinell, using a 2 per cent. copper-vanadium iron, whilst a corresponding increase in a plain iron will involve a difference of about 170 points Brinell. The advantages from the machining aspect will be obvious.

TABLE X.—*Typical Analyses and Applications of Molybdenum Cast Irons.*

Application.	T.C.	Si.	Mn.	Ni.	Cr.	Mo.	Cu.	V.
High-strength iron	2.8	2.2	0.8	—	—	0.35	—	—
Hot working dies	3.3	1.3	0.5	—	—	0.9	—	—
Heavy lathe beds	3.1	1.25	0.75	1.0	—	0.5	—	—
Valve bodies	3.21	2.16	0.81	—	0.31	0.41	—	—
High-pressure pumps	3.16	1.36	0.55	1.03	0.41	0.73	—	—
Diesel pistons	2.55	1.6	0.7	1.25	—	0.7	—	0.12
Cylinder blocks	3.1	2.0	0.8	—	0.5	0.3	0.6	—

Alloys containing vanadium in conjunction with nickel, copper, chromium and titanium are utilised for a wide variety of purposes, particularly in the U.S.A. In all cases the vanadium addition is of a very small order. Table XI shows a few typical examples from American practice illustrating the many alloy combinations.

TABLE XI.—*Typical Analyses of Alloy Cast Irons containing Vanadium.* (Amer. Van. Corp.)

Application.	T.C.	Si.	Mn.	Ni.	Cr.	Mo.	Cu.	V.
Brass mill rolls	3.0	0.8	0.3	—	—	—	—	0.25
Grate bars	3.7	1.7	0.55	—	—	—	—	0.15
Brakedrums	3.15	1.9	0.65	—	—	—	1.5	0.1
Forming dies	3.6	1.4	0.5	2.0	0.7	—	—	0.15
Diesel heads	3.05	1.85	0.8	1.25	—	0.75	—	0.1

Copper

Copper additions to cast iron have received their full share of attention. The first work appears to have been undertaken about 1900, after which, except for an odd Paper or two, little interest appears to have been taken until after the war. From 1920 onward there have been frequent Papers, more particularly from German and American sources. The latest British publications are those of Sallitt[43] and Nicol Smith,[44] and a monograph published by the Copper Development Association.[45]

The influence of copper on chill has aroused controversy, but there is a preponderance of opinion in favour of regarding copper as a graphitising agent. The work of Nicol Smith

indicates that copper only acts as a graphitiser up to additions of 3 per cent., after which it tends to induce chill, this being attributed to a dilution effect, and not to carbide formation. The effect on the microstructure is slight, graphite and pearlite refinement being reported. Super-cooled graphite is induced under certain conditions.

The mechanical properties, tensile and transverse strengths, and hardness are raised to a slight degree by simple copper addition, but the effects are noticeable if the copper addition is coincident with silicon reduction, as in the case of nickel. Carbon content also exerts a marked effect under these conditions, and maximum benefits apparently necessitate carbon contents of under 3 per cent. Opinion appears divided on the question of the relative merits of a copper addition as compared with other elements, but it has been suggested that copper may find useful application, by employing it to replace nickel in part, in which case the economic benefits are unquestionable. Copper does, however, form a valuable constituent of certain complex alloy irons, such as the chromium-copper iron developed for the "Ford" cast crankshaft, the austenitic iron Ni-resist, copper-chrome-molybdenum cylinder irons, etc.

Other Elements

Many other elements have been added to cast iron from time to time, but their use, as yet, cannot be considered as beyond the early development stage. Attention may be directed to two of these elements, namely, aluminium and titanium. The former functions as a graphitising agent when added in small quantities, and also acts as a deoxidising agent. With larger quantities the iron becomes white, and heat- and corrosion-resisting properties have been reported by a number of workers. Founding difficulties are encountered, due to scum formation. Titanium has a very strong graphitising action, superior to that of silicon when the amounts are small. Improved transverse strength and wear resistance are claimed.

Heat-Treatable Cast Irons

The foregoing remarks have been applied specifically to alloy irons in which alloy additions have been used to secure improved structure and mechanical properties in the as-cast condition. However, since the matrix of a cast iron is, in effect, identical with that of a fairly high-carbon steel, possibilities for heat-treatment exist. It has been found that ordinary cast iron will not stand the thermal shock of a quenching treatment; but with alloy additions the critical points, and the rate of cooling necessary to induce hardening, may be altered to permit of heat-treatment without trouble due to cracking. Hardness of the order of 400 Brinell may be obtained in the as-cast condition by the use of a fairly high nickel content, with or without chromium; a typical composition is 5 per cent. nickel and 0.75 per cent. chromium. Such an iron has a martensitic structure, and is only machinable using tools of the Widia type, and finishing by grinding.

In many cases, however, hardness of the same order may be sought in the finished article, but the machining costs might be prohibitive if carried out on the hardened material, and the heat-treatable cast irons have been developed to meet these conditions. The nature of these irons is such that, in general, they are easily machinable as cast, after which they may be quenched and tempered to the required hardness. The nature of the heat-treatment will vary with the section of the casting. With increasing section, the alloy content must be raised to ensure full hardening. This may result in some degree of "air-hardening" in the lighter sections as cast, but an annealing treatment, followed by slow cooling, will soften the casting throughout, enabling the machining operation to be carried out, the material being subsequently hardened by further treatment.

The popular heat-treatable irons contain 2 to 3 per cent. of nickel, with or without chromium, the latter addition being recommended for heavy sections. The heat-treatment consists of a quench in oil from 850 deg. C. followed by tempering to the desired strength and hardness. By varying the tempering temperature between 300 and 600 deg. C., tensile strengths of from 16 to 20 tons per sq. in. are readily obtainable, with Brinell numbers of 350 to 400. For softening purposes, it is only necessary to reheat to about 600 to 700 deg. C. and furnace-cool. For detailed information Papers by Hurst[46 47] and many other workers[48 49] are available.

A special form of heat-treatment for the production of intense surface hardness is the process known as "nitriding," well known in connection with steels and applied to cast iron by Hurst[50 51 52]. The iron used contains chromium and aluminium, a typical analysis being T.C, 2.6; C.C, 1.23; Si, 2.58; Mn, 0.61; Cr, 1.69, and Al, 1.43 per cent. The process consists of subjecting the material to the action of dry ammonia gas at a temperature of approximately 500 deg. C. The castings are nitrided *after* quenching and tempering, the operation taking from 60 to 90 hrs., according to the depth of penetration required. Hardnesses of 600 to 700 Brinell may be obtained in this manner. This process is being applied with great success to the production of motor-vehicle cylinder liners; in fact, one can generalise to the extent of

stating that the motor-vehicle industry offers the largest field so far for the employment of heat-treated cast irons.

Special Irons

The last few years have seen the evolution of a number of alloy irons having outstanding properties in their own particular fields. In general, these consist of irons containing appreciable percentages of alloy elements, and their manufacture may involve departures from ordinary foundry practice. Prominent amongst these irons are the heat- and corrosion-resisting irons known by such names as Silal, Nicrosilal, and Ni-resist; irons produced by the process of inoculation, with or without alloy addition, such as Meehanite and Ni-tensyl, and finally chilled alloy iron such as Ni-hard. It is outside the scope of this Paper to deal at length with these irons, but the salient features will be indicated.

Heat-Resisting Irons

Ordinary grey iron, when subjected to high temperatures, particularly if of an intermittent nature. exhibits the phenomenon of "growth." This involves a marked permanent expansion, coupled with cracking and flaking of the surface, with the result that the life of the material is short. This phenomenon has received extensive study, and it has been established that the root cause of the trouble lies in the oxidation of the graphite flakes together with decomposition of the matrix pearlite. The development of heat-resisting irons has, in consequence, been associated with the production of irons containing a minimum of graphite, coupled with as fine a flake size as possible, removal or stabilising of the pearlite, and the addition of other elements resistant to oxidation. Another factor of importance, in the case of intermittent heating, is the volume change associated with the passage of the iron through the carbon change point; hence removal of the critical point to a temperature outside the working range of the material will also assist the problem.

White irons, irons of low silicon content, and low alloy irons are all superior to ordinary grey cast iron, but each has its own particular disadvantages, and intensive research during the last few years has led to the introduction of irons of vastly superior resistance.

The British Cast Iron Research Association has introduced two irons in the heat-resistance field known as Silal and Nicrosilal. Silal[53] is a high-silicon iron with a low total carbon. The silicon percentage varies from 4 to 10 per cent., and the carbon is present almost wholly as graphite in a very fine state of division. The matrix consists of ferrite only. A moment's reflection will enable one to realise that the heat-resisting properties are due to the manner in which such a structure reduces the growth-promoting factors.

Silal has proved very satisfactory where the service conditions have been pure heat-resistance. It is very brittle, however, and should not be used under conditions of stress, whilst rapid heating and cooling may also cause trouble due to cracking. The silicon content is adjusted to the temperature requirements, and it is important that it should be chosen with care, as too high a value will mean unnecessary brittleness and machining difficulty, whilst too low a value will mean inferior heat-resistance, in which connection Morgan has pointed out that internal oxidation in an iron of this class may result in more rapid failure than a common iron. A typical analysis of a Silal iron suitable for work at, say, 900 deg. C. is:—T.C, 2.39; C.C, 0.08; Si, 5.72; and Mn, 0.68 per cent.

TABLE XII.—*Typical Compositions of Austenitic Cast Irons.*

	"Ni-resist."	"Nicrosilal."
T.C. Per cent. ..	2.44	1.75
Gr. Per cent. ..	1.7	1.47
Si. Per cent. ..	1.11	5.84
Mn. Per cent. ..	0.76	0.68
S. Per cent. ..	0.057	0.039
P. Per cent. ..	0.26	0.045
Ni. Per cent. ..	16.56	17.72
Cr. Per cent. ..	3.3	2.1
Cu. Per cent. ..	7.3	—

Nicrosilal[54, 55] and Ni-resist[56] may be considered together. The former emanated from the B.C.I.R.A., whilst the latter was first introduced in the U.S.A. under the name of Nimol. Both irons have a structure consisting of fine graphite in an austenitic matrix, induced by substantial additions of nickel. The nature of the matrix confers an important advantage on these irons as compared with Silal, namely, a considerable measure of ductility, and easy machining. Typical compositions are compared in Table XII. The austenitic cast irons are markedly superior to ordinary cast iron at elevated temperatures, and when used for this purpose it is beneficial to keep the chromium content as high as possible compatible with ease of machining. Nicrosilal offers a greater resistance to heat than Ni-resist, the latter having been developed, in the first instance, as a corrosion-resisting iron.

A Paper of great interest,[57] more particularly perhaps to the engineer, appeared in 1936, covering an investigation into the creep of five irons, which included Silal, Nicrosilal, Ni-resist, a

nickel-chromium iron and a common grey iron. The investigation was directed to ascertaining, amongst other things, the suitability of the three special irons for high-temperature steam plant. The complete superiority of the special irons was demonstrated. Curiously enough, both Nicrosilal and Ni-resist proved better at high temperatures than at lower ones. Another interesting discovery was also made, namely, that the rates of creep and growth of the ordinary grey iron and the nickel-chrome iron were considerably reduced by a preliminary heat-treatment below the critical temperature.

Ni-resist, as mentioned above, was developed originally as a corrosion-resisting iron. It has a corrosion resistance equal, or even superior, to bronze under many conditions, whilst possessing better wear resistance. Table XIII, due to Hurst, compares the properties of austenitic iron with those of ordinary cast iron and the common non-ferrous alloys. It will be noted that the mechanical properties compare very favourably with brass and bronze. In common with other austenitic materials, Ni-resist has a tendency to work-harden, and this is particularly useful where the corrosion is accompanied by abrasion, as in the case of, say, the pumping of sewage. Ni-resist is finding increasing application in the chemical industry, and ample data are available for the use of engineers and others to enable them to select the most suitable composition for their requirements.

TABLE XIII.—*General Properties of Austenitic Cast Irons compared with Cast Iron and Non-Ferrous Alloys.* (Hurst.)

	Austenitic cast iron.	Ordinary cast iron.	Brass.	Bronze.
Specific gravity	7.5—7.6	6.9—7.7	8.0—8.2	8.2—8.5
Specific heat	—	0.12	0.09	0.26
Thermal conductivity	0.08	0.11—0.13	0.26	0.26
Magnetic permeability (max.)	1.03	240.0	1.0	1.0
Specific resist. Microhms per cm.^{3}	150.0	95.0	7.0	16.0
Resistance temp. coeffic. 0—100 deg. C.	0.00045	0.0019	0.002	0.00065
Coeffic. of expansion	1.8×10^{-5}	1.1×10^{-5}	1.88—1.98×10^{-5}	1.8×10^{-5}
Tensile strength. Tons per sq. in.	15—25	12—20	20—40	20 app.
Elongation. Per cent.	1—3	Nil	20	8
Mod. of elasticity. Lbs./in.$^2\times10^{-6}$	14—21	14—18	11—14	11—14

Inoculated Iron

At the beginning of this Paper, production of fine graphite was mentioned as likely to confer added strength on an iron. It has been seen that the majority of the alloy elements do assist in a certain measure in this direction, but so far no mention has been made of procedures having the production of fine graphite as their specific object. It has been found that marked graphite refinement may be accomplished by superheating an iron or by making a ladle addition of a graphitising agent to an iron which under normal conditions would solidify as a white iron. The latter process is termed "inoculation," and is mentioned because it is an integral part of the production of the special iron known as Ni-tensyl. Norbury and Morgan[58] have described the production of fine graphite by an addition of ferro-titanium followed by oxidation by bubbling carbon dioxide gas through the metal.

Ni-tensyl,[59] which in common with Silal, Nicrosilal, etc., is the subject of patents, has been sponsored by the Mond Nickel Company. Briefly, it consists of a high-strength matrix, accompanied by finely divided graphite. It has the great merit of admirable mechanical properties, combined with low cost, since the sole alloy addition consists of 1.5 per cent. nickel, which together with ferro-silicon is added in the ladle.

The mechanical properties may be described as startling when compared with normal high-duty and alloy cast irons, as 25 tons per sq. in. is a usual figure, and values up to 30 tons have been reported. Further, the iron is amenable to heat-treatment, in which case the 30-ton figure may be obtained with reasonable certainty every time. As to the figures quoted, it should be pointed out that adequate foundry practice is assumed. As an indication of the type of work which can be produced, the case of a crusher frame weighing 17 tons finished can be cited, wherein the tensile strength in the centre of a section 9 in. thick was 23 tons per sq. in. This iron is easily machined at Brinell hardnesses of 250 and over. It can obviously be employed for a wide variety of work, and may be used as a substitute for steel castings in many cases.

Ni-hard

The last of the special irons to be considered is again due to the Mond Nickel Company, namely, Ni-hard.[60] Ordinary white irons produced either as-cast or by chilling suffer from brittleness and lack of strength, and these defects have been mitigated in the iron to be described. The under-

lying principle is the retention of the massive carbides characteristic of a white iron, accompanied by a martensitic matrix instead of the pearlitic one found in white iron. At the same time, the alloy additions responsible for the martensite in the surface layers also refine the underlying grey core. The net result is a much higher hardness in the chill and vastly improved core strength. The importance of increased core strength will be apparent in such castings as rolls, where torque has to be transmitted. It will be appreciated that machining will not be easy, but this is not to be expected in the nature of things.

However, except where extreme hardness is required, machining may be carried out using Widia tools; in the limiting case, grinding is the only possible procedure. Ni-hard may be applied for all purposes where white irons have been used in the past, and service conditions have afforded ample confirmation of its superiority, as is stressed in Tables XIV and XV.

TABLE XIV.—*Typical Compositions of "Ni-Hard." (Bur. Inform. on Nickel.)*

	A.	B.	C.	D.
T.C. Per cent...	3.0	2.8	3.6	3.6
Si. Per cent. ..	0.8	0.5	0.8	0.5
Mn. Per cent. ..	1.2	1.2	0.8	0.8
S. Per cent. ..	0.1	0.1	0.1	0.1
P. Per cent. ..	0.3	0.3	0.3	0.3
Ni. Per cent. ..	4.5	4.5	4.5	4.5
Cr. Per cent. ..	1.0	0.75	1.5	1.5
Mo. Per cent. ..	—	0.25	—	0.25

Type A is for light-section chilled castings of maximum strength; B is for heavy castings of maximum strength; C is for light castings of maximum hardness; D is for heavy castings of maximum hardness.

TABLE XV.—*Typical Results of Tests of Chilled Plain and "Ni-Hard" Irons.*

	Unalloyed iron.		"Ni-Hard."	
	High carbon.	Low carbon.	High carbon.	Low carbon.
T.C. Per cent.	3.50	2.75	3.50	2.75
Si. Per cent.	0.75	0.75	0.75	0.75
Ni. Per cent...	—	—	4.50	4.50
Cr. Per cent.	—	—	1.50	1.50
Brinell hardness of chilled surface	500	400	650—700	575
Shore hardness on chill face	70	55	90	78
Tensile strength in chilled section. Tons/sq. in.	16—18	21—24	25—27	31—36
Tensile strength in grey core. Tons/sq. in.	7—11	10—17.5	13—16	18—22

The Production Angle

It remains to give some account of the production of alloy irons in the foundry. Straight away it can be stated categorically that success with alloy irons is dependent on ability to produce ordinary irons of the highest class. Alloy additions are not a medicine for poor foundry practice, and the dabbler is likely to burn his fingers.

If a customer be required to pay an enhanced price for an alloy iron casting, he demands, first and foremost, value for his money in the form of better service and better quality, which stresses the important point that there should be the closest co-operation between the customer and the founder. The former should be encouraged to give the fullest details of the job for which the casting is required, so that the founder may supply him with the most suitable material; in this way the customer will receive the full value of the alloy iron, whereas if information is withheld a perfectly good casting may be supplied which, through being of unsuitable composition, may be little superior to an ordinary straight engineering iron.

So far as the low alloy addition irons are concerned, 75 per cent. of the battle is the ability to produce a suitable base iron, which, taken in general, involves the production of an iron having a total carbon of 3 to 3.3 per cent.; silicon controlled accurately to suit requirements, generally about 1 to 1.5 per cent.; low phosphorus, and a manganese content of about 0.7 per cent. It is hardly necessary to point out that this will involve an accurate knowledge of the composition of all raw materials and irreproachable cupola practice.

Compounding the Alloys

The alloying elements may be introduced into the melt in a variety of ways. The commonest element, namely nickel, is available in several forms. The most popular of these is nickel "F" shot, which is a nickel-silicon alloy containing 92 per cent. of nickel, and has a melting point of about 1,260 deg. C., which renders its solution quite simple. The same material is available in ingot form, whilst pure nickel may also be obtained as shot or ingot. The remaining choice is the use of pig-iron containing nickel.

Present-day practice in the choice and method of addition has been reported on by many authorities, the general concensus of opinion being as follows:—For small quantities of iron, the addition of " F " shot, introduced into the metal stream as close to the tap hole as convenient as the metal is tapped into the ladle. It is also recommended that the ladle is suspended from a spring balance during the operation to ensure the correct weight of iron being used to suit the addition.

For appreciable quantities of iron, the nickel should be introduced via the cupola, but opinions differ as to the form of the addition. One well-known authority avoids the use of any concentrated form such as ingots, and advises a nickel-bearing pig. If ingots are used there is a slight loss to 2 to 2½ per cent. The nickel iron should be charged first where possible, and the alloy added in the first part of the charge; additionally the amount of alloy iron should exceed requirements to avoid contamination. It will be realised that in the case of irons made in furnaces other than the cupola, the above problems do not arise, and the nickel may be added in any form, a short time prior to tapping.

Chromium Additions

Chromium is rather more difficult to add than nickel. It is available as ferro-chrome, as a chrome pig-iron, or as chromium briquettes. The solution of ferro-chrome is a matter of difficulty, and opinion appears to regard its use as a ladle addition as undesirable, although with care this method can be made to give satisfactory results where not more than 0.5 per cent. of chromium is required in the metal. The finely crushed ferro-chrome should be well rabbled into the metal or losses may be excessive. Under the best conditions the losses may be up to 15 per cent. of the amount added.

The best method undoubtedly is the use of a suitable chromium pig-iron, and this applies also where larger quantities of chromium are required. Hurst[61] has published some interesting figures in connection with chromium additions in various forms. Excessive loss was encountered when ferro-chrome was used in the cupola, and experiments using chrome pig-irons of varying chromium content showed that the smallest losses were obtained with an 8 per cent. chromium pig. It is emphasised, however, that variations may be expected under differing cupola conditions.

Adding Molybdenum, Vanadium and Copper

Additions of molybdenum may be made as ferro-molybdenum containing 55 to 65 per cent. metallic molybdenum. The crushed alloy may be added at the spout as in the case of nickel. It is recommended that no addition be made until a reasonable amount of metal is in the ladle, otherwise trouble may ensue due to the ferro-molybdenum sticking to the bottom. Molybdenum pig is not readily available, but an alternative for air-furnace or rotary-furnace work is calcium molybdate. If used, ample time must be allowed for solution—about two hours for safety.

There is little to say concerning vanadium. It may be added in the ladle as ferro-vanadium, or alternatively vanadium pig-irons are available. Losses must be taken into consideration in ladle additions.

In the case of copper, there is the advantage that scrap copper in any form may be used, either as a ladle addition, as part of the cupola charge or just prior to tapping in other types of furnace. The copper passes into solution easily, and the only precaution necessary is to stir the ladle well, as with fairly large additions there may be a tendency to segregation at the bottom of the ladle. Oxidation losses need not be considered.

Technique for Ni-Resist and Nicrosilal

Austenitic cast irons of the Ni-resist and Nicrosilal type may be made either in the cupola or the crucible furnace. In the production of Ni-resist, the charge is made up of a suitable base iron to which a Ni-Cu-Cr pig is added. Monel metal may also be used together with a chromium pig. Ladle additions should be avoided. Melting losses are experienced with the silicon and manganese, and in the case of crucible melting carbon also.

The foundry technique requires close attention, as the metal has little life and should be poured as hot and as quickly as possible. Feeder heads should be on the most generous lines, and it is recommended that the cross-sectional area of the feeders should exceed the heaviest section of the casting. The question of dry-sand or green-sand moulds for these irons is uncertain, as good results have been obtained with both. It is important to note that where chaplets are required, these should be of austenitic iron or Monel metal.

Handling Ni-tensyl

Ni-tensyl is usually produced in the cupola. The base iron recommended is a low total-carbon iron of 2.5 to 3 per cent.; silicon, 0.5 to 0.8 per cent., and in particular low phosphorus—0.2 per cent. maximum. The charge may consist almost entirely of steel, avoiding too light material. In the rotary furnace the charge must consist of refined pig-iron in the main, in order to obtain the required carbon. Inoculation

should be carried out in the ladle or the bath just prior to pouring. The metal is comparatively "dead" due to possessing a short freezing range, and should be poured as soon after inoculation as practicable. Runners, etc., should be on the same generous lines as in the case of the austenitic irons. As regards the moulding, steel-foundry technique is advised, as the contraction is strong and tearing may occur. For the same reason the castings should be released as soon as possible, and core grids, etc., removed or broken.

With regard to Ni-hard, the introduction of the alloy additions and the foundry technique follow the practice outlined for low alloy additions and normal white-iron practice.

Conclusion

Sufficient has been said in the space available to indicate the salient features of alloy irons and their production. It must not be thought for one moment that alloy cast irons are to be regarded as rendering all other irons obsolete; far from it. Normal grey cast iron will always satisfy a very large percentage of all ordinary requirements. Likewise, it is not claimed that high strength is not obtainable by other methods, but it is claimed that alloy irons possess decided advantages as regards uniformity of structure in differing sections, coupled with greater freedom from porosity, *i.e.*, a finer all-round grain. The special irons are a different proposition, and cannot be duplicated by alternative methods of manufacture.

For a Paper of this description, it is necessary to quote extensively from the work of many investigators, and the author would like to offer his debt to the many gentlemen whose Papers have been abstracted. Acknowledgment is also due to the Copper Development Association, the Climax Molybdenum Corporation and the American Vanadium Corporation, whose publications have been freely abstracted in their respective sections. Valuable assistance has been given to the author by the Bureau of Information on Nickel in connection with the special irons, and for the loan of lantern slides. Slides have also been made by Mr. Forrest, and the authorities of the Bradford Technical College.

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DISCUSSION

The PRESIDENT (Mr. A. S. Worcester) said that Mr. MacColl had obviously gone to a great deal of trouble to frame the Paper in such a way that it brought down alloy irons to their common uses, described in a manner the average foundryman might reasonably understand.

MR. W. G. THORNTON (Bradford—Past-President) asked whether it was possible to produce a test bar purely from pearlite. He had been rather surprised the lecturer had not mentioned anything as to the wearing qualities of iron containing molybdenum, and any information on that point would be appreciated.

MR. MACCOLL said it was obviously impossible to produce a pearlitic test bar free from graphite. In regard to the wearing resistance of molybdenum, it did impart certain important properties in that direction. There was a good deal of technical information on that matter available.

Wearing Properties

MR. A. W. WALKER (Huddersfield—Past-President) said that whilst the speaker's review of what could be done with these alloys was extremely interesting and informative in regard to special work, it had to be remembered that the facilities for using these irons as they should be used hardly existed in the average everyday foundry. Commenting on methods of application of the alloys, Mr. Walker felt one could not be sure of getting a positive value by adding at the spout. In regard to the observations on wearing properties of a cast iron, it must be kept in mind that Brinell hardness was not a sure guide as to wearing property. He was unaware that the addition of nickel necessarily increased heat resistance of any iron, though with the addition of chromium it might have some such effect. Whilst Mr. MacColl had given some valuable and useful data, yet the average foundryman must not expect to become an alloy expert merely because he was adding something at the spout. Further information as to estimating molybdenum would be welcome.

MR. MACCOLL replied that there were acknowledged experts who refused to agree that one could add alloys successfully at the ladle. On the other hand, the general consensus of opinion inclined to the idea that it could be done. It was not claimed that nickel in small quantity induced heat resistance, but did so when the iron became austenitic. Chromium did, of course, induce heat resistance.

Function of Graphite

MR. H. FORREST (Bradford—Past-President), speaking on the spout addition of alloys, said his personal experience of adding nickel at the spout was that the nickel content analysed out as calculated, but the addition must be made with care. The nickel should not be dumped into the metal stream as it comes from the tap hole, but should be added carefully whilst the ladle was filling. In regard to the addition of molybdenum, Mr. Forrest said it was as well to remember that this alloy was very powdery, and there was the possibility that if added at the spout a certain amount of it might be carried away. On the point as to wearing qualities, it seemed to him that this was not a matter they could ascribe to any particular element or any particular addition. The addition of alloys must be regulated to suit various types of metal structure. The formation of graphite had a very big bearing, and the absence of ferrite was essential. In reference to estimating molybdenum, as raised by Mr. Walker, Mr. Forrest said a method had been worked out by two members of the West Yorkshire Branch of the Institute, which had been adopted by the British Cast Iron Research Association and by a number of leading analysts, and in his (Mr. Forrest's) opinion it gave a better approximation of estimating molybdenum than anything else he knew.

MR. WALKER said he was, of course, glad to realise that members of the Branch were contributing to the development of the industry in the way mentioned by Mr. Forrest, but for ordinary foundry practice purposes it was as well to remember that the average foundryman had not quite the same sense of detailed care as an analyst in adding to the ladle.

The PRESIDENT (Mr. Worcester) said it was quite true, and important to remember, that the addition of "a handful of dope" in the form of alloys, must not be expected to be a cure-all for general foundry problems. The basis of alloy additions was that it must not be done with low carbon irons, or trouble would result.

Closing the discussion, the CHAIRMAN said he

felt Mr. MacColl's Paper would be regarded as a really concise collation of alloy data.

Vote of Thanks

Mr. S. W. Wise (Bradford, Hon. Secretary), proposing a vote of thanks to Mr. MacColl, said Mr. MacColl had condensed a mass of facts to an almost unbelievable extent to get his subject into one Paper.

Mr. W. Riley (Harrogate) seconded.

Mr. MacColl, in response, said one of the greatest values of preparing a Paper for submission to a technical audience was the extent to which one's own knowledge was widened by the research involved. The preparation of a Paper brought its own reward in that way, but he was grateful also for the observations made by members during the discussion.

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