Mr. W. B. Lake, J.P.,

President, 1940–41

PROCEEDINGS
OF THE
INSTITUTE OF BRITISH FOUNDRYMEN

VOLUME XXXIII. 1939-1940

Containing the Papers prepared for the Thirty-Seventh Annual Conference of the Institute and a selection of the Papers presented to the Branch Meetings held during the Session 1939-1940.

Edited by J. BOLTON, Assistant Secretary

Published by the
Institute of British Foundrymen

General Office :
Saint John Street Chambers, Deansgate, Manchester, 3
(Registered Office : 49, Wellington Street, Strand, London, W.C.2)

The Institute of British Foundrymen

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

Officers, 1940-41

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, "Cotswold," Barnt Green, 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, "Ashlea," 11, East Ave., Stoke Park, 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., Woodhill Grange, Woodhall Hills, nr. Stanningley, Yorks.

HON. TREASURER:

S. H. Russell, Bath Lane, Leicester.

SECRETARY 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.

COUNCIL

DELEGATES ELECTED AT ANNUAL GENERAL MEETING:

H. Bunting, 11, North Avenue, Darley Abbey, near Derby.
V. Delport, 7, Kenton Gardens, Kenton, Harrow, Middlesex.
A. B. Everest, Ph.D., B.Sc., The Mond Nickel Co., Ltd., Grosvenor House, Park Lane, London, W.1.
J. W. Gardom, 31, Wye Cliff Road, Handsworth, Birmingham, 20.
E. Longden, A.M.I.Mech.E., 11, Welton Avenue, Didsbury Park, Manchester.
R. A. Miles, 16, Deansgate, Manchester.
F. K. Neath, B.Sc., Hollywell House, Armley, Leeds, 12.
H. J. Roe, 29, Park Road, Moseley, Birmingham, 13.
P. A. Russell, B.Sc., Bath Lane, Leicester.
A. W. Walker, " Ailsa Craig," 113, Dalton Green Lane, Huddersfield.

BRANCH DELEGATES:

(*Branch represented shown in brackets.*)

H. J. Beck, Barton House, 12 Rosamund's Ride. Normanton, Derby. (East Midlands).
L. W. Bolton, A.M.I.Mech.E., 21, St. Paul's Square, Birmingham, 3. (Birmingham.)
W. N. Cook, B.Sc., 10, Stanley Road, Heaton Moor, Stockport. (Lancashire.)
J. W. Donaldson, D.Sc., Scott's Shipbuilding & Engineering Co., Ltd., Greenock, Scotland. (Scottish.)
G. Elston, R. & W. Hawthorn, Leslie & Co., Ltd., St. Peter's Works, Newcastle-upon-Tyne. (Newcastle.)
T. H. Gameson, 47, Somerset Road, Handsworth Wood, Birmingham. (Birmingham.)
A. Hares, 648, Stapleton Road, Bristol, 5. (Wales and Monmouth.)
J. Jackson, Howard & Bullough, Ltd., Accrington. (Lancashire.)
R. A. Jones, Butley Hall Close, Prestbury. (Lancashire.)
C. H. Kain, Lake & Elliot, Ltd., Albion Works, Braintree, Essex. (London.)
B. B. Kent, Cerne Easter, Westerham, Kent. (London.)
H. W. Lockwood, Stewarts & Lloyds, Ltd., Winchester House, Old Broad Street, London, E.C.2 (London.)
G. T. Lunt, " San Simeon," Newbridge Crescent, Wolverhampton. (Birmingham.)
N. McManus, M.B.E., The Argus Foundry, Thornliebank, near Glasgow. (Scottish.)
A. E. Peace, Caerhayes, Evans Avenue, Allestree, near Derby. (East Midlands.)
A. Phillips, 1, Melfort Avenue, off Edge Lane, Stretford, Manchester. (Lancashire.)
N. D. Ridsdale, F.C.S., Farnley Grange, Ingerthorpe, near Markington, Harrogate.
T. Shanks, Leslie Park, Denny, Stirlingshire. (Scottish.)
W. H. Salmon, Assoc. Met., 38, Glebe Road, Crookesmoor, Sheffield. (Sheffield.)
J. N. Simm, 61, Marine Drive, Monkseaton, Northumberland. (Newcastle.)
F. E. Steele, 130, Birley Moor Road, Frecheville, Sheffield. (Sheffield.)
W. G. Thornton, " Riverslea," Cottingley Bridge, Bingley, Yorks. (West Riding of Yorkshire.)
A. S. Worcester, Toria House, 162, Victoria Road, Lockwood, Huddersfield. (West 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.

N. C. Blythe, 24, Bagnell Road, King's Heath, Birmingham, 14.
A. A. Timmins, A.I.C., 21, St. Paul's Square, Birmingham, 3.

EAST MIDLANDS.

S. E. Dawson, F.I.C., 21, Middleton Crescent, Beeston, Notts.
S. A. Horton, Three, Mostyn Avenue, Littleover, Derby.

LANCASHIRE.

W. Holland, 24, Tresco Avenue, King's Road, Stretford, Manchester.
A. Boyes, "Roseville," 7, Kirkstall Road, Davyhulme, Manchester.

LONDON.

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

MIDDLESBROUGH AND DISTRICT.

D. R. Kinnell, A.M.Inst.B.E., Surrendon, Marton-in-Cleveland, Yorks.
J. K. Smithson, The North Eastern Iron Refining Co., Ltd., Stillington, Stockton-on-Tees. (*Acting Secretary.*)

NEWCASTLE-UPON-TYNE AND DISTRICT.

E. B. Ellis, 36, King's Road, Monkseaton, Northumberland.
C. Lashly, M.C., Sir W. G. Armstrong Whitworth & Co. (Ironfounders), Ltd., Close Works, Gateshead-on-Tyne.

SCOTTISH.

N. A. W. Erskine, Gartcows Drive, Falkirk, Scotland.
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.

W. J. Petersen, A.M.I.Mech.E., Austral Iron Works, P.O. Box 1098, 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.

H. A. MacColl, B. Sc., 87, Lincoln Road, Walsall.
S. W. Wise, 110, Pullan Avenue, Eccleshill, Bradford, Yorks.

Presidents and Honorary Secretaries of Sections

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.

A. Codd, 48, Moorlands Avenue, Lincoln.
E. R. Walter, M.Sc., The Technical College, Lincoln.

LANCASHIRE—BURNLEY SECTION.

J. Richardson, 38, Willows Lane, Accrington, Lancs.
H. Buckley, "Ellesmere," Norfolk Avenue, Burnley, Lancs.

LONDON—EAST ANGLIAN SECTION.

H. H. Shepherd, Crane, Ltd., Nacton Works, Ipswich, Suffolk.
J. L. Francis, A.M.I. Mech. E., Ranelagh Works, Ipswich, Suffolk.

SCOTTISH—FALKIRK SECTION.

Alex. Cunningham, 430, Main St., Stenhousemuir, Larbert.
T. R. Goodwin, "Viewfield," 126, Main St., 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., Lambert Street, Richmond, E. 1, Victoria, Australia.

SOUTH AFRICA.

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

AWARDS 1939-40

THE "OLIVER STUBBS" GOLD MEDAL

1940 Award to Mr. A. E. PEACE

" in recognition of the many valuable papers which he has presented to the Branches of the Institute and at Annual Conferences, and in recognition of the considerable experimental work which he has carried out as Convener of the Malleable Cast Iron Sub-Committee."

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 } Two Awards
E. Longden }
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.
1940.—A. E. Peace.

THE MERITORIOUS SERVICES MEDAL

The 1940 Award was made to Mr. JOHN BELL, in recognition of his valuable services to the Institute, particularly as Honorary Secretary of the Scottish Branch, which position he had held for seventeen years.

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.
1940.—J. Bell.

THE "E. J. FOX" GOLD MEDAL

1940 Award was made to Mr. W. J. DAWSON, Sheffield, in recognition of the valuable work he has done as Chairman of the Steel Castings Research Committee.

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

1937.—Professor Emeritus Thomas Turner, M.Sc.
1938.—J. E. Hurst, D.Met.
1939.—Dr. Harry A. Schwartz.
1940.—W. J. Dawson.

DIPLOMAS OF THE INSTITUTE

were awarded to :—

Mr. A. HOPWOOD, for his paper on " Phosphor-Bronze Castings of Heavy Sections," presented to the London Branch.

Mr. A. J. SHORE, for his paper on " Principles of Foundry Management," presented to the Birmingham Branch.

Mr. J. LAING, for his paper on " Gating and Pouring Temperatures in Non-Ferrous Foundry Practice," presented to the Lancashire Branch.

Mr. H. G. HALL, for his paper on " Malleable Cast Iron," presented to the Birmingham Branch.

Mr. A. MARSHALL, for his paper on " Production of Some Engineering Castings," presented to the Lancashire and Scottish Branches.

Mr. F. G. JACKSON, for his paper on " Some Jobbing Problems," presented to the Wales & Monmouth Branch.

Diplomas for Papers prepared for the cancelled Cheltenham Conference, were Awarded to :—

Mr. R. C. TUCKER, for his paper on " Chromium Heat-Resisting Cast Irons."

Mr. J. L. FRANCIS, for his paper on " The Production of Pressure-Resisting and High-Duty Iron Castings."

Mr. E. W. DOWSON, for his paper on " The Design of Test Pieces for Carbon Steel Castings," prepared jointly with Mr. C. H. Kain.

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.

1940.—Not delivered.

CONTENTS

Papers Prepared for the cancelled Cheltenham Conference :—

Papers Presented to Branches :—

VOLUME XXXIII

It will be noted that this volume contains no report of the 38th Annual Conference which was to have been held at Cheltenham on June 7th and 8th, 1940; the Conference had to be cancelled at short notice. The Annual General Meeting arranged to be held concurrently was postponed. Later His Majesty's Privy Council directed that during the present war the Council of the Institute should have power to dispense with the holding of Annual General Meetings if this was found necessary or desirable. The Council of the Institute availed itself of this authority, and no Annual General Meeting was held during 1940. The Papers prepared for the cancelled Cheltenham Conference are included in this volume.

The restrictions placed upon the consumption of paper have necessitated a reduction in the size of this volume.

Due to the postponement of the June Council meeting, the annual awards of Diplomas were not made until after the preparation of this volume had been commenced, and for this reason it was not found possible to group together those Papers in respect of which Diplomas were awarded. Such papers are, however, indicated by footnotes.

Editor.

The Institute of British Foundrymen

THE 37th ANNUAL REPORT

This report covers the period May 1, 1939, to April 30, 1940. The first four months of the period under review, namely, May to August, was a time of considerable activity, the most notable feature being the International Foundry Congress.

The outbreak of war found most of the Branches with their winter programmes arranged, but consequent upon the general uncertainty some delay was experienced by some Branches in commencing their winter's work. By the end of 1939 many of the Institute's activities were functioning under almost normal conditions, and it is satisfactory to be able to record that the Institute's membership shows an increase over that of twelve months ago, and the financial condition is satisfactory.

Deaths

It is with regret that the Council reports the deaths of ten members; amongst some of those who were well known were the following:—

Mr. W. H. Sherburn, a Life Member of the Institute, which he joined in 1906. He was the second President of the Lancashire Branch, and was prominently associated with that Branch for many years. He was awarded the Oliver Stubbs Medal in 1923.

Mr. J. E. Fletcher, who was one of the best-known personalities in the ironfoundry industry, and also in the wrought-iron industry. He was responsible for many new developments, was the author of numerous Papers, and was for many years consultant to the British Cast Iron Research Association.

Mr. J. H. Quicke, of Madeira, who took a close interest in the Institute's work in spite of his being resident so far away from this country.

Mr. C. M. Tate, a well-known member of the Lancashire Branch, who was a consistent and strong supporter of the Burnley Section of that Branch.

Mr. J. Chadwick, of Bolton, a Life Member.

The Council also records with regret the deaths of the following non-members:—

Mrs. J. Hepworth, wife of Mr. J. Hepworth, J.P., M.P., President in 1938-39.

Mr. R. S. MacPherran, an American metallurgist of world-wide reputation, who was particularly well known in this country, which he had visited on many occasions.

Mr. F. W. Bridges, who was responsible for the organisation of the numerous Foundry Exhibitions which were held in London, and whose hospitality had been enjoyed by members of the Institute on many occasions.

Honours Conferred Upon Members

Amongst those members who received honours during the period covered by this Report are the following:—

Sir Robert A. Hadfield, Bart., F.R.S., was made a Freeman of the City of Sheffield.

Prof. Sir H. C. H. Carpenter, F.R.S., was awarded the Honda Prize of the Japan Metallurgical Society and was the first foreigner to receive this award.

Mr. J. E. Hurst, Past-President, has received the Honorary Degree of Doctor of Metallurgy of the University of Sheffield.

Lord Austin of Longbridge has been elected President of the British Cast Iron Research Association.

Mr. C. W. Bigg. Past-President, was appointed Director for Iron Castings of the Iron and Steel Control of the Ministry of Supply.

Prof. J. H. Andrew, D.Sc., has been elected President of the Institute of Vitreous Enamellers.

Finance

The year 1939 was somewhat difficult financially, but it is satisfactory to report that the year's working showed a surplus of £25 income over expenditure. The very heavy expenditure incurred on account of the International Foundry Congress was entirely met by the funds of the Congress itself, which were derived from voluntary contributions and by payments from those who participated. The heavy cost of printing the Papers was largely met by the registration fees.

The item of printing and stationery, however, shows an increase over the same item in 1938, and this is due to a reserve having been made for the increased cost of the exceptionally large volume of "Proceedings" published in April, 1940. This reserve is a special item of expenditure, and will not be a recurring charge.

Awards

E. J. Fox Gold Medal.—On the recommendation of the Assessors, Sir W. J. Larke, and Prof. Sir H. C. H. Carpenter, the E. J. Fox Gold Medal for 1939 was awarded to Dr. H. A. Schwartz, of Cleveland, Ohio, "in recognition of the outstanding services which he has rendered to the development of malleable iron castings." The Medal was presented to Dr. Schwartz by the Lord Mayor of London at the opening meeting of the International Foundry Congress.

The Council has accepted the recommendation of the Assessors to make the 1940 award to Mr. W. J. Dawson, chairman of the Steel Castings Research Committee, "in recognition of his services to the industry as chairman of this Committee, and in other capacities."

Oliver Stubbs Gold Medal.—The Oliver Stubbs Gold Medal for the year 1939 was awarded to Mr. J. G. Pearce, director of the British Cast Iron Research Association, and a member of the Council of the Institute, "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 presentation was made to Mr. Pearce by the Lord Mayor of London at the International Foundry Congress.

Meritorious Services Medal.—The Meritorious Services Medal was awarded to Mr. J. E. Cooke for his services in an administrative capacity, particularly as Honorary Secretary of the Lancashire Branch.

Diplomas.—The following Diplomas were awarded in June, 1939, for Papers presented to Branches during the previous winter session:—

Mr. S. Carter and Mr. A. W. Walker, West Riding of Yorkshire Branch.

Mr. W. W. Braidwood, Scottish Branch.

Mr. R. D. Lawrie, Lancashire Branch.

Mr. W. West and Mr. C. C. Hodgson, Lancashire Branch.

Mr. J. Dearden, Scottish Branch.

Diplomas were also awarded to the following authors for Papers presented to the International Foundry Congress:—Mr. G. L. Bailey, Mr. F. A. Melmoth, Mr. A. J. Murphy, Mr. J. J. Sheehan, and Mr. G. R. Shotton.

Buchanan Medals and Prizes.—The awards of the Buchanan Medals and Prizes are given later in this Report under the section, Educational Work.

John Surtees Memorial Competition.—The examinations for the award of the John Surtees Medals and Prizes are held alternately by the Scottish and Newcastle Branches. The awards in the 1940 competition conducted by the Scottish Branch are as follow:—

Gold Medal.—John Allan, Glasgow.

Silver Medal.—Christopher A. Kay, Motherwell.

Supplementary Prizes.—Robert B. Jamieson, Glasgow; A. Mackintosh, Glasgow.

Edward Williams Lecture

The Fourth Edward Williams Lecture was delivered by Prof. W. L. Bragg, O.B.E., M.C., D.Sc., M.A., F.R.S., at the opening session of the International Foundry Congress in June, and was on "The Atomic Pattern of Metals."

International Foundry Congress

This Institute was entrusted by the International Committee of Foundry Technical Associations with the organisation of the 1939 International Foundry Congress. The Congress was held in the Dorchester Hotel, London, from June 12 to 17, and was attended by some 650 members of various foundry associations, and ladies, representing 22 countries. Mr. W. B. Lake, J.P., presided over the opening meeting, and he and the Vice-Presidents, Major R. Miles and Mr. D. H. Wood, together with Mr. F. J. Cook, Past-President, presided over other meetings.

On the Sunday previous to the opening of the Congress a number of overseas visitors together with some of the visitors to the Congress from this country, and their ladies, were entertained at a garden party by Mr. Barrington Hooper, C.B.E., and Mrs. Hooper, at their home "Southward," Harrow.

The Congress was officially opened by the Rt. Hon. the Lord Mayor of London, Sir Frank Bowater, on Tuesday, June 13. The President then delivered his address, and the Edward Williams Lecture was delivered by Prof. W. L. Bragg.

On the evening of the same day, the Congress was honoured by His Majesty's Government, who gave a reception in honour of the Congress at Lancaster House, at which the guests were received by the Rt. Hon. Viscount Runciman, P.C. (Lord President of the Council), and the Viscountess Runciman.

On the evening of Wednesday, June 14, the banquet was held, at which the Rt. Hon. Oliver Stanley, M.C., M.P., President of the Board of Trade, and Dr. Guido Vanzetti, President of the International Committee of Foundry Technical Associations, were the principal guests.

On Thursday, June 15, members of the Congress and ladies were entertained at a reception and dance by the President, Mr. W. B. Lake, J.P., and Mrs. Lake, and on Saturday, June 17, members and ladies participated in a trip to Windsor and on the Thames.

No fewer than 35 Papers on a variety of subjects of interest to the modern foundryman were presented by authors of several different nationalities. Of special interest were a number of Papers on light alloys, and a special session on steel-foundry practice, held in conjunction with the Iron and Steel Institute.

Members visited a number of works in the London area, also at Ipswich, Dunstable, Dartford, and in other towns easy of access from London. Various visits to works, art galleries and other places of interest were arranged for ladies, including a visit to the interesting Barbers' Hall.

Considerable hospitality was accorded by various individuals, especially by the directors of some of the works which were visited.

Table I.—*Changes in Membership*, 1939–1940.

	Subscribing firms.	Members.	Associate members.	Associates.	Associates (students).	Total.
At April 30, 1939	74	974	1,094	133	32	2,307
Additions and transfers from other grades	6	63	77	7	6	159
	80	1,037	1,171	140	38	2,466
Loss and transfers to other grades.. ..	2	41	49	10	1	103
At April 30, 1940	78	996	1,122	130	37	2,363

The Council expresses its indebtedness to:—

His Majesty's Government, and the Rt. Hon. Viscount Runciman and Viscountess Runciman.

Sir Frank Bowater, Kt.

The Rt. Hon. Oliver Stanley, M.C., M.P.

The Patrons of the Congress.

Prof. W. L. Bragg, O.B.E., M.C., D.Sc., M.A., F.R.S.

Mr. and Mrs. Barrington Hooper.

Mr. J. Hepworth, J.P., M.P., Ex-President.

The Ford Motor Company (England), Limited

Crane, Limited.

Mr. A. W. G. and Mr. T. G. Bagshawe for their hospitality, and to all other firms who arranged visits to their works, and arranged hospitality.

The Worshipful Company of Barbers.

The Congress Organisation Committee.

Mr. V. Delport, Secretary of the London Branch Organisation Committee, and to other members of the Committee.

Mr. V. C. Faulkner, Past-President, and staff of "The Foundry Trade Journal."

Subscribers to the Congress funds, especially to the Foundry Trades' Equipment and Supplies Association, for their very handsome donation.

All the authors of Papers presented to the Congress, and to their respective firms.

Dr. Guido Vanzetti, President of the International Committee of Foundry Technical Associations, and to the officials of the various Associations represented on the Committee.

All who acted as Stewards, and to the many members of the Institute, particularly of the London Branch, who undertook willingly the very considerable amount of work involved.

Post-Congress Tour

The Post-Congress Tour which followed the International Congress enabled a number of the overseas visitors to see much of the industrial activities and something of the scenic beauty of Great Britain.

The tour lasted for two weeks, about 100 visitors participated in the first week, whilst nearly 40 remained for the second week. Six Branches of the Institute participated, and entertained the visitors for periods in their respective areas; these Branches were the Birmingham, East Midlands, Sheffield, Lancashire, Scottish and Newcastle Branches.

Through the efforts of the Branch members, and by the courtesy of various firms, visits were made to some of the most important foundries in the country. Considerable hospitality was given to the visitors, and especially to the ladies, for whom programmes were carried out in each centre.

This tour was considered by all the visitors to be most successful, and they were profuse in their expression of thanks for the kindness and hospitality which they received.

For the success of this tour, the Institute is greatly indebted to:—

Presidents, Secretaries, Councils and members of the Branches which were visited.

The various firms who invited the visitors to inspect their plants.

The Civic Authorities in various cities and towns for their interest and practical help, par ticularly to the Lord Provost of Glasgow for the magnificent Reception which he gave.

All those who provided the necessary funds, and to all who dispensed hospitality in any way.

Branch Activities

All the Branches with the exception of two have carried out programmes of meetings with Papers and discussions. Special local difficulties prevail in the case of the two Branches whose session's programmes were cancelled, but even these Branches endeavoured to hold meetings in the spring.

The energetic manner in which Branch officials and Branch Councils faced the difficult situation has been responsible for the successful winter's work, which is just concluding, and the Council expresses its gratitude to these officials, and to the members of the Branches for their efforts. It is significant that a large proportion of the Branch meetings have been well attended, and the standard of Papers and discussions has been high.

Table II.—*Analysis of Membership at April 30, 1940.*

Branch.	Subscribing firms.		Members.*		Associate members.		Associates.		Associates (students).		Total.	
Birmingham	8	(8)	160	(157)	157	(157)	16	(15)	8	(7)	349	(344)
East Midlands	4	(4)	70	(67)	97	(102)	3	(5)	2	(2)	176	(180)
Lancashire	14	(14)	133	(127)	209	(198)	27	(25)	1	(—)	384	(364)
London	10	(10)	205	(203)	121	(125)	3	(5)	—	(—)	339	(343)
Middlesbrough	1	(1)	30	(27)	48	(44)	8	(8)	7	(7)	94	(87)
Newcastle	6	(7)	32	(34)	27	(30)	55	(56)	11	(11)	131	(138)
Scottish	7	(7)	90	(99)	193	(185)	4	(6)	1	(2)	295	(299)
Sheffield	7	(6)	97	(97)	68	(69)	2	(2)	1	(1)	175	(175)
South African	13	(10)	46	(41)	32	(27)	9	(7)	—	(—)	100	(85)
Wales and Mon ..	3	(2)	49	(44)	53	(51)	—	(—)	6	(2)	111	(99)
W.R. of Yorks	4	(5)	57	(55)	95	(89)	3	(3)	—	(—)	159	(152)
Unattached	1	(—)	27	(23)	22	(17)	—	(1)	—	(—)	50	(41)
	76	(74)	996	(974)	1,122	(1,094)	130	(133)	37	(32)	2,363	(2,307)

Figures in brackets are for April 30, 1939.

* Including representatives of Subscribing Firm Members.

The South African Branch makes steady progress, and is undertaking certain special work for the benefit of its members, in addition to its routine activities. A new departure was instituted by this Branch, in that it contributed a Paper to the International Foundry Congress, the Paper being presented by the Branch President, Mr. A. H. Guy.

Educational Work

The following are the results of the examinations held under the auspices of the City and Guilds of London Institute and in conjunction with this Institute, in April and May, 1939:—

	No. of candidates.	Pass 1st class.	Pass 2nd class.	Percentage of passes.
Patternmaking— Intermediate grade	61	17	27	72.6
Patternmaking— Final grade ..	24	18	3	87.5
Foundry practice and science	110	35	39	67.2

Prizes were awarded to:—

Patternmaking—*Intermediate Grade*

Mr. Lance Bell, Constantine Technical College, Middlesbrough. Bronze Medal of the City and Guilds of London Institute.

Patternmaking—*Final Grade*

Mr. Walter Glover, Coventry Technical College. Silver Medal of the City and Guilds of London Institute.

Foundry Practice and Science

Mr. Lance Bell, Constantine Technical College, Middlesbrough. Bronze Medal of the City and Guilds of London Institute.

Buchanan Silver Medals and Book Prizes were awarded to:—

Patternmaking—*Final*

Buchanan Silver Medal—Mr. William Charles Marshall, Abbey Street School, Derby.

Buchanan Book Prizes—Mr. Walter Glover, Coventry Technical College.

Mr. Alfred Eric Harlow, Coventry Technical College.

Mr. Maurice Thurlow, Coventry Technical College.

Foundry Practice and Science

Buchanan Silver Medal—Mr. John Noel Sherar, Abbey Street School, Derby.

Buchanan Book Prizes—Mr. Lance Bell, Constantine Technical College, Middlesbrough.

Mr. Albert Horton, Sheffield University.

Mr. John Matthew Costello, Sheffield University.

National Certificates in Mechanical Engineering

These certificates are issued by the Board of Education and the Institution of Mechanical Engineers, and endorsed by the President of this Institute in respect of special foundry subjects. Forty-four National Certificates have been so endorsed during the year, making a total of 220 since the scheme was commenced.

The Degree Course in Foundry Metallurgy at the University of Sheffield continues to make progress.

The British Foundry School has completed four successful years, but has unfortunately been suspended temporarily due to the war.

The first Fellowship offered by the Worshipful Company of Founders for advanced training in foundry work has been won by Mr. Ludlow, a student of the British Foundry School.

Kindred Associations

Close relations continue between the Institute and kindred Institutions, a number of joint meetings having taken place during the year. The Council is particularly gratified that the Iron and Steel Institute accepted an invitation to participate in a joint meeting on steel castings at the recent International Foundry Congress and thus enabled the Institute to reciprocate the Iron and Steel Institute's hospitality which has been enjoyed on several occasions.

International Relations

The close relations which have existed for many years between the Institute and corresponding bodies in other countries were further cemented by the International Foundry Congress held under the auspices of the Institute in June last. The outbreak of war has naturally interrupted any further development of this character and the International Foundry Congress arranged to be held in Italy during 1940 has been postponed until a more opportune time.

The International Committee of Foundry Technical Associations and the International Committee on Testing Cast Iron held meetings in London in June, the former under the Presidency of Dr. Guido Vanzetti, of Milan, a member of the Institute, and the latter under Dr. J. E. Hurst, a Past-President of the Institute.

The Secretary of the Institute was appointed Honorary Secretary of the latter Committee and continues to act as Secretary of the former. The active work of both Committees has now been suspended.

Dr. Hurst attended the forty-third annual convention of the American Foundrymen's Association at Cincinnati in May, 1939, and presented the Institute's official Exchange Paper, the author of which was Mr. F. Whitehouse. The Exchange Paper on behalf of the Institute which has been prepared by Mr. J. J. Sheehan will be presented at the forthcoming convention of the American Foundrymen's Association to be held at Chicago.

Among the many Papers presented to the International Foundry Congress, were no fewer than eleven Papers presented on behalf of various overseas foundry associations, and this year a Paper is being presented on behalf of the American Foundrymen's Association by two Canadian authors, namely, Mr. A. E. Cartwright and Mr. C. C. Brisbois.

By-Laws and Supplementary Charter

The By-laws which were approved at the adjourned annual general meeting on October 15, 1938, were submitted to His Majesty's Privy Council, together with an application for a Supplementary Charter rendered necessary in order to give the necessary powers to adopt certain of the new By-laws. The Privy Council has not been able to grant this Charter and it has been decided to leave the matter in abeyance until the end of the war.

Publications

For some years the Board of Development has given careful consideration to improvements in the methods and dates of publication of the Institute's " Proceedings " in order to give better service to members. The first step in the realisation of the objects has been achieved in Volume XXXII of the " Proceedings " published in April this year. A larger-sized page has been introduced, the lay-out has been altered drastically and a new binding has been used. Many letters of appreciation and approval of the new format have been received. It is hoped that the next issue will be further enhanced by the use of a more modern type face. Special Report No. 2, being a report of the Melting Furnaces Sub-Committee, was also issued during the year.

British Cast Iron Research Association

The work of the British Cast Iron Research Association proceeded normally until the outbreak of war. From July, 1939, the abstracts on vitreous enamelling previously published in the quarterly Bulletin were issued as a separate publication—" Enamelling Abstracts "—sent to members of the British Cast Iron Research Association and the Institute of Vitreous Enamellers and available to others interested. The publication is quarterly.

The Association is registered by the Department of Scientific and Industrial Research as a central scientific agency for the industry and will act as an organised scientific unit, so that the services normally available are being continued. At the suggestion of the Home Office, the Association is acting through the Anti-Glare Committee, of which the director is chairman, as the body approving schemes for eliminating glare from foundry furnaces, in accordance with the requirements of the Civil Defence Act. Foundries may obtain a State grant up to 50 per cent. of the capital cost of an approved scheme.

Both as part of its ordinary work and also through the Ironfounders' National Confederation, the Association is actively assisting in the extended uses of cast iron, in view of the national emergency.

Council

Four meetings of the Council and fifteen meetings of the Executive Committee and other standing committees have been held. These meetings have been held in London and Birmingham.

Of the ten members of the Council who are elected by ballot for a period of two years, five retire each year and the five who were to have retired at the annual general meeting which was arranged to be held on June 8 were:—Mr. H. Bunting, Dr. A. B. Everest, Mr. J. W. Gardom, Mr. B. Hird, and Mr. F. K. Neath. These gentlemen offer themselves for re-election and are eligible for re-election for a further period of two years.

Officers

The Council has unanimously requested the President and the Senior and Junior Vice-Presidents to accept nomination for re-election to their respective offices for the year 1940-41, and the officers concerned have agreed to accede to these requests.

The Council wishes to express its thanks to Mr. S. H. Russell, Past-President and Honorary Treasurer, for the care with which he has managed the finances of the Institute and also for the work which he has carried out as Chairman of the Organisation Committee. This office has involved an immense amount of detailed work which Mr. Russell has carried out with considerable devotion and ability.

The Council also wishes to remind members that Mr. Russell continues to act as Chairman of the Advisory Committee of the City and Guilds of London Institute in connection with Examinations in Foundry Practice and Science and Patternmaking, a position which he has held with considerable success for several years.

The Council also wishes to thank Mr. J. W. Gardom, Convener of the Technical Committee, for his work and his devotion to the interests of the Committee during an exceptionally difficult period.

The Council has agreed to loan the services of the Secretary to the Iron and Steel Control of the Ministry of Supply and suitable arrangements have been made to continue the secretarial work of the Institute through the Assistant Secretary and under the direction of the Secretary.

Annual Conference

In accordance with the normal rota, it had been arranged that the Conference in 1940 should take place at Middlesbrough and the Middlesbrough Branch had already made considerable progress with the arrangements. The outbreak of war necessitated that the matter be reconsidered and it was decided to hold a short Conference at an easily accessible centre; after careful consideration Cheltenham was chosen. The Thirty-Seventh Annual Conference will, therefore, be held at Cheltenham on Friday and Saturday, June 7 and 8. The Council gratefully acknowledges the assistance which it is receiving in the organisation of the Conference from the civic authorities in Cheltenham and the hospitality which is being tendered by His Worship the Mayor. The Council is grateful to the Middlesbrough Branch for agreeing to postpone its claim to a Conference until a later date.

W. B. Lake, *President.*
T. Makemson, *Secretary.*

The Council feels that it is expressing the feelings of all members of the Institute in tendering its congratulations to the President, Mr. W. B. Lake, on the attainment of his seventieth birthday, which occurred during the Post-Congress Tour in June last. A presentation was made to him by the members of the tour in Manchester, and on his return to Braintree he was the recipient of several presentations including a portrait in oils from his co-directors, staff, and workpeople.—T.M

EIGHTH ANNUAL REPORT OF THE TECHNICAL COMMITTEE

The work of the Technical Committee is one of the few activities of the Institute which have been interrupted by the war. Membership of the Committee necessitates the carrying out of a certain amount of work of a technical nature, which is done by the members voluntarily in their own time. The war has brought its own especial problems and intense activity to most of these members in regard to the firms with which they are associated, and it has not been possible therefore for them to devote quite the same amount of time to the Technical Committee activities.

In spite of these preoccupations, the members have accomplished a good deal of work during the year. Close co-operation has been maintained in the preparation and revision of specifications of interest to the industry. Several sub-committees have made progress with some of the investigations which they have in hand, and the Melting Furnaces Sub-Committee has completed a valuable piece of work by the publication of Special Report No. 2 on "Melting Furnaces for Grey Cast Iron."

The question of policy during the war period has been given very careful consideration, and whilst realising that some of the ordinary work of the Committee may have to be suspended for the war period, it is recognised that the war conditions have brought their problems to the industry, in the solving of which the members of the Committee are particularly fitted to assist. As far as possible their experience and knowledge will be placed at the disposal of the industry, and of the various official bodies who are working in conjunction with it. The Committee will keep its organisation intact, but it will hold its meetings less frequently than before the war. Its present work will be completed as far as possible, and put into a condition where it can be resumed when circumstances are more favourable. The Committee will offer its services in an advisory capacity to various official bodies.

J. W. Gardom, *Convener.*

BALANCE SHEET 31st December, 1939

LIABILITIES.

	£ s. d.	£ s. d.
SUBSCRIPTIONS PAID IN ADVANCE		91 12 0
SUNDRY CREDITORS		743 2 0
SECRETARY'S POLICY FUND		18 8 8
THE OLIVER STUBBS MEDAL FUND :—		
Balance from last Account	212 19 3	
Interest to date	12 3 10	
	225 3 1	
Less : Cost of Medal	10 2 0	
		215 1 1
THE BUCHANAN MEDAL FUND :—		
Balance from last Account	121 15 10	
Interest to date	4 11 9	
	126 7 7	
Less : Cost of Medals and Prizes	6 6 7	
		120 1 0
THE E. J. FOX MEDAL FUND :—		
Balance from last Account	496 2 8	
Interest to date	15 16 0	
	511 18 8	
Less : Cost of Medal	15 17 6	
		496 1 2
TECHNICAL DEVELOPMENT FUND :—		
Balance from last Account	505 9 5	
Interest to date	13 4 7	
		518 14 0
ACCUMULATED FUND :—		
Balance 31st December, 1938	2,527 11 11	
Transfer from International Conference Fund	40 18 11	
Excess of Income over Expenditure for the year ended 31st December, 1939	25 18 3	
	2,594 9 1	
Deduct : Costs on Royal Charter to date	76 16 0	
		2,517 13 1
		£4,720 13 0

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

19/21, Queen Victoria Street,
London, E.C.4.
12th April, 1940.

ASSETS.

	£ s. d.	£ s. d.
CASH IN HAND OF SECRETARIES :—		
Lancashire Branch	19 17 11	
Birmingham Branch	39 17 3	
Scottish Branch	38 15 11	
Sheffield Branch	49 19 5	
London Branch	58 13 4	
East Midlands Branch	22 7 8	
West Riding of Yorkshire Branch	10 6 11	
Wales and Monmouth Branch	33 15 4	
Middlesbrough Branch	5 14 7	
Newcastle Branch	19 0 2	
South African Branch	36 14 4	
		335 2 10
CASH IN HAND—SECRETARY'S POLICY FUND		18 8 8
Do. HEAD OFFICE PETTY CASH		0 1 10
SUNDRY DEBTORS :—		
Subscriptions due and subsequently received		33 1 6
Amount in hands of Solicitors re proposed new Charter		73 4 0
LLOYDS BANK LTD.		462 8 2
THE OLIVER STUBBS MEDAL FUND :—		
£342 5s. 7d. Local Loans 3% Stock at cost	200 0 0	
Balance at Lloyds Bank Ltd.	15 1 1	
		215 1 1
THE BUCHANAN MEDAL FUND :—		
£125, 3½% Conversion Stock at cost	98 6 9	
Balance at Midland Bank	21 14 3	
		120 1 0
THE E. J. FOX MEDAL FUND :—		
£462 19s. 3d., 3½% Conversion Stock at cost	500 0 0	
Less : Overdraft at Lloyds Bank	3 18 10	
		496 1 2
TECHNICAL DEVELOPMENT FUND :—		
Balance at Manchester & Salford Savings Bank		518 14 0
INVESTMENTS :—		
£650, 3½% War Loan at cost	630 8 4	
£653 19s. 0d., Local Loans 3% Stock at cost	451 13 9	
£964 5s. 1d., 3% 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	55 14 9	
Less : Depreciation 10%	5 11 6	
		50 3 3
SUPERANNUATION INSURANCE :—		
Unexpired premium		18 8 7
		£4,720 13 0

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.

INCOME & EXPENDITURE ACCOUNT for the Year Ended 31st December, 1939

EXPENDITURE.

1938 £ s. d.	1938 £ s. d.		£ s. d.	£ s. d.
158 18 10		Postages		165 4 9
834 2 9		Printing and Stationery including printing of "Proceedings"		1,101 12 1
153 2 8		Council Finance and Annual Meeting Expenses		110 4 8
3 0 0		Medal—Past President		
		Branch Expenses :—		
	125 10 6	Lancashire................	105 11 7	
	86 5 0	Birmingham	80 2 9	
	76 15 8	Scottish	74 17 8	
	49 18 6	Sheffield	32 2 1	
	89 7 4	London	46 9 4	
	54 1 0	East Midlands	51 12 4	
	35 6 2	Newcastle	30 3 10	
	35 18 3	West Riding of Yorkshire ..	43 3 2	
	34 16 4	Wales and Monmouth	20 6 3	
	24 13 1	Middlesbrough	23 15 0	
	76 13 5	South Africa	69 14 8	
689 5 3				577 18 8
12 12 0		Audit Fee and Accountancy Charges		12 12 0
	146 10 5	Incidental Expenses........		148 5 11
		Subscriptions :—		
		British Standards Institution	10 10 0	
	13 5 0	Joint Commission on materials	5 5 0	
159 15 5				15 15 0
		Salaries :—		
886 17 9		Secretary and Staff		907 11 11
55 5 10		Superannuation Insurance (Secretary)		55 5 10
13 12 0		Rent, Rates, &c., of Office *less* Received		103 3 3
		Subscription :—		
5 0 0		International Committee ..		
6 3 10		Depreciation of Furniture ..		5 11 6
		John Surtees Memorial Examination :—		
10 4 0		Grants to Branches		6 6 0
3,088 0 4				3,209 11 7
122 11 10		Excess of Income over Expenditure carried to Balance Sheet		25 18 3
3,210 12 2				£3,235 9 10

INCOME

	£ s. d.	£ s. d.	1938 £ s. d.	1938 £ s. d.
Subscriptions Received :—				
Lancashire Branch............		453 17 0		443 2 0
Birmingham Branch		477 8 6		457 16 6
Scottish Branch		375 5 6		401 12 6
Sheffield Branch		245 13 0		261 19 6
London Branch		503 9 0		490 17 6
East Midlands Branch		225 4 0		243 12 0
Newcastle Branch		133 11 0		129 0 0
West Riding of Yorkshire Branch		203 14 0		168 10 6
Wales & Monmouth Branch....		122 1 0		136 15 0
Middlesbrough		111 15 0		87 12 6
Unattached Members		51 11 9		43 9 1
South African Branch		156 9 0		154 7 0
		3,057 19 4		3,018 14 1
Add :—				
Subscriptions in Advance 1938	164 1 0		223 19 0	
Subscriptions Due 1939	33 1 6	197 2 6	74 3 6	298 2 6
		3,255 1 10		3,316 16 7
Less :—				
Subscriptions in Advance 1939	91 12 0		1 0	
Subscriptions Due 1938	74 3 6	165 15 6	82 2 0	246 3 0
		3,089 6 4		3,070 13 7
Conference Registration Fees. .				29 12 6
Polish Conference Surplus				0 10 10
Sale of "Proceedings," Etc. ..		24 12 1		16 4 0
Interest on Investments and Cash on Deposits		96 0 10		85 6 1
John Surtees Memorial Examination Surplus		24 12 5		6 0 8
Profit on Sale of Badges		18 2		2 4 6
		£3,235 9 10		£3,210 12 2

PAPERS PREPARED FOR

ANNUAL CONFERENCE

Paper No. 706

Chromium Heat-Resisting Cast Irons

By R. C. TUCKER, M.A. (Member)

It is the author's intention to portray the present knowledge of heat-resisting cast irons, with special reference to chromium cast irons. He will only touch upon some of the highly-alloyed cast irons, Ni-Resist, Nicrosilal, Silal and Cralfer, because these are the results of investigations carried out by large research organisations, and there is a constant flow of reports concerning these alloys emanating from the interested organisations. There is no central industrial or research organisation devoted to the study and commercial application of chromium alloys as in the case of nickel and molybdenum alloys. The result is that published data tend to have an "interested" bias, and it will do these alloys no harm for someone to point out in as unbiassed a manner as possible the results which can be obtained by the use of chromium alone.

The simplest type of heat-resisting cast iron available to-day is "hematite," which loose but traditional phrase covers a wide range of structures and types. By weight, it is the most important heat-resisting cast iron and in spite of the long period over which it has been used in heat-resisting conditions there are still many problems associated with its use.

The Ingots Committee of the Iron and Steel Institute has, as all cast-iron metallurgists know, published some very interesting reports on the life of "hematite" cast-iron ingot moulds, and their conclusions are roughly as follows:—

(*a*) It is only possible to determine the factors affecting the life of ingot moulds by the careful statistical analysis of a large number of carefully controlled service tests.

(*b*) The presence of 10 per cent. of steel in the cupola charge can have a beneficial effect in some cases.

(*c*) The presence of up to 0.3 per cent. of phosphorus has a beneficial effect and is not more common because of the widespread practice of introducing scrap moulds into the acid open-hearth process.

It is very likely that no such complete analysis of service results has been attempted in any other type of service. Most of the service conditions of heat-resisting cast iron are not under strict control and service records unless of a statistical nature are distinctly misleading in many cases.

"Hematite" cast iron does not resist oxidation, is very prone to "growth" and is mechanically weak on "static" tests. Its only good quality is its ability to resist major cracking caused by heat shock, and there seems to be distinct evidence that the worse it behaves when tested in the ordinary ways, the better will be its resistance to heat shock. The present method of testing for heat-shock resistance is to water-quench 1-in. dia. test-pieces from 650 deg. C. a number of times. This test, like many other laboratory tests, has many limitations because it is difficult to introduce the factors of thickness and shape, and, in any case, almost any hematite cast iron will resist this test for a large number of quenches.

It has been found, however, in studying ingot moulds (*loc. cit.*) that certain microstructures are desirable for the avoidance of major cracking (Fig. 1). The coarse graphite is surrounded by ferrite with only small amounts of pearlite and other impurities, and this is perhaps the best test that can be applied in the absence of service records.

Pig-Casting-Machine Moulds

Some years ago the author encountered some surprising results in the manufacture of pig-casting-machine moulds, and a description of the case will, no doubt, raise a sympathetic feeling in the minds of many foundrymen.

Tradition said that such moulds should be made in pure West Coast hematite. The Ingot-moulds Sub-committee and private investigation were beginning to point to the use of some steel and phosphoric iron as indicated above.

Boldly, these were introduced and two sets of moulds to the same design went through the shops at the same time and were installed indiscriminately on two new machines. In a few months, from one machine, came a serious complaint of major cracking, from the other a satisfactory report. Visits to the machines and careful investigation showed that the service conditions were widely different. The replace moulds for the cracked moulds were made in pure West Coast hematite, and the complaints ceased for a time. Later, however, several more orders were received, indicating a continuance of rapid failure and similar lack of satisfactory service from other suppliers! Obviously, if the moulds are of uniform quality, and the machine starts with all new moulds, there will come a period of very heavy replacements followed by an apparent improvement, followed again by a period of fairly heavy replacements, the intensity of these periods gradually dying down to a fairly uniform wastage.

Fig. 1.—Microstructure of Good Hematite. × 500.

A heavy mild-steel frame mounted on trunnions was made and a set of six moulds mounted on it:—

(*a*) Two in West Coast hematite of an approved analysis.

(*b*) Two of a 10 per cent. mild-steel mix with East Coast hematite and of almost identical chemical analysis.

(*c*) One mould of (*a*) plus 1 per cent. nickel.

(*d*) One mould of (*a*) plus 1 per cent. copper.

These were limed and repeatedly filled with molten foundry iron, and cooled with a hose as nearly as possible as in practice. They were rotated and tipped, " stickers " were removed with a crowbar and the underside was hosed for a similar period. They were then re-limed and refilled with molten metal as soon as possible. The two alloyed moulds showed early cracks at the lip which gradually increased in size. The other moulds showed no sign of major cracking for 200 casts, except for some very small cracks on the lips, after 100 casts, which appeared unchanged after 200 tests.

The moulds were then placed in general use for casting spare metal in the foundry, and after several months without liming or quenching gradually failed by growth and the tearing out of lumps from the bottom by " stickers." This test reproduced as nearly as possible service conditions in a normal pig-casting machine and agreed with the results obtained in the complaint-free machine.

Fig. 2.—Low-Temperature Carbonisation Retort Castings in Low-Chromium Iron.

The other machine was operating in conditions which are comparatively new to the pig-iron industry, and these conditions lead to rapid failure of almost any type of cast-iron mould. This has been confirmed by two other cases. This example shows how departure from precedent can bring a host of recriminations about the ears of the foundry technical staff from customer, sales and drawing office if it coincides with a change in service conditions.

The improvements to be expected by departing from precedent are probably small, and of the order of a 10 to 15 per cent. increase in life at the most, and the author is now firmly convinced that the introduction of steel and phosphorus into an established good hematite mixture is a step in the wrong direction where heat shock is probable.

Recently, the B.C.I.R.A. tried their titanium-carbon dioxide method of refining the graphite in these irons, and a set of ingot moulds was cast. Some improvement in life was noticed, but the test should be done in moulds that are prone to periods of major cracking, *i.e.*, mould designs that are on the limit of safety, and the results of such tests are awaited with interest. The refining of the graphite should improve the resistance to growth.

High-Duty Cast Iron

The next group of cast irons used for heat resistance is synonymous with the group known as high-duty cast irons and made usually for their mechanical properties. Of these the earliest was " Lanz Perlit." They have a rather more stable pearlite and finer graphite than ordinary foundry iron. These two factors enabled experimenters (*e.g.*, Dawson) to demonstrate their superior growth resistance at 450 to 550 deg. C. At higher temperatures, however, and for intermittent service the difference is very small. They generally do not resist to scaling or heat shock, and on short-time tensile tests their strength is only maintained up to 500 deg. C. These irons contain no carbide stabilisers or special strengthening elements and are not very important from this point of view.

Low-Alloy Cast Irons

The third group consists of low-alloy cast irons designed for specific purposes, and the influence of special elements begins to be felt. These low-alloy irons are not resistant to heat shock and are only very slightly more scale resistant than ordinary engineering cast irons (*q.v.*). The properties which must be sought are, therefore, machinability, good foundry properties, growth resistance, toughness and strength at operating temperatures.

The author has found, from practical experience, that these low-alloy irons depend for their properties on very close control of the structure and analysis, and a combined carbon of 0.8 to 1.3 per cent. is aimed at in most cases. It is only possible to control the structure by the use of modern methods, as the old methods of chromium addition were uncertain. Much has been written about the difficulty of dissolving high-carbon ferro-chrome in cast iron, and it is true that, with dull iron, hard spots are often encountered. The problem is not one of melting the ferro-chrome, but is one of dissolving it, and the proper operation of the cupola gives metal hot enough to *dissolve* completely the high *melting* carbides of 4 to 6 per cent. carbon ferro-chrome.

The addition of chromium can be accomplished in various ways. Lump ferro-chromium in the cupola often spreads to other charges and is usually unsuitable except for melts of some tons collected in one ladle and well mixed. Ferro-chrome briquettes are much more satisfactory, and a trial carried out on a 10-ton casting when these briquettes first became available gave the following results:—

FIG. 3.—MICROSTRUCTURE OF LOW-CHROMIUM CAST IRON. × 250.

Metal in ladle.	Chromium. Per cent.
3 tons	0.60
5 tons	0.62
7 tons	0.63
10 tons	0.62
Sought	0.60 to 0.70

The cheaper variety at 4 to 6 per cent. carbon is quite satisfactory, and there is no need to purchase the low-carbon material. Crushed 4 to 6 per cent. carbon ferro-chrome can be added to the cupola stream in amounts up to 0.6 per cent. Cr when treating small quantities of standard metal. The ladles should be weighed, but it is nearly always sufficient to exercise proper control on ladle lining and to estimate the quantity of metal by eye. If closer control of ladle additions is necessary, then powdered ferro-chrome is an unsatisfactory material (as is powdered ferro-silicon or ferro-molybdenum), because some of the powder is invariably blown away from the falling stream by air currents.

The most accurate and reproducible method of chromium addition is by the use of modern exothermic mixtures. The most satisfactory so far tried by the author is of Canadian origin, and is marketed under the name of Chrom X. This material is in the form of 10-lb. bricks, each containing 5 lbs. of chromium and giving practically 100 per cent. recovery. They consist of chrome ore mixed with carbonaceous and exothermic material and are usually added to the ladle. They are deliquescent and must be dried before use, unless a hot ladle is available: in the latter case the material is placed in the hot ladle and the action starts immediately. The material glows white hot and dissolves completely in the metal when it is tapped on to it.

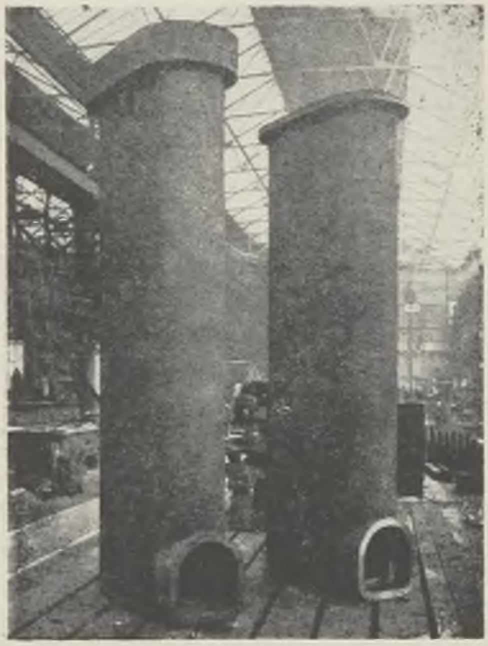


Fig. 4.—Chemical Retorts Cast in Low-Chromium Cast Iron.

The slag is alkaline and gummy and should be dried up by lime unless teapot ladles or a mixer be used. The slight inconveniences of drying the bricks and dealing with the slag are hardly noticed in a well-run foundry and are well balanced by the certainty of the results obtained.

It is far easier to control chromium by this method than by any other simple and inexpensive method. When added to the cupola charge, the bricks remain in their correct charge and tests carried out by the author indicate that the chromium lost in this way is less than 5 per cent., as compared with 15 to 20 per cent. with briquettes.

In order to see how much chromium can be added by the use of Chrom X, a severe test was carried out in the following way. A 10-ton ladleful of low-chromium cast iron (0.62 per cent.) was well mixed by "rodding" and sampled by means of a hand ladle for a chill test. About 20 lbs. of metal was left in the hand ladle and Chrom X broken up was added to give a maximum of 10 per cent. of chromium. The slag and compound were skimmed off before the action ceased and a test-bar could still be poured from the metal. In fact, fluidity seemed to be unimpaired. The chromium in the test-bar was 6 per cent. In a repeat test under more favourable conditions, about 20 lbs. of hot metal (free from chromium) were poured on to 4 lbs. Chrom X (= 10 per cent. Cr), reacting in a hot hand ladle and the reaction allowed to go to completion. The slag was held back and a test-bar cast. The analysis showed 10 per cent. chromium.

Types of Low-Chromium Irons

The various types of low-chromium cast irons used for heat-resisting purposes are as follows:

(*a*) Low-temperature carbonisation retort castings operating at 700 deg. C. These castings, shown in Fig. 2, are 1 in. thick and 10 ft. long and must be machined on each flange. There were occasional complaints of hard corners, but when the machine shops became used to them and a suitable technique was adopted, no further troubles were experienced. Carbide-tipped tools could not be used because of holes cored in each flange to take bolts. The castings have proved very successful in service and only "grew" $\frac{1}{8}$ in. in length in two years, except on one plate where poor conditions had led to direct flame impingement. After re-machining to size the castings went back into service for a further campaign.

The metal used was of the following average composition: T.C, 3.25; Si, 1.35; Mn, 0.6; S, 0.1; P, 0.3; and Cr, 0.6 per cent.

These castings would be a much easier proposition to-day because of the greater control over the chromium additions, although the control was made sufficiently good for the job by the use of rapid chill tests and adjustment of the metal in the ladle by soft iron. The structure of one of the castings, which is shown in Fig. 3, is a carbide network with pearlite and medium graphite, and hard spots were encountered on machining (combined carbon is 0.86 per cent.).

The next problem was the manufacture of chemical retorts for use at 850 deg. C. Two of these 9-ton retorts (3 in. thick) are shown in Fig. 4, and a similar composition (T.C, 3.25; Si, 1.2; Mn, 0.6; S, 0.1; P, 0.1; and Cr, 0.65 per cent.) was adopted with due regard for the extra thickness and increased danger of cracking.

These castings have stood up very well in service and the temperature has been raised to 950 deg. C. without decreasing the life. They are too large to test easily and, as no wasters have been made as yet, it is only possible to judge the initial structure by the appearance of the head or ingate. There is a minor carbide network and fairly coarse graphite. After service the structure is very similar to that shown in Fig. 12, showing that after the carbide has been spheroidised, there is little further change.

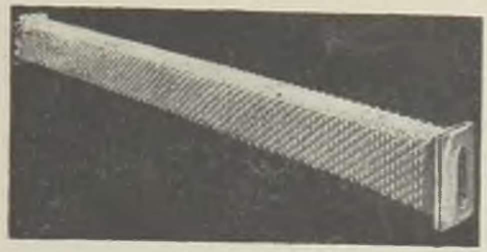


Fig. 5.—Needle Exchange Elements Cast in 30 per cent. Chromium Alloy.

Heat-Exchange Elements

A more difficult problem is encountered in the manufacture of the well-known Newton needle heat-exchange elements, because the thin sections and needles (Fig. 5) demand very fluid metal. Apart from any metallurgical requirements, it is only possible to cast these elements with few rejects if the body of the casting be grey. It is necessary therefore to determine the best composition and structure which will not only meet the service requirements, but give little trouble in the foundry. Again, chromium cast irons have proved the most satisfactory all-round material, but over 1 per cent. chromium is necessary, with silicon raised to give the desired structure. At one time it was thought that a slight modification of the previous compositions would be ideal, but if the cross-section is too small to allow the full development of the carbide network found so useful in the thicker castings and if the castings are made soft enough to be grey with the low-chrome : low-silicon alloy irons, there is great danger of the scaling and growth being greater than the corresponding unalloyed iron. The introduction of a high-chrome : high-silicon iron gives less scaling and much less growth. The body of these castings may operate up to 650 deg. C. and the needles in the gas stream are up to 850 deg. C. at their tips.

The tests on which these compositions were standardised were carried out some years ago and modified slightly to aid the production of a high percentage of good castings. Recent tests have shown, however, that the modification has led to slight improvement in growth resistance.

Testing for Elevated Temperature Use

A few words about the testing procedure for scaling, growth and strength at high temperatures are necessary in order to show why some of the author's results are not in accord with earlier work.

Growth Tests.—Outibridge carried out tests on test-bars held in cast-iron pipes plugged with clay. Carpenter and Rugan heated their bars to 900 deg. C. in a cast-iron muffle, enclosed in a brick muffle to avoid direct flame. Donaldson heated his bars to 800 deg. C. for 8-hour periods, and all these experimenters had trouble with scale and in fact measured growth plus scale.

Fortunately, most of their irons grew so much at these temperatures that the results were not greatly affected and their results are mostly correct. When, however, as in Donaldson's early work,[1] a test-bar containing chromium was tested, 0.28 per cent. *shrinkage* was noted. The author's earlier tests also used machined bars and included the scale, but above 650 deg. C. the results were very erratic and at 750 deg. C. the scale often flaked off during a series of heating cycles and gave a negative growth.

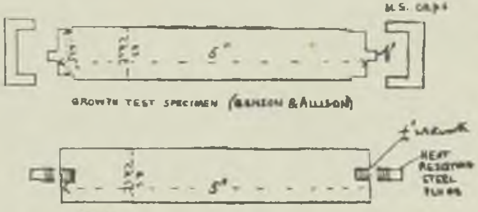


Fig. 6.—Growth Test-Pieces.

In 1938 Benson and Allison presented a Paper to the Bradford Conference of the Institute, in which they described a growth test-piece consisting of a bar machined to ¼ in. carrying measuring pips at each end, and protecting these pips by pressed-on mild-steel caps. For short tests and fairly low temperatures (650 deg. C.) this worked well in the author's hands, but for the now imperative long-time tests and for higher temperatures, the caps stick and leak;

moreover, phosphoric irons, which become embrittled, often break before the caps are removed.

The author has therefore adopted the test-piece shown in Fig. 6. The studs at each end are of heat-resisting steel and are machined to ¼ in. Whitworth and screwed into the tapped holes in the ends of the 5-in. test-piece. The assembly is then ground parallel and measured. The greater thermal expansion of the steel holds the stud firmly in position. These studs are satisfactory up to at least 1,100 deg. C. With these pieces growth tests of great accuracy can be carried out up to 900 deg. C. for long periods.

The author uses an ordinary Vernier caliper reading to 0.001 in., which has proved quite satisfactory for works purposes. It corresponds to 0.02 per cent. on 5 in.

It is found that, for heat-resisting cast iron, tests of 250 hours' duration at 5-hr. cycles are the shortest tests which give uniform growth at 650 deg. C., and at 750 deg. C. the test should not be much shorter. These carbide-network irons change their structure only slowly on heating and finally reach a state where the excess carbide decomposes and spheroidises in a ground-mass of ferrite.

It is interesting to note here also that in the cantilever test the rate of deflection is high at first and decreases to a small rate after 50 to 100 hours. The growth rate at 650 deg. C. is also large for the first 100 hours, and then gradually becomes very small. These points are brought out by the typical curves shown in Fig. 7. Here the rapid growth of the carbide network (Fig. 3) is followed by a marked falling-off, while the unalloyed cylinder grey iron grows normally.

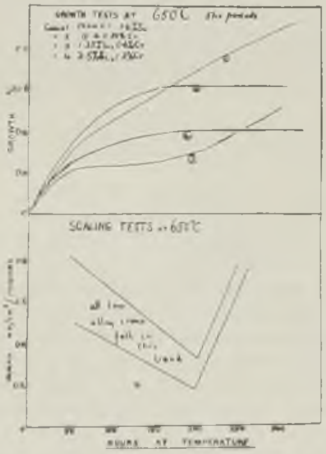


Fig. 7.—Growth and Scaling Tests at 650 deg. C.

Fig. 8 shows growth tests at 750 deg. C. and here the cylinder iron has a high rate of growth, slightly exceeded by the iron V4, which is the same iron containing 0.3 per cent. chromium, and which is still grey (combined carbon 0.75 per cent.). The higher alloyed irons of slightly differing compositions chosen for their range from hard to soft fracture all fall into a group which have much flatter curves, but different rates during the first 50 hours. At this temperature it seems that it is wisest to err on the side of softness in these irons (obtained by higher silicon, not by lower chromium), and, as this gives better founding and machining properties, this is sought in practice.

Scaling Tests

The scaling of these irons is examined by introducing into the same muffle as the six growth bars, six 1-in. lengths of the same test-bars, previously weighed; these are re-weighed when the bars are measured, *i.e.*, after every 50 hours at temperature. The bars are 0.875 in. in diameter and the gains in weight increase greatly between 650 and 670 deg. C. This is shown in Figs. 7 and 8.

Strength Tests

The strength of these irons at high temperature is difficult to measure. Practically the only work published on the creep of cast irons is in a Paper[3] by Tapsell, Becker and Conway. The irons and temperatures chosen were unfortunately incompatible, as the austenitic Nicrosilal proved unstable and became martensitic. The use of higher nickel renders these irons more stable, and it is understood that better results were obtained later. Short-time tensile tests are worthless except as a first attempt. Prolonged tensile creep tests are complicated by the growth occurring at the same time. As even creep-test data on steels must be correlated with previous engineering experience before they can be used and then an arbitrary figure chosen as a standard for comparing different steels, there seemed to the author no fundamental reason why an empirical test should not be applied to cast iron and the behaviour of known irons in the test and in service correlated.

Some years ago the B.C.I.R.A. installed a cantilever test, and did some interesting tests on it. The author, attracted by the idea, made inquiries and found some of the conditions under which these tests were carried out. The fact that the plastic bending of a bar cannot be calculated to fibre stresses, prevents this test from becoming a direct measure of strength at high temperatures, but, as an empirical way of studying the rigidity of cast irons at various temperatures, it offers the advantage of simplicity and the elimination of growth interference.

Fig. 9 is a diagram of the apparatus set up by the author to study this question. In a small and crowded works laboratory it was necessary to make the apparatus compact. A massive frame of welded mild steel carries the 0.875 in. dia. "as-cast" bar and a Nichrome-wire-wound furnace fits over the bar and just allows the insertion of a platinum—platinum-rhodium thermocouple (without sheath) and also allows some bending of the bar. The load must be chosen so that the rate of deflection is very small in order that long-time tests will not cause the bar to bend far enough to foul the furnace tube. This construction was in the nature of a first attempt, and in the present reconstruction of the furnace a split tube internally wound with a Nichrome spiral is being installed. The deflection is measured by the tilting mirror which operates by a Meccano chain attached to the bar 10 in. from the centre of the furnace, and which is carried over a Meccano sprocket on the same rod as the mirror. The chain is held in slight tension by a lead weight hung at the end.

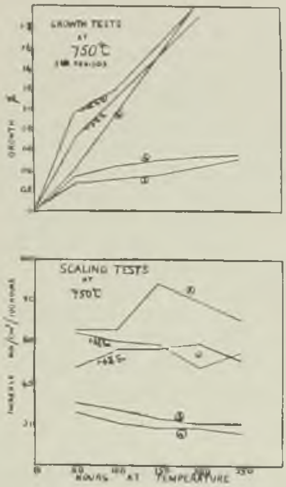


Fig. 8.—Growth and Scaling Tests at 750 deg. C.

The load is applied by a dead weight hung at 10 in. from the centre of the furnace. In series with the Nichrome furnace (26 s.w.g.) is another furnace wound with thicker wire (20 s.w.g.). In this is a glass bulb operating a mercury make-and-break, which regulates the current and temperatures of both furnaces. The bulb attached to the other end of the U-tube is maintained in melting ice in a thermos flask. By means of this regulator the temperature of the small furnace round the bar could be controlled within 15 deg. C. for long periods.

The light from a galvanometer lamp was reflected from the tilting mirror on to a galvanometer scale, and it was found convenient to construct the apparatus so that 1 cm. deflection on the scale corresponded to 0.012 cm. deflection on the bar. This could easily be altered by varying the size of the sprocket wheel or the distance of the scale from the mirror.

It was found very early that cast irons do not have a constant rate of deflection and that at 650 deg. C. the rate falls off to a very small value. At 750 deg. C. the rate is, of course, greater, but falls off to a small constant value. It is only possible to quote a few isolated tests, because each test takes several weeks and the apparatus is not yet in its final form.

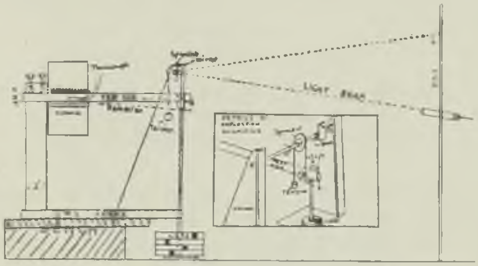
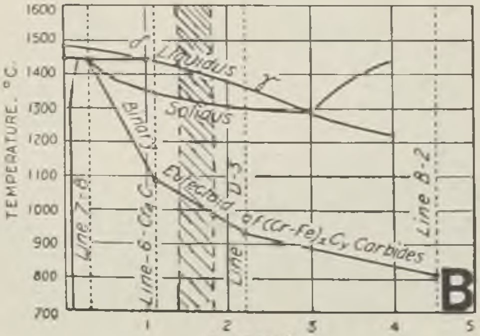


Fig. 9.—Cantilever Test for Strength at Elevated Temperatures.

An engineering iron and a chromium-alloy heat-resisting iron containing more than 1 per cent. chromium have about the same rates of deflection at various stages and at 650 deg. C. The rates fall off rapidly in the first 20 hours, and after two weeks attain very small values. A long time has been spent in choosing suitable loads and temperatures for long-period tests (up to several months). It was proved that short-time tests have little value, and it is disturbing to see the rates of deflection at 750 deg. C., even at loads as low as 10 lbs., in the first few days. The method shows great promise of sorting irons into a series, but up to the present the chromium addition cannot be said to have strengthened the iron at high temperatures to any great extent.

It is intended finally to determine the influence of phosphorus, nickel, molybdenum and tungsten on the "creep" of cast iron, but it will be a long time before the series is completed. The next material to be tried will be a mild-steel bar for comparison purposes.

The effect of temperature on strength is mentioned by Pfannenschmidt,[5] who measured the tensile strength at room temperature after several hours at different high temperatures. His low-silicon, low-chromium cast iron "Cr" actually increases in tensile strength even after 120 hours at 900 deg. C., whereas a nickel-chrome cast iron began to show permanent damage after 48 hours at 800 deg. C., and a cylinder iron at 600 deg. C.



Chromium = 30 per cent. = constant.

FIG. 10.—SECTION THROUGH THE FE-CR-C SYSTEM (TEMPERATURE AND CONCENTRATION DATA ARE APPROXIMATE).

At the same conference Morgan, of the B.C.I.R.A. refers to the cantilever test and states that even brittle irons bend readily at 850 deg. C., and that increases in silicon increase the stiffness, but the tests mentioned lasted only four days, which may be long enough at 850 deg. C., but is very much too short a time at 650 deg. or 750 deg. C.

The introduction of small percentages of chromium is shown to be under close control and to have beneficial effects on growth and scaling while machinability and toughness are unimpaired.

High-Alloy Cast Irons

The last section of this Paper deals with the high-alloy cast irons, which, because of their high cost, exceptional properties and special manufacturing methods, fall into a class by themselves. Smalley, in 1932, made the statement in discussing Morgan's Paper (*loc. cit.*) that 8 per cent. chromium electric-furnace steel was cheaper and better, but forgot that Morgan has specifically stated that austenitic cast irons were best used above 850 deg. C. because of the possible danger of the austenite becoming unstable. This is prevented by high nickel, but there is no published information showing whether the stabilisation is indeed 100 per cent. or merely improved. An 8 per cent. chromium steel is best used at temperatures about 650 to 700 deg. C., at which temperature the low-chromium cast irons could be a serious and cheaper competitor. The austenitic cast irons Nicrosilal and Ni-Resist are well-known and excellent materials to use in situations where replacement means the interruption of production and entails high labour costs.

They are scale resistant up to 1,000 deg. C., do not grow appreciably, and have appreciable strength in bending at 850 deg. C. (Morgan, *loc. cit.*). P. A. Russell and others have delivered Papers to this Institute showing that, although cupola melting is possible, it is too erratic, and oil-fired or electric furnaces are much superior.

Many investigators have reported the excellent effect of aluminium in moderate quantities in promoting the scale resistance of cast irons. The difficulty of alloying aluminium with regularity and without the formation of oxide was almost insuperable for practical development until the introduction of a special technique[4] patented by the B.C.I.R.A. and the Dominion Ferro Alloy Corporation.

The resulting iron is known as Cralfer, and contains 7½ per cent. aluminium and some chromium. The resistance to growth at 950 deg. C. is given in the literature, as follows:—

Grey iron	24.0% by volume	After 6 × 3 hours + 1 × 20 hours at 950 deg. C.
Silal	1.5% ,, ,,	
Cralfer	1.3% ,, ,,	

There is no published information about strength at high temperatures or long-time growth tests, and it is to be expected that this material is a growth- and scale-resistant alloy only.

The 30 to 35 per cent. chromium cast irons have been known for many years and used for scale resistance and resistance to sulphur-containing flue-gases below the dewpoint. There must be a relation between the chromium content and the carbon content because the carbon forms chromium carbides first and then the excess chromium is dissolved in the ferrite. This chrome-ferrite must have sufficient chromium to be scale-resistant. In the author's foundry the material is crucible melted. Valenta[6] gives an excellent account of these alloys from the metallurgical standpoint.

Fig. 10 shows a cross-section of the ternary iron-carbon-chromium diagram at 30 per cent. chromium, which shows that this material melts at 1,400 deg. C. and no phase change occurs below 1,000 deg. C. (carbon 1 to 2 per cent.). It is found from experience that at this chromium figure (and up to 35 per cent. Cr) and below 1.5 per cent. carbon the "life" of the alloy is impaired greatly.

There are no crucibles of 400 lbs. capacity commercially available in this country except graphite, and carbon pick-up in these is excessive with low-carbon alloys. Above 2.2 per cent. carbon, the alloys are too hard to machine (Fig. 11, Valenta, *loc. cit.*), so a carbon content of 1.6 to 2.0 per cent. is used. Fig. 5 shows the type of needle air-heater element which is cast regularly in this alloy. These alloys are somewhat brittle when cold, but have a tensile strength of 28 tons per sq. in. The brittleness appears to be a function of the grain size, and this can be improved by careful attention to the details of melting and pouring.

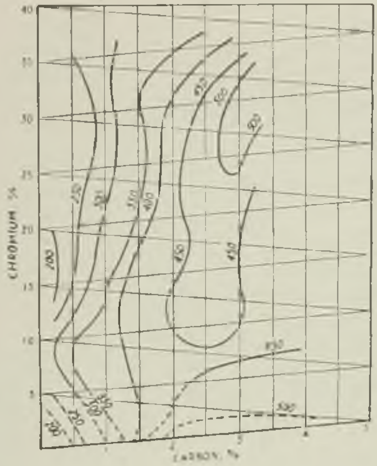


FIG. 11.—BRINELL HARDNESS OF FE-CR-C ALLOYS AS CAST.

The effect of small quantities of nickel is well marked in this direction, but at the cost of machinability. These alloys—they are ferritic—are scale-resistant up to 1,050 deg. C., but are not particularly strong at high temperatures.

The use of these alloys in annealing-furnace carriages at 850 deg. C. was marred by cracking, due partly to design and partly to the rigidity of this material. At 920 deg. C. the castings warped under load, and it was found necessary to introduce small amounts of nickel to improve the toughness (cold) and strength at high temperatures. The grain size is very much finer with 1 to 1½ per cent. nickel. The service results from these modified carriages are not yet available, but considerable improvement seems to have been attained. It is proposed to examine the effect of nickel, tungsten, molybdenum and aluminium on the strength of these alloys at high temperatures, and for this purpose ordinary creep-test apparatus should prove suitable owing to the absence of growth. The photomicrograph in Fig. 12 shows the carbide-ferrite structure of the plain 30 to 35 per cent. Cr, 1.8 per cent. C alloy.

From this brief summary of the outstanding facts, the author hopes to stimulate interest in these chromium-alloy cast irons and to remove the bogey of hard spots and lack of control which have given so much trouble in the past. Chromium in small amounts is the growth-preventer *par excellence.* Chromium in large amounts is the outstanding scale-preventer. Other alloys may modify and improve other properties, but they do not improve these two special qualities of cast irons.

FIG. 12.—CARBIDE-FERRITE STRUCTURE OF 30 TO 35 PER CENT. CR, 1.8 PER CENT. C ALLOY, AS CAST. × 250.

The author wishes to thank the general manager of the Thorncliffe Ironworks, Mr. W. T. Kitching, for permission to publish this Paper, and acknowledges with gratitude the loan of photographs of castings made in these irons by Mr. F. W. Whitehouse, foundry manager, Newton Chambers & Company, Limited. It is regretted that the Paper is not more comprehensive, but at the present time it seems to be impossible to continue some of the researches, of which the results presented in this Paper are the mere beginnings.

REFERENCES

[1] Proc. Inst. Brit. Found., 1925.
[2] Journ. Iron and Steel Inst., 1936.
[3] Proc. Inst. Brit. Found., 1932–3
[4] T. Tyrie, "Foundry Trade Journal," March 7, 1940.
[5] I. & S. I. Carnegie Scholarship Memoirs, vol. XIX, 1930

Paper No. 707

Production of Pressure-Resisting and High-Duty Iron Castings*

By J. L. FRANCIS, A.M.I.Mech.E. (Associate Member)

The foundry with which the author is associated is not laid out for production of large numbers of standard castings. It is essentially a jobbing foundry wherein the few-off job is the rule rather than the exception. Mechanisation is, therefore, not readily applicable to any great extent. Tackle and equipment must be designed so as to allow of the maximum elasticity in use, that is, so that it may be adaptable to various jobs, not specialised for one single purpose, as is done with advantage where quantity production is concerned.

Many things militate against the production of sound castings, even when conditions and circumstances under which they are made are normal. With the country at war, abnormal conditions prevail, making the usual difficulties greater and imposing others at a time when foundries are required to give a maximum output produced regularly to schedule. In order to prevent disorganisation of programmes, castings must pass into service with the utmost despatch. Castings which are obviously wasters on knocking out are bad; those with defects revealed only after machining are worse; but worst of all are the ones which have to be rejected after water-pressure testing, when in the majority of cases machining operations have been completed. In these times work which has to be repeated is not only a loss of time and money, but places an extra burden upon men and machinery already working to capacity.

Metal Practice

Before proceeding to deal with typical high-duty and pressure-resisting castings, the problem of providing correct metal for the work may be considered. This aspect of the matter is not least in importance or effect. Here again the point of maximum adaptability arises, and the metal practice evolved by the author has to cater for castings of diverse weight, size and type. Simplicity of operation is an asset in most spheres of activity and is particularly so with regard to founding. Consequently grades of pig-iron and scrap should be kept to a minimum and the number of different metal mixtures made as few as possible.

Type and Range of Castings

The system to be described has been worked out to embrace straight and alloyed grey-iron castings, weighing from a few ounces to 2 tons. Excepting flywheels, which are not pressure-resisting castings, the work cannot be termed heavy. Most of it enters into the medium or light category. Metal sections range between $\frac{5}{16}$ in. and $1\frac{1}{2}$ in. thick; hence the problem occasioned by excessive slow cooling of massive sections yielding coarse-grained structures is not often met. Occasionally it becomes necessary to make castings of size, weight and section beyond that stipulated, but in any case they are required for machines which for the most part must conform to exacting conditions of service.

Pistons, cylinders, liners and valve covers form a class wherein resistance to pressure and wear is of paramount concern. Working pressures in some instances rise to as high as 3,500 lbs. per sq. in. For these castings ease of machining is of secondary consideration. Intricate coring and wide sectional variations obtain to form water jackets and air spaces. Moreover, no leakage must take place between the water and air. Briefly, the castings are of just the kind most difficult to make sound and for which this property is of supreme moment.

Chemical and Metallurgical Control

Systematic working and production of standard grades of iron having constantly uniform chemical and physical properties cannot be attained without efficient chemical and metallurgical control. Indeed, such control forms part of the very foundation upon which progress in the founding of sound castings has been built up. Pig-irons and other components of the furnace charges must conform to specifications. On delivery, representative samples are taken and tested to ensure that the materials comply. Once standard analyses are established for given classes of work they should

---

* The author was awarded a Diploma for this Paper.

be maintained reasonably constant. Distinct grades of cast iron possessing known and reliable physical data facilitate calculations involved in design. Agreement as to the effect of design on casting soundness is unanimous, hence anything tending towards simplification of design is a good step in the desired direction.

The term "high-duty iron" used in these notes refers to material able to fulfil the requirements of British Standard Specification No. 786 (1938), which covers a tensile strength of from 15 to 22 tons per sq. in. obtained from the 0.875-in. dia. cast bar, machined to 0.564 sq. in. section.

TABLE I.—*Raw Materials Used.*

Material.	Mark.	Chemical specification. Per cent.					Remarks.
		T.C.	Si.	Mn.	S.	P.	
Pig-iron	A	3.25 to 3.50	3.50 to 4.00	1.75 to 2.00	0.04 max.	1.00	Soft foundry.
Do.	B	3.50 to 4.00	2.50 to 3.00	0.75 to 1.00	0.03 to 0.04	0.25 to 0.50	Scotch.
Do.	C	3.00 to 3.25	1.25 to 1.50	1.25	0.05 to 0.07	0.50 max.	Cylinder.
Do.	D	3.00 max.	1.00 to 1.30	1.25 to 1.50	0.06 to 0.08	0.50 max.	Refined.
Do.	E	3.00 max.	1.80 to 2.20	1.25 to 1.50	0.06 max.	0.45 max.	Refined.
Foreign scrap	F	3.50	2.00	0.50	0.10	0.75	Average composition.
Returns: Grades 1 and 2.	G	3.30	1.80 to 2.25	0.80	0.08	0.80	Composition varies according to proportions, Grades 1 and 2
Returns: Grades 3, 4 and 5.	H	3.10	1.45	0.85	0.10	0.50	Composition varies according to proportions, Grades 3, 4 and 5.
Alloyed returns ..	J	3.10	1.45	0.85	0.10	0.45	Alloy content according to additions made.
Steel scrap	K	0.30	0.10 to 0.20	0.50	0.05	0.05	Average composition.

Melting Practice

All the iron is melted in cupolas fitted with receivers. Melting practice and the selection of charge components are therefore based on this mode of production. Cost and economy must always be borne in mind in all phases of commercial manufacture, and these points have been given due consideration relative to other requirements.

Standard grades and mixings of iron suitable for special classes of castings are of little use unless the mixture charged, as distinct units, can be drawn off at the tap hole with their individuality maintained. Where circumstances permit the running of a cast with one grade of metal only, the problem is simple of solution. When the moulds to be cast for one day's work need different qualities of iron, charging and melting operations must follow a planned programme under close supervision.

A system giving good results in practice is worked as follows:—The cupolas employed hold six charges of 10 cwts. each, and the softest grade of iron is charged directly on to the coke bed, giving a double advantage. First, the softest grade, listed as No. 1 in Table II, is used to pour the less exacting castings, and, secondly, a gradual blending towards harder iron can take place. Taking a definite case, suppose two $\frac{1}{2}$-ton charges of grade 1 are placed first, followed by 10 cwts. of grade 2, which is a little harder. Two further charges of grades 3 or 4, cylinder iron, can follow, making a total of five. Table II gives another and harder grade, No. 5, which can be used with or without alloy additions. If this is needed, it follows after Grades 3 and 4, making the furnace fully charged ready for blowing to commence. Other charges wanted to complete the cast are put on as required in reverse order, so that the grades work back again to softer metal.

TABLE II.—*Material Covered by the Paper.*

Grade.	Cupola charge. Per cent.	Chemical analysis. Per cent.					Physical tests.		Suitable to meet specification.	Suitable for casting.
		T.C.	Si.	Mn.	S.	P.	Tensile Tons per sq. in	Transverse Tons per sq. in		
1	30 A 30 F 40 G	3.3	2.3	0.75	0.08	0.85	12.0	24.0	B.S.I. No. 321(1938) Grade "A." 0.875-in. dia. bar.	Bedplates, standards, pulleys, machine tools, small details and fittings to withstand no wear. General-purpose castings of light section.
2	15 B 15 D 20 F 40 G 10 K	3.25	1.70	0.70	0.08	0.65	14.0	25.5	British Admiralty, 13 to 14 tons per sq. in. 0.875-in. dia. bar	Flywheels, crankcases, covers, gearcases, small compressor bodies, cylinders where liners are fitted. Medium-sectioned castings not required to withstand high working pressure.
3	25 A 25 D 40 H 10 K	3.20	1.65	1.0	0.10	0.55	15.0	26.5	B.S.I. No. 786(1938) Grade I, also British Admiralty, 14 tons per sq. in. 0.875-in. dia. bar.	Cylinder covers, heavy flywheels, pistons, steam cylinders, parts in sliding contact and all castings similar to above needing a tighter metal giving more wear and pressure resistance.
4	20 C 30 E 40 H 10 K	3.0	1.4	0.95	0.10	0.45	16.0	28.0	B.S.I. No. 786(1938) Grade I, also British Admiralty, 16 tons per sq. in. 0.875-in. dia. bar.	Cylinder liners, H.-P. covers, rotors, crossheads, water-jacketed castings and castings of heavy section to meet heavy wear and pressure conditions.
5	20 E 30 C 40 H 10 K	3.0	1.15	1.0	0.10	0.45	17.0 Higher tests with alloy additions.	30.0	B.S.I. No. 786(1938) Grades II and III, 0.875-in. dia. bar.	Castings as above and those required for specially severe working conditions.

In practice, the system resolves into taking the quantities of the various grades required to pour the moulds prepared, and charging in the manner described. A programme is made out with the exact order in which the different castings are to be poured, the weight of iron necessary and the size of ladle to be used. Then, when melting is in progress, no time is lost in making decisions of this nature; confusion also is avoided. Time is a very important factor in gauging the grades as they come down. Unless the whole business is worked strictly to schedule, it becomes a muddle.

The timetable is based on a constant melting rate, which is obtained through a standardised method of cupola operation. Regularity of charging and melting must go on without a hitch; therefore, reasonable uniformity in size of pig and scrap is important. Hanging up of the furnace distorts the timing and the charging of an extra coke split has a similar effect. Thus, the practice of separating grades of metal by heavier coke charges is not satisfactory.

After melting is properly under way in the cupola previously mentioned, that is, after the first three charges, 10 cwts. of iron are melted every 7 min. Having established a constant rate of melting and the placing of charges in an arranged order, it is possible to tell exactly the stage reached at any point during the blow, the grade of metal which is melting and how much more may be expected. The presence of someone responsible for this timing is necessary throughout the duration of the melt. Likewise, too, the men who weigh out and load the charges must be trained and trustworthy.

By the practice of timing the melting of the charges and tapping at the end of completed periods, the danger of splitting a charge, thereby getting a wrong mixture, is prevented. Only complete charge units should be tapped. Some of the work may require casting from small hand shanks. These ought not to be caught when the furnace is dry, as most irregular results come from so doing. One or more complete charges should be present in the receiver or well of the furnace.

Selection of Charge Components

Specified compositions for five pig-irons and chemical analysis of foundry returns and bought scrap are included in Table I. Apart from ferro-alloys, these items are sufficient to provide the grades of iron shown by Table II, which gives as well an idea of their purpose and the minimum tensile and transverse strengths capable of being produced.

Total carbon content has a pronounced bearing on soundness. Pig-irons of hyper-eutectic composition are not suitable for direct use in producing high-duty iron castings. Hematites are not favoured for this reason. It will be noted that all the materials listed in Table I have carbon equivalent values at or below the eutectic value of 4.3 per cent., excepting item B. Two of the pig-irons, D and E, are of the refined type and reserved for use in the highest-grade mixtures. Leaving out of account thick-sectioned work of 2 in. and over, the most satisfactory total carbon content lies between 3.1 and 3.3 per cent. Values between these limits yield strong metal of close grain with reasonable machining qualities.

To keep within this range the carbon content of the charge materials must be restricted to under 3.5 per cent. for high-duty compositions, unless high percentages of steel scrap are included to dilute it. Steel scrap up to 10 or 15 per cent. of the total charge may be incorporated with advantage and no modification of the normal melting practice. Larger proportions require special precautions in melting, and when used with other pig and scrap for direct pouring into moulds, troubles due to shrinkage and heterogeneity of the product are likely to be experienced.

Total Carbon

Much has been done and published about the effect of total carbon content on cast irons, and its fundamental influence is widely recognised. As already stated, it must be controlled for high-duty castings. For work within the range of sectional thickness quoted, the limits mentioned are satisfactory, and can be maintained regularly without great difficulty or highly specialised cupola technique, providing T.C is not present to excess in the materials charged. Charge materials having excess of coarse graphite tend to retain this characteristic even after passage through the cupola.

The charge coke is the greatest source of carbon entering the cupola, and to limit carbon pick-up it must be dense, of suitable quality and not charged greatly in excess of the quantity necessary to provide heat for melting and superheating the iron. Indeed, a study of the correct coke ratios for the bed and between the charges forms an essential factor in obtaining satisfactory high-duty castings.

Upon the quantity of coke to be burned depends the volume of the air blast. With uniform blast volume, coke splits and metal charges, total carbon pick-up increases with height of coke bed. It also increases with increase of coke splits, blast volume and bed charge remaining constant. Blast volume should remain uniform throughout the blow. Raising the air volume tends to burn away the coke from the charges above the melting zone, with the result that the bed becomes lowered and metal charges melt too near the tuyeres.

Fast melting and removal of the iron from the coke bed minimises carbon pick-up. Receivers are advantageous from this point of view, and also because they allow of the tuyeres being placed nearer the base of the furnace, thus reducing the height of coke in the bed.

Although control of the total carbon ratio is a major factor in the manufacture of successful high-duty iron castings, it is not sufficient to consider it without taking into account the influence of silicon and phosphorus at the same time. The range of carbon given above applies where these two elements are restricted to within certain proportions. Pure iron-carbon alloys solidify at steadily decreasing temperatures until the eutectic composition is reached at 4.3 per cent. carbon. When silicon and phosphorus are introduced, they have the effect of reducing the amount of carbon for the alloy of lowest melting point. It has been found that the reduction of carbon is 0.3 per cent. for each 1.0 per cent. of silicon, and 0.3 per cent. also for each 1.0 per cent. of phosphorus present. Consequently an iron with 1.0 per cent. each of silicon and phosphorus reaches the eutectic composition with 3.7 per cent. total carbon. Any carbon above this amount tends towards excessive graphitisation under normal conditions of cooling.

A convenient method of evaluating cast irons with respect to their eutectic condition has been suggested by the B.C.I.R.A. It consists in calculating the "carbon equivalent" value, which is the percentage of total carbon actually found to be present, plus the carbon equivalents of the silicon and phosphorus contents as mentioned. Thus, if the iron quoted above with 1.0 per cent. each of silicon and phosphorus had also 3.3 per cent. total carbon, its carbon equivalent value would be 3.3 plus 0.6, or 3.9 per cent. Incidentally, the author has found that as a general rule no composition of grey cast iron is likely to fulfil the definition for high-duty material unless the carbon equivalent value derived as explained is kept below 3.9 per cent.; a useful range is from 3.6 per cent.

Shrinkage Defects

Rejects resulting from shrinkage in one or other of its forms are a trouble particularly in evidence with castings of high-duty iron. It is an unfortunate fact that the higher-quality irons exhibit a greater tendency towards shrinkage during solidification because the expansion due to graphitisation is not so great as in high-carbon grey irons, and the liquid contraction is not counteracted to so great a degree. For this reason, it is desirable to maintain total carbon ratios at as high a level as possible consistent with high-duty properties, and the metal practice outlined has been instituted with this point in mind.

Actually the amount of liquid shrinkage which must occur is not altered much by chemical composition. Casting temperature exerts the predominating effect, and high-duty irons need to be cast hot, since their range of fluidity is not so great as that of soft phosphoric irons.

Shrinkage defects have been classified under four headings:—(1) Piping; (2) sinking; (3) porosity; and (4) cracking and warping. Although all are due to the inevitable volume changes which occur during the transition from the high-temperature liquid phase to the solid phase at atmospheric temperature, they are controlled to some extent by temperature of metal when poured, casting design, composition of metal and the mould conditions, particularly with respect to size and placing of runners and risers.

Piping is not very prevalent in grey-iron castings unless they are very massive indeed. Sinking is more often found and may be regarded as incipient piping. Porosity is the main anxiety with pressure-resisting castings, oftentimes this is not revealed until the hydraulic test is applied.

Phosphorus and its effect on porosity have provided a basis for much discussion. There is no doubt that substantial percentages increase the range over which solidification takes place. For pressure-resisting castings of complicated design with ribs, bosses and abrupt changes of section, it is better to restrict it to around 0.3 per cent. Such castings have many places where feeding is impossible to apply. Thick sections naturally cool slowly with predisposition to formation of coarse grain and porosity. Therefore it is logical to avoid a composition which will allow these places to contain liquid metal longer than is necessary.

Some authorities think that the *rôle* played by phosphorus in causing porosity is over-emphasised. They invariably quote instances of castings containing appreciable amounts of it which have not shown any trace of porosity and have, moreover, functioned perfectly in service. Whilst it is not possible to refute such evidence, at the same time the instances brought forward, upon examination, often turn out to be of a type or design such as would not be highly susceptible to the defect which high phosphorus content helps to cause. Certain types of casting do benefit from the presence of phosphorus, but the high-duty casting for pressure resistance is certainly not one of them.

Work carried out by the B.C.I.R.A. confirms that the type of shrinkage defect depends on the proportions of silicon, carbon and phosphorus in the metal. An increase in one or all of these elements assists in bringing about porosity and by correct regulation the tendency may be considerably lessened. The conclusions reached were that, with silicon at 1.5 per cent. and phosphorus greater than 0.25 per cent., total carbon must not exceed about 3.4 per cent. Similarly, with 2.0 per cent. silicon, the limit for total carbon is at 3.2 per cent., and for 3.0 per cent. silicon at around 2.7 per cent. Silicon and phosphorus are easier to control with cupola melting than is total carbon, so that metal analyses should be adjusted along these lines.

High Manganese Content

A study of Table I will reveal the fact that all the pig-irons contain manganese in amounts beyond the average. The idea is to arrange the charges so that a manganese content of between 0.75 and 1.0 per cent. is present in the castings. From experience gathered during 20 years the author is convinced of the benefits to be derived from manganese up to this amount, particularly for castings of the high-duty type. He has dealt at length with this subject elsewhere.[1] Others [2, 3, 4], have also written on the subject.

Briefly, manganese assists towards the production of sound castings by combining with the sulphur. To ensure an absence of iron sulphide, an excess of manganese beyond the theoretical quantity for chemical combination with the sulphur is needed. Norbury has suggested a minimum ratio of 1.7 times the sulphur content plus 0.3 per cent., which works out at 0.47 per cent. manganese for a sulphur content of 0.1 per cent. By adopting this practice, the iron is less likely to form hard or chilled edges. A surplus of manganese above that required by Norbury's formula is advisable as melting losses may reach 30 per cent. Apart from this, manganese helps to increase fluidity, shortens the freezing range and gives a closer-grained iron, so that the more manganese there is present—at any rate up to 1.0 per cent.—the less tendency exists for shrinkage to occur as draw-holes.

Alloyed Cast Iron

Additions to cast iron of elements such as copper, nickel, chromium and molybdenum have done much to widen its field of usefulness by imparting new properties. For most applications, ruling out the highly alloyed special cast irons, the combined or total alloy additions are not required in excess of 2 or 3 per cent., quantities which allow of introduction directly to the molten iron in the ladle. Special combinations of the alloy metals are available, so arranged that an exothermic reaction results and no temperature drop is caused.

The five grades of cast iron set out in Table II are of themselves enough for many and varied casting requirements. Suitable ladle additions to either grade 4 or 5 will extend the range considerably and include castings for internal-combustion engines, Diesel-engine liners, brakedrums, heat-treatable cast iron and iron for chilled castings.

Several advantages accrue from the addition of alloys direct to the melt in the ladle as opposed to their incorporation as such in the cupola charge. Chromium is subject to a substantial loss in passage through the furnace and forms a very refractory slag. Moreover, accurate determination of the amount to be used for a definite percentage in the casting is difficult as the degree of oxidation varies.

Nickel is not subject to oxidation and loss in the furnace like chromium, but here again ladle additions are more exact, confining the alloy to a given volume of metal. Much more latitude in working is possible, as charges can be alloyed differently from one to another, as the castings to be poured may require, without any alteration to the basis charges entering the furnace.

To summarise, ladle additions are more precise, suffer the minimum wastage of alloying elements, ensure that the alloys are just where required, and, providing proper precautions are taken in making the additions, no troubles from lack of solubility or homogeneous mixing arise.

Pressure-tightness and good wearing qualities are main characteristics striven for in the castings described here. For these properties nickel alone or in combination with copper suffices to render thick sections dense and sound and maintain thin sections grey and machinable. Alloying is accordingly restricted to the use of these two metals in the majority of cases.

A point which will stand emphasis is that for receiving alloy additions a good base iron is desirable. Ferro-alloys are expensive materials, and they should be utilised to the maximum advantage. It is possible to load up an ordinary soft iron with alloys until it meets the high-duty specification, but this is an uneconomical use of alloys. They should be reserved for use with a good base iron and not in an attempt to make a poor iron into a fair one. Another factor to remember is the need for adjusting the composition of the base iron to suit the additions being made. Most of the elements used for alloying have a plus or minus silicon equivalent which must be allowed for in order to get optimum results.

Segregation of Returned Scrap

Iron returned from the foundry for remelting is kept to its separate grades, as indicated in Table I. By so doing, alloy-bearing scrap is available for re-use in similar mixtures and the new additions needed subsequently will be less in proportion to the quantity already there. Care over this matter ensures that alloyed material does not contaminate mixtures where it is not wanted, although nickel and copper in small amounts cannot do harm to any composition.

Table II shows that "foreign" or bought cast-iron scrap F is employed in the two lowest grades 1 and 2 only. Its chemical analysis is not known definitely; thus it should not be employed in charges for high-duty castings. Runners, risers, etc., from grades 1 and 2 are collected and stored separately to form item G of Table I. Likewise, returns from grades 3, 4 and 5 are gathered together under H. The remaining classification J represents the alloyed returns previously mentioned. Segregation of the scrap returns in this way helps considerably in maintaining that regularity of product stressed above. It also contributes in no small degree towards soundness. Another valuable attribute of the grading and separation of returns exists in the knowledge of its chemical constitution. Regular check analyses on the grades melted ensure this, making it a constituent of known effect, and in this respect equal to pig-iron. Allocation of the proportion of foundry returns used in the charges is such that a balance is struck between production and consumption, ensuring neither excessive accumulation nor shortage.

Cast-iron Liners

Having now given some idea of the class of castings manufactured, the properties required of them, difficulties to be overcome and the metal practice which gives satisfactory results, some examples of individual castings may be considered. No matter how good the selection of materials, the melting practice and metallurgical control, they are all defeated if the moulds and cores are badly or carelessly made. Moulding skill and experience play a very large part in the successful production of the kind of castings featured here, and much could be written on this aspect alone, if space and time permitted. As it is, the matter can be stressed and then taken for granted, since it is impossible to deal adequately with it in this Paper.

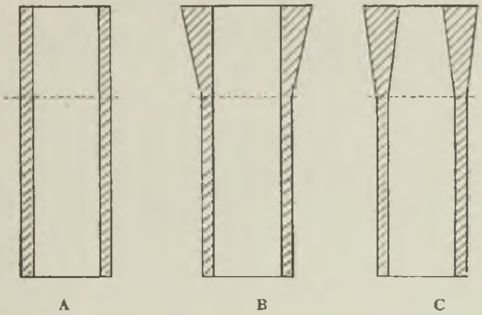


Fig. 1.—Headers for Liner Castings.

A plain cylindrical casting for use as a liner, in spite of its simple appearance, is difficult to make free from defect, especially if it has to withstand hydraulic or oil pressure. Usually these castings are machined over the entire surface and are required to exhibit no blemishes of any kind, and, moreover, to offer a high resistance to wear. Liners offer symmetry and evenness of section without intricate coring—conditions which make for uniform cooling and soundness. Nevertheless, the proportion of wasters made with these castings is probably as high as in any class.

Adequate pressure heads of the self-feeding type are indispensable, together with top running. Fig. 1 illustrates three kinds of header for liner castings. That marked A is of the same section as the casting and cools at the same rate. Its extra metal is, therefore, not liquid long enough to give efficient feeding, and it is effective only as a sullage piece. Head B holds more metal and maintains it liquid after the thinner section below has set, so that it is available for counteracting liquid shrinkage taking place lower down. Theoretically head C gives the maximum self-feeding effect, because its centre-line coincides with that of the liner wall.

In practice type B has been found to give good results, in conjunction with equally-spaced top gates, giving an equal distribution of hot

Fig 2.—Group of Small Miscellaneous Castings.

metal and ensuring that finally the hottest iron is in the feeding head, causing progressive solidification from the bottom upwards. Top pouring also keeps the surface of the rising metal in a state of agitation until the mould is full, thereby helping to prevent dirt or scum from remaining attached to mould or core walls and assisting its journey to the top. Deep liners have one bottom in-gate, which is opened a few seconds before the top gates, so that the latter deliver on to a cushion of metal. All the runners are fed from an ample horse-shoe-shaped runner basin of capacity about equal to the content of the liner head. The heads are about one-third the length of the liner and flared to give an average thickness of twice that of the wall. Whilst any casting section can be fed upwards from metal supplied beneath, it cannot be done with the same size of gates and gate pressure, nor to the same advantage as feeding from above, for in the latter case the force of gravity is acting with instead of against the operation.

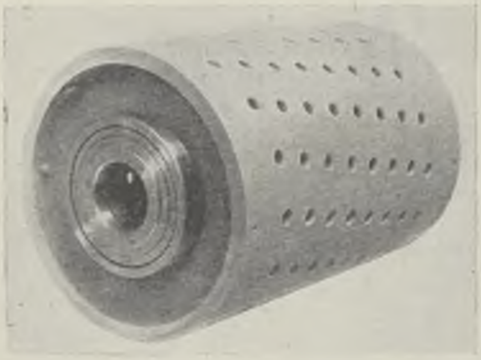


FIG. 3.—FINISHED REVOLVING LINER.

Two small liners can be seen in the background of the group of miscellaneous castings shown in Fig. 2. The tapered head of the one on the left is just visible, at the bottom. Fig. 3 depicts a revolving liner in its finished state. It forms part of a rotary compressor and is free to revolve under the action of the blades expelled by centrifugal force from the slots in the rotor. Reference to Fig. 4 helps to make this clear. The holes form ports for the suction and delivery air. Due to the liner being free to revolve and carried round with the blades, much higher speeds of rotation are possible.

Cast-iron Rotors

Fig. 5 illustrates diagrammatically the casting which forms a rotor for the type of compressor or exhauster just mentioned. From the viewpoint of moulding, it is a fairly simple, straightforward job. Ultimately, however, it forms part of a special machine (Fig. 4), which runs at 585 r.p.m., and must be a perfect casting in every respect. Machining is done over the whole of the outside surface, including both ends, the centre is bored out for the driving shaft and each of the six ribs is slotted to take a blade. Under running conditions the blades move in and out of the slots continuously at high speed. Thus, it is of the utmost importance that they work smoothly and uniformly in their housings. The jamming of a blade is capable of wrecking the machine.

Other vital considerations include accurate balancing of the rotor. To assist in this, the six segment cores need accurate making and positioning in the mould, where they are held by prints projecting through each end; the holes so formed are finally plugged, as shown in Fig. 4. Lubrication of the blades in their slots takes place by way of the driving shaft, so that no open-grained or porous metal can be tolerated in the bore or slots as oil, under pressure, would percolate into any of the various compartments formed by the ribs and throw the machine out of balance. No hard spots or non-uniformity of metal structure must exist, tending to deviate the milling cutter from its true path in cutting the long narrow slots, because it is essential for these to be dead true. The dimensions of the casting are given in Fig. 5, and it weighs 16½ cwts. Other similar rotors of smaller size are made, and the moulding and casting practice is the same. A hydraulic test is made on the bore and spaces between the ribs to ensure pressure-tightness.

With a casting of heavy section, such as this, liquid shrinkage has to be effectively counteracted, for in any place where a shrinkage defect might form, machining occurs to reveal it. In place of a sand core for the centre bore, a solid cast-iron stick 2⅜ in. dia. is used to ensure sound close-grained metal. This cannot be removed on fettling and is machined out. Fig. 6 shows five of the six segment cores in position round the centre densener; the pattern for making the latter is standing alongside the flat, circular core containing the top prints for the segment cores.

Nothing must prevent free expansion of the long densener, for extension from temperature rise when casting is considerable and if restrained bending occurs with disastrous effect on the bore. The densener does definitely give the desired result in that speed of cooling of the thick wall of the centre hole is so adjusted that it does not remain liquid long enough to allow of drawing away of metal by the radial and circular ribs which spring from it.

Solidification, however, causes a volume reduction which cannot be prevented, and is of considerable proportion for a casting such as this. Neglect to make provision for it is revealed by the appearance of shrinkage cavities on the top plate over the centre boss and radial webs (Fig. 7). To overcome this, the large feeding head, of dimensions shown in Fig. 5, is fitted. It is shown also in Fig. 8, together with the complete running and feeding system.

A limit to the dimensions of the feeding head is imposed from the fact that it may not interfere with the six vents from the segment cores, taken off from the top prints. Their re-

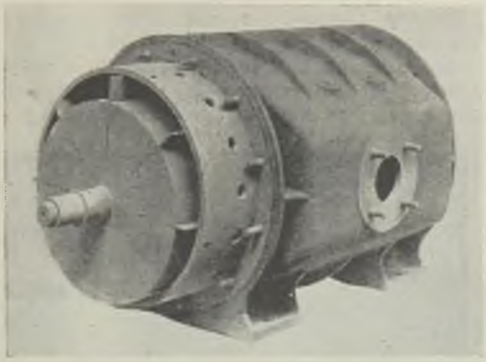


FIG. 4.—ASSEMBLY OF ROTOR.

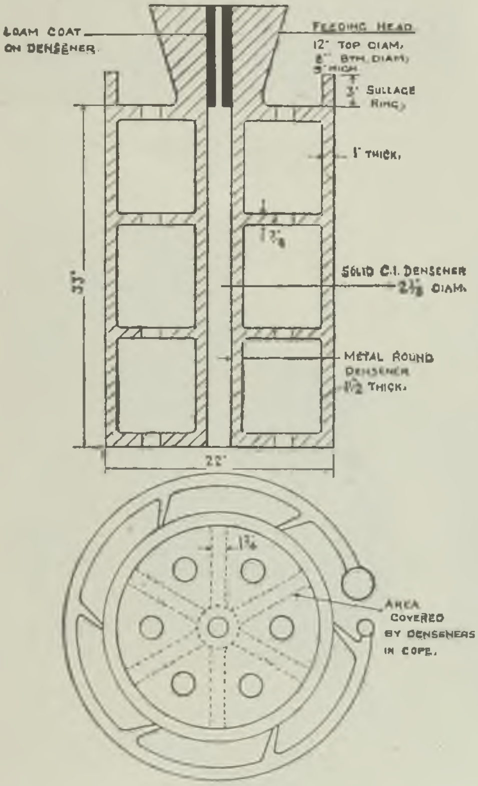


FIG. 5.—ROTOR CASTING.

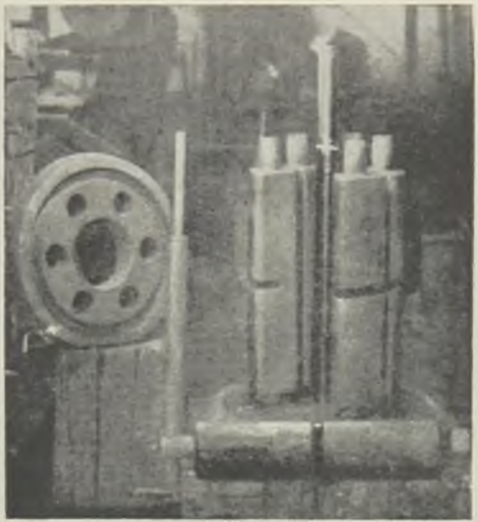


FIG. 6.—FIVE OF THE SIX SEGMENT CORES IN POSITION.

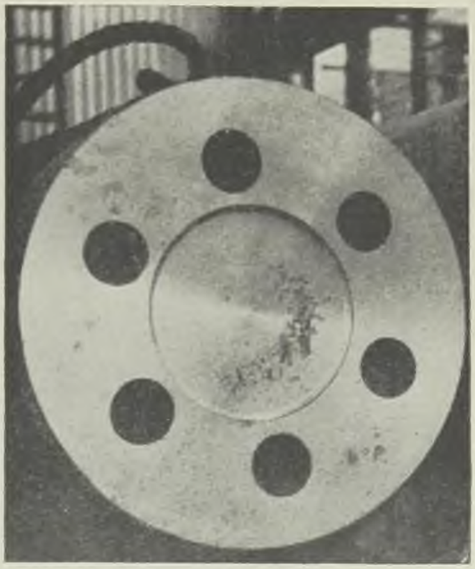


FIG. 7.—SHRINKAGE CAVITIES DUE TO FAULTY FEEDING.

lationship to it is seen from Fig. 6, which also shows the reduction in diameter of the densener over the portion which is contained in the head. The shouldered length is coated with loam to make it uniform in size; arrows chalked on it indicate the part referred to. If this precaution be not taken, the heavy densener will chill the head and seriously impair its value as a feeder.

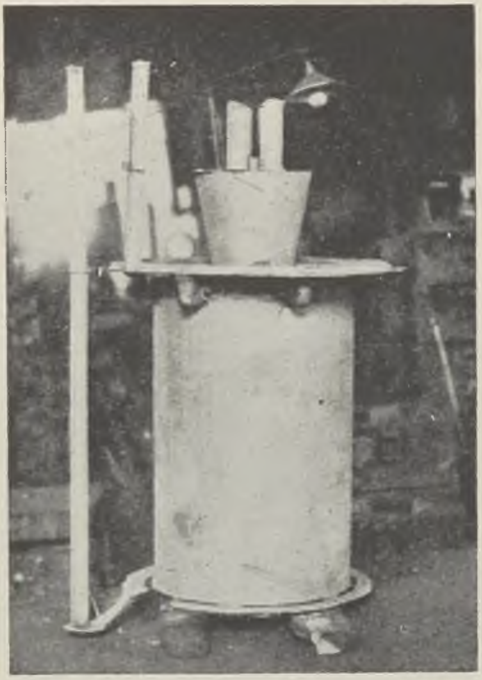


Fig. 8.—Running and Feeding System for Casting Shown in Fig. 5.

Temperature and Speed of Pouring

Pouring temperature and speed are important factors in the making of castings of all kinds, although the permissible latitude varies greatly. A temperature of the metal higher than usual may help to eliminate shrinkage de-

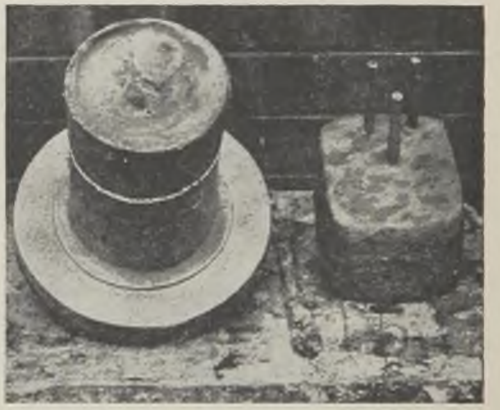


Fig. 9.—Coupling Casting and Pencil Runners.

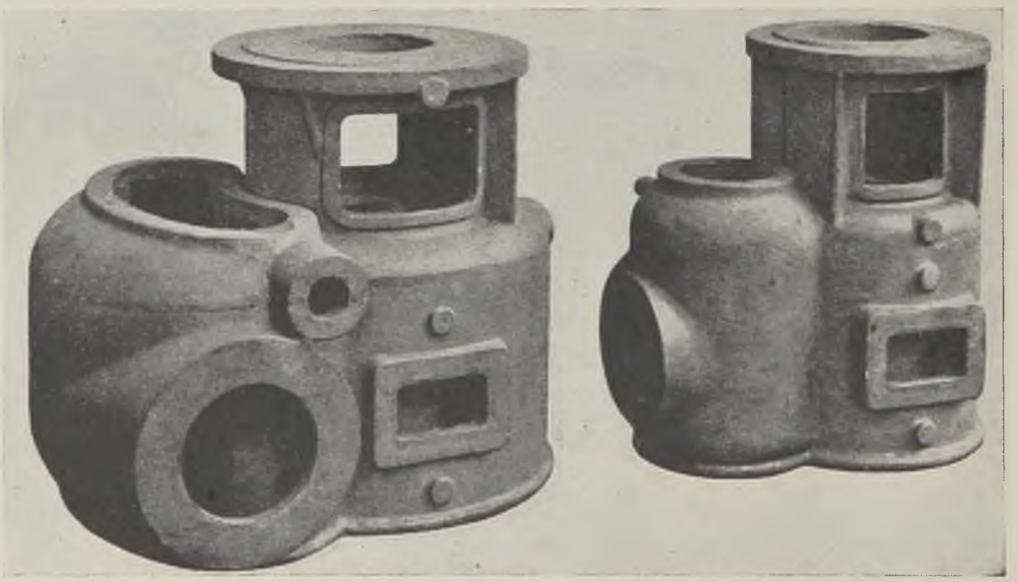


Fig. 10.—Typical Air Cylinders for Compressors.

fects, although the amount of liquid shrinkage is greater. The hotter a cupola-melted iron is poured, the quicker and more uniformly it cools through the freezing range. Before solidification commences, the surrounding sand and cores become heated and tend to equalise the cooling speed throughout the casting. Actually, the mass of sand acts in the capacity of a heat accumulator, assisting natural feeding from the runners and risers and reducing casting strains.

With the rotor casting, its symmetry of form is an asset in that it lends itself to uniform distribution of the metal by means of the two sets of six in-gates shown in Fig. 8. Two separate down-runners are used, one supplying the bottom gates and the other the top. Each of these down-runners is fitted with a plug and the bottom one is lifted first. After a fair amount of metal has entered, the other downgate is opened and pouring finished by entry from the top gates. The method of running illustrated not only gives equal flow to all parts of the mould, but it helps to ensure progressive solidification upwards from the bottom with the hottest metal in the feeding head, a principle to be observed for all castings and previously stressed.

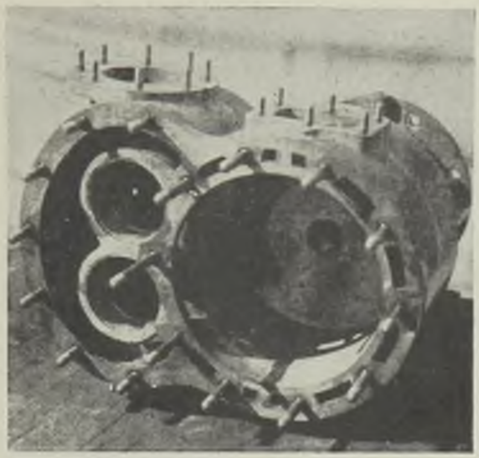


Fig. 11.—Jacket and Valve Chamber.

Respecting speed of pouring, experience is essential in gauging this satisfactory. H. W. Dietert[5] has carried out much experimental work and made many calculations along these lines. A study of this aspect of casting production is worth while, because when pouring speeds are correctly adjusted, maximum self-feeding tendencies are encouraged.

A. McRae Smith[6] has said: "Good, hot, clean metal of the correct composition poured into moulds at the correct predetermined rate, with correct distribution in the mould, will always give perfect castings." Ronceray, too, has made investigations on this subject. While the pencil type of runner that he developed is applicable mainly to lumpy castings of simple design, it aims at supplying metal to the mould at such a rate that much of the liquid shrinkage has taken place by the time pouring is finished. Very hot metal is indispensable when pencil runners are employed. Heavy coupling castings are poured through pencil gates with great success. Before this principle was applied a solid densener was used to get the bore sound. Now the boss is extended, pencil gates equally spaced are cut on top, no centre core is used, and couplings poured with hot metal in this way turn out perfectly sound. The amount of liquid shrinkage which takes place can be seen from the sunken condition of the extended solid boss. Fig. 9 illustrates one such coupling and the details described.

Fig. 12.—Jacket and Centre Cores in Position.

Reverting to the rotor casting, the best results are obtained when the size of the gates and the metal temperature are adjusted to give a pouring time of 65 secs. When in-gates are too small, the time of pouring becomes lengthened, with the danger that the castings may not run, or part of the mould may drop due to prolonged exposure to the rising metal. In any case, it is likely that the movement of the metal is so sluggish that dirt and scum will be left attached to mould and cores and be trapped in corners. Too fast pouring, on the other hand, is inclined to produce dirty castings by reason of mould and core erosion and from difficulty in keeping the runners choked. Turbulence is set up and air and gases sucked into the mould.

Compressor Cylinders

Figs. 10 and 11 show typical air cylinders for a vertical, double-acting, two-stage compressor. The larger (Fig. 10) is the low-pressure and the other the high-pressure cylinder. They weigh 10 and 6 cwts. respectively, but larger ones are made. An idea of the bore, jacket and valve chamber is obtained from Fig. 11 Both cylinders are cast in the position shown in Fig. 10, although the high-pressure one is moulded in halves, on the flat, and turned up for casting.

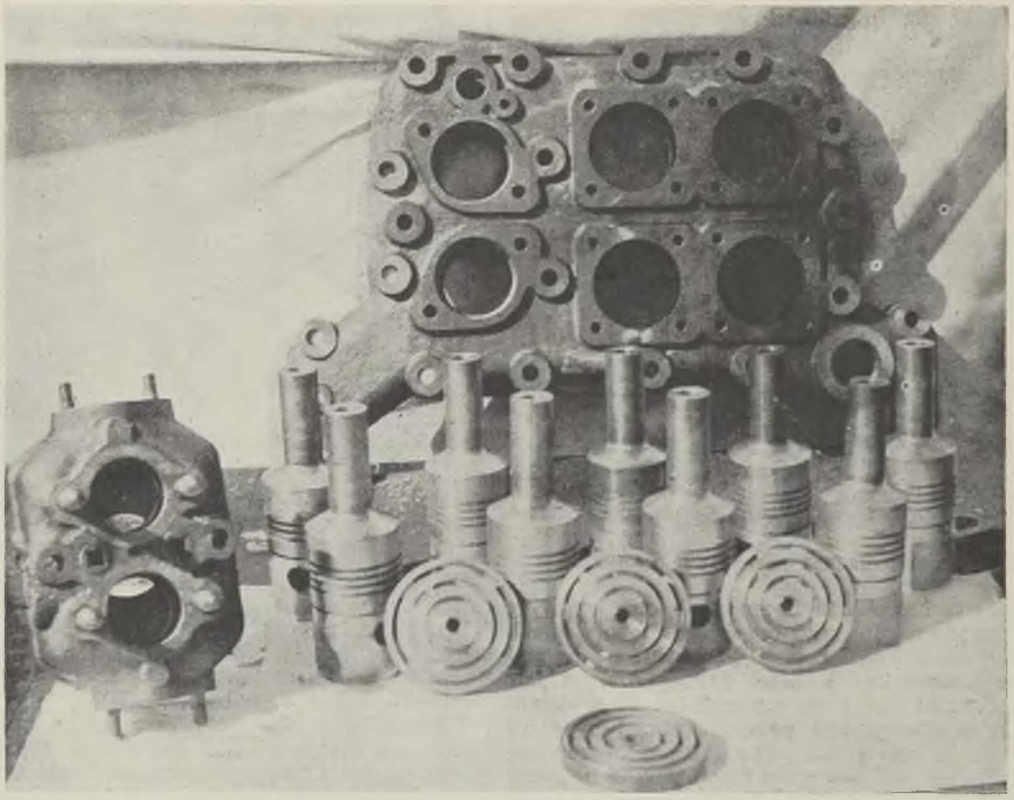


Fig. 13.—Group of Castings Including Covers and Pistons.

Considering the low-pressure cylinder, the mould is made up of a bottom, three middles and a top part. It has two down-sticks—run simultaneously—terminating in a spray of four in-gates to each. One set enters the bottom flange and the other is cut in the joint which shows in Fig. 10. Risers are taken off from the top of the valve chamber and from the top flange; the latter is rod fed. A general idea of the jacket and centre cores in position is given from the view in Fig. 12.

One single down-runner, with gates cut in the top and bottom flanges and at the shoulder, is used for the high-pressure cylinder. The top flange also takes the riser, which in this case is not fed. These cylinders are hydraulically tested in jackets and bores; also all the internal stud bosses must be sound.

Cylinder Covers

Two kinds of cover are shown with a group of other castings in Fig. 13. Attention is drawn to the number of stud bosses passing through the air and water spaces, which have to be free from porosity. The valve pockets, too, must machine cleanly and without blemish. Many other shapes and sizes of cover are made, but they nearly all possess similar features.

The large cover of Fig. 13 is moulded with the face showing in the drag. Runners and a riser are cut on the joint, and the riser is not fed. All the stud bosses are cast solid and pass right through water and air spaces, the walls of which are only $\frac{5}{16}$ in. thick.

Pistons

Several single-acting pistons are also shown in Fig. 13, and others of a different kind in Fig. 14. In all cases these are run from the top, through gates cut in the locating print arranged so as not to come opposite the gudgeon-pin bosses. The pistons with two diameters have the large part in the top. Metal thickness in all the examples shown is slight, and usually the moulds are poured from hand shanks.

Ring grooves and gudgeon-pin holes must in all cases be free from porosity, and the sloping shoulders of the stemmed pistons are expected to give a clean surface when machined. The shoulder is a likely place in which to find a defect; the abrupt change of diameter tends to check the metal flow and act similarly to a skim-gate. Therefore, unless the iron is hot and lively, dirt may be left behind.

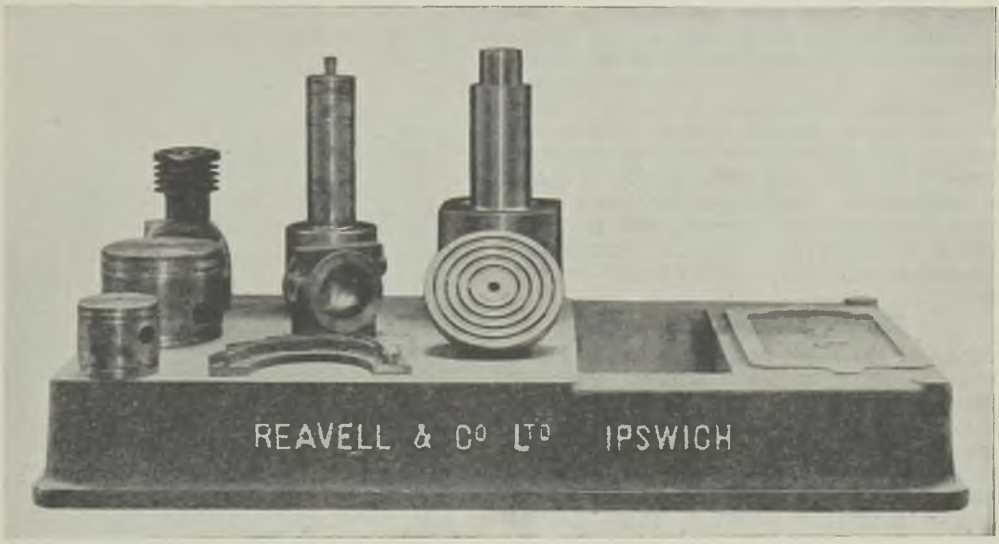


Fig. 14.—Bedplate and Pistons.

Bodies and Casings

Compressor bodies and casings are made in a large range of types and sizes. A rotary casing has already been featured in Fig. 4. They are cast with the feet in the drag; two downrunners connect with gates cut from the joint to enter the flange at each end. Risers are taken off from the flange at both ends, on top, and whistlers are cut through above each boss. The casing illustrated is air-cooled, but a water-cooled jacketed type is also made.

Some unusual features occur in the quadruplex type casing of Fig. 15; four radial cylinders form an integral part of the casting, and these are surrounded by air and water spaces as in the sectional diagram, Fig. 16. It is moulded and cast in the horizontal position, the face seen in Fig. 15 being at the top. Runners enter at the bottom of the suction facing mid-way between the two cylinder bores seen on the right, and a riser is taken off the top face. Two dummy risers are attached, one to each of the feet in the cope. Thirty-eight cores are contained in the completed mould, and the particular casing illustrated weighs 16 cwts.

A double-bore compressor body is represented by Fig. 17, with coolers as part of the casting, whilst sectional diagram Fig. 18 shows a three-cylinder body with vertical intercooler as a separate casting. These bodies are moulded on a machine of the jar-ram, roll-over and draw type. They are moulded and cast with the bores horizontal, the runners being cut on the joint at the bottom of the crankcase and two risers attached to the cooler or jacket above the bores.

Where bodies have a wall of metal common to two bores, open-grained metal is likely to appear at this juncture. Small densener strips built into the cylinder cores, so as to come adjacent to the place in question, will prevent its occurrence. In some cases the design calls for the fitting of wet or dry liners, and here the problem of soundness is not so acute.

Bedplates and Standards

Bedplates also vary greatly in size and design; the one depicted in Fig. 14 is a simple sole-plate to take the compressor and motor. That in Fig. 19 has to contain oil and has cast-in bearings for the crankshaft, similar to the one shown sectionally in Fig. 20. It weighs 17 cwts., and to ensure a sound base, which is cast upwards, a flow-off gate is used.

The standard seen in the same photograph weighs 16 cwts.; it is moulded and cast horizontally. Good surfaces are required on the crosshead guides. Metal enters the mould from a gate at the end of the lower flange, the riser coming off the flange at the top. Strains set up during cooling are liable to cause cracking; thus the practice is to break the main core irons at a suitable interval after the job is cast.

Flywheels

Here again divers kinds are necessary. The one shown in Fig. 21 is one of the largest, weighing about 20 cwts. Nearly all the pulleys and flywheels are of the disc or plate type, and the heavy ones are run with a number of comparatively small runners spaced equidistantly on the plate, and fed on the rim. On the wheel illustrated there is no boss, merely a facing for the coupling. For designs carrying a heavy boss a solid cast-iron densener, with plenty of taper, is employed to ensure a close-grained bore and sound metal in which to cut the keyway.

Machine-Moulded Castings

Many of the small castings shown in Fig. 2 are made on moulding machines. Amongst these are the single-bore and double-bore compressor bodies with cooling fins, also the air-cooled casings for small rotary compressors. The little valve bodies, too, are machine-moulded. Plate valve seats and guards are produced on a squeezer machine. These also are shown in Figs. 2 and 13. A good example of the larger plate valve seating appears poised on top of the bedplate in Fig. 14. As can be seen, the castings are shallow and therefore suited to moulding by pressure.

The concentric rings forming the seatings for the plate valves must machine up without the slightest speck or defect, otherwise they are rejected, since high-pressure air would leak past the valves. Then, too, the annular spaces between the seatings require to be true and smooth, so as to offer a minimum frictional resistance to air flow. Machining allowances are so small that the castings must be exact to pattern. An oil-bonded facing sand of fine grain size is used in order to get the small projections forming the air spaces to stand up whilst the mould is lifted from the pattern. Slots are provided in the pattern plates to coincide with those of the pattern, so that, as the mould rises from the plate, metal fingers follow through to support the thin walls of sand until clear of the pattern; the device in action gives the converse effect of the usual application of the stripping plate.

General Principles

A few specific examples of castings have been taken and the production methods which have yielded soundness and satisfaction have been briefly indicated. Although concerned with individual items, some of the points discussed may prove helpful in other cases. Those mentioned form part only of the large number of diversified types, sizes, weights and designs needed in the construction of the extensive range of compressors made. Many other different castings offering equally difficult and interesting problems could have been selected had space and time permitted. Instead, the remaining paragraphs will contain some principles of founding which have general application.

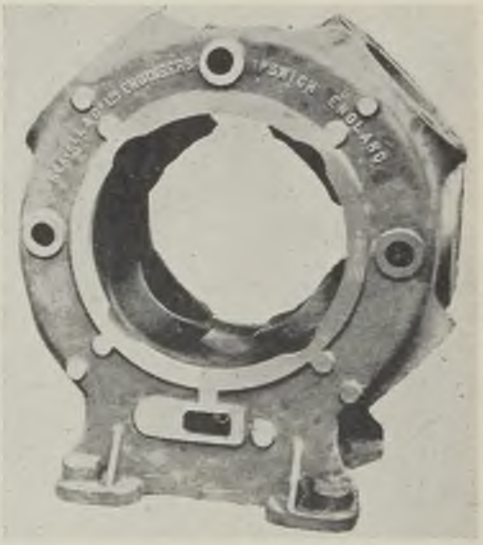


Fig. 15.—Quadruplex Casing.

Defects in castings have always been a major cause of anxiety among foundrymen. Little likelihood exists of this source of worry ever being removed, because shrinkage of liquid metal during solidification is a natural phenomenon impossible to prevent. Volume contraction during freezing, aggravated by a solidification range and non-uniform cooling, is responsible for all liquid shrinkage troubles.

Casting technique continually improves and design grows more complex, coupled with requirements of a more exacting nature. At the same time methods of inspection and testing, devised to discover defects, become increasingly rigorous and severe. When due consideration is accorded these facts, together with all the influences tending to cause defective castings, it is remarkable that the percentage of good castings is as high as it is.

Conditions for Minimum Shrinkage Defects

In theory, a metal or alloy solidifying at a fixed temperature instantly in all parts of a mould, would form a casting perfectly free from draws, shrinks, casting strains, segregation, porosity and lack of homogeneity of structure. Unfortunately, simultaneous and instantaneous freezing is never likely to happen in practice.

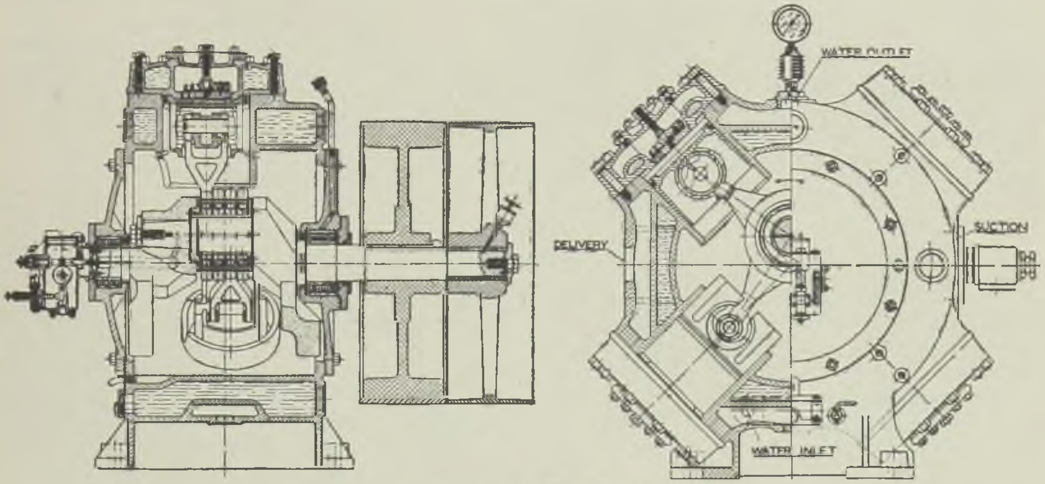


Fig. 16.—Quadruplex Type of Casing.

Although there are a number of metals which either singly or in combination will freeze without an extended range, the temperature at which solidification takes place is not attained by all parts of a mould at the same time. The more complex the casting and the greater the variation in its sectional thickness, the larger the divergence from instantaneous solidification.

Immediately conditions depart from instantaneous solidification, those causing shrinkage and allied defects are set up. Under the circumstances, progressive solidification is the answer to the problem. Gating, running and risering should be studied from this point of view, although, of course, other considerations have weight in determining their exact positions. Dull metal is an unfailing cause of trouble; runners may set before the casting has had time to feed, resulting in the appearance of a shrink hole and, most likely, porosity. Early closing of the runner removes the ferrostatic pressure and allows evolution of the surplus gases which become trapped in the stiffening metal. Porosity so occasioned is often too small to be seen, but is disclosed by water sweating through on hydraulic testing. E. Longden[7] says: "Fluid head pressure plays a very important part in aiding soundness in any metal. If a mould contains intricate cores, then every increase in the height of the riser and gate heads will be of the greatest aid in inducing gases to pass from the core sand and away through the vents rather than bubble into the molten metal. While there is little or no direct effect on the grain structure of the metal there is no doubt that head pressure induces a higher degree of soundness in any type of mould." Examination of many of the resources employed by foundrymen to produce sound castings discloses that their main effect is to facilitate uniform or progressive solidification.

Risers and Feeding Heads

To this end the importance of the placing of gates and runners has been stressed. It is well to remember that delayed cooling of a thin section can achieve the same ultimate effect as speeding the setting of a thick section. Thus placing the in-gates on the lightest section of a mould may be the simplest, easiest and quickest method of attaining the desired result. As a practical way of equalising the temperature of a mould the method is not as general as it well might be.

Fresh problems arise with almost every different casting, and whilst experience gained from previous work is an undoubted advantage they remain to some extent individual to that particular job and part of its peculiarities.

Risers and feeding heads attached to a mould do not help simultaneous solidification. They exert a contrary effect and the efficiency with which they do it measures their degree of success. The principle underlying their use is that of progressive freezing. Providing heavy sections have the requisite accessibility they lend themselves to feeding. It is obvious that metal in a feeding head should solidify last and be fluid enough to act as a reservoir able to supply liquid metal as the solidification of the casting below it causes the metal there to recede. A pair of well-formed feeding heads, suitably positioned, can ensure soundness over quite a large volume of casting, whereas denseners applied to the same end would be awkward and of large size, introducing casting strains and the hazard of difficulty in machining. With conditions and circumstances as cited above the introduction of feeding rods into the head is useful and justified.

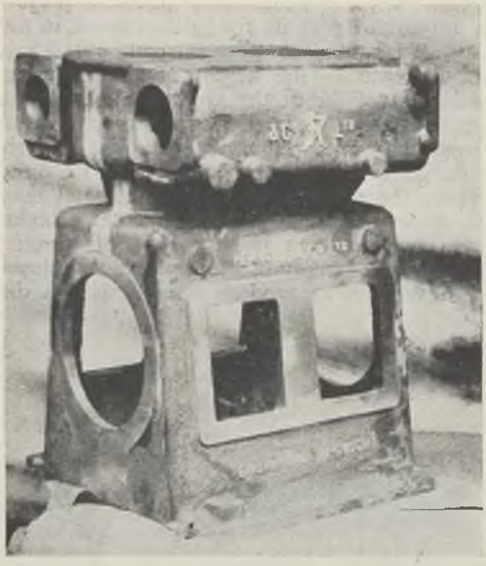


Fig. 17.—Double-Bore Compressor Body.

Rod-feeding, however, is often used where it is unnecessary and detrimental. For feeding comparatively large volumes in castings of simple form and few cores such as the rims of heavy flywheels it has a sphere of usefulness. On the other hand, high-duty irons of low total carbon content have a short freezing range. To rod-feed these may result in partially solid material from the heat getting pushed down into an important surface underneath, or the grain of the metal may be disturbed and dragged about beyond recovery. Heads of the self-feeding type are necessary in such instances, but in any case feeding with the aid of rods is an operation demanding care and skill.

Denseners

Densening is not synonymous with chilling; the latter term should be reserved for describing a means for retaining the majority, or all, of the total carbon in the combined form so as to give an iron with a mottled or white fracture. Liquid shrinkage troubles occur in many castings at places where risers and feeding cannot be applied, under conditions which are all against progressive freezing. The alternative remedy is therefore to endeavour to obtain simultaneous solidification by means of

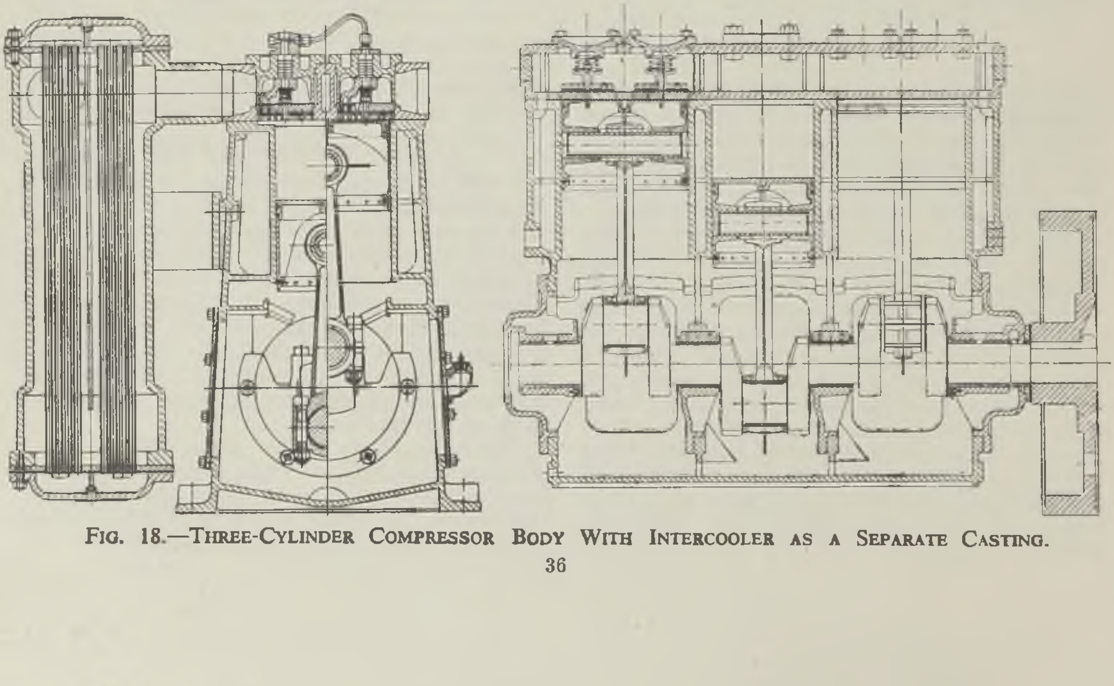


Fig. 18.—Three-Cylinder Compressor Body With Intercooler as a Separate Casting.

denseners, so that the metal structure is rendered uniformly close. There is another aspect of their use in which accelerated cooling at a selected spot will impart a structure of greater denseness than ordinary mould conditions can give. Here the purpose is not so much a desire to overcome porosity due to liquid shrinkage as to confer better resistance to wear. Both purposes are accomplished at the same time in some applications; a case in point is the cylinder-bore core shown in Fig. 12. Here strip denseners are spaced out longitudinally at regular intervals. They are just discernible in the illustration.

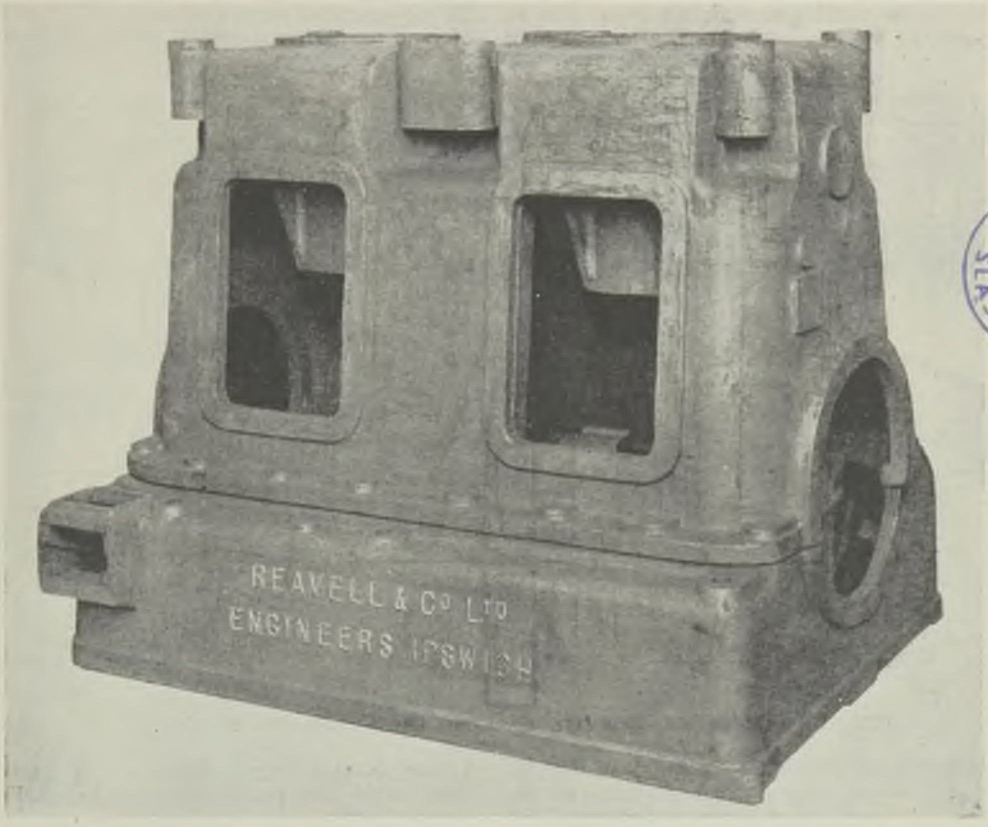


Fig. 19.—Bedplate Designed to Carry Cast-in Bearings.

Machining trouble arising from employment of denseners indicates that they are too heavy and drastic in action. Corners and sharp edges, where cooling is naturally accelerated, are often hard where cast in high-duty iron. A precautionary measure is to place denseners well back from such places. Denseners in the form of long strips must have their continuity interrupted at intervals to obviate buckling when they become hot. Carelessly prepared denseners can give rise to defects as a result of moisture condensing on them causing rust. Because of this hazard their use has been criticised, but with proper treatment and preparation it should not happen.

Use of Inserts

Metal lies up to a densener much better than on it; thus arrangement of them should be made bearing this fact in mind. If placed where hot metal flows past to any extent, their beneficial influence is completely destroyed. Metallic inserts act as denseners in so far as they tend to hasten cooling and minimise shrinkage. They differ, however, in that they form a part of the casting unless in a situation where removal by machining takes place subsequently. Discretion is needed especially in placing inserts, since indiscriminate use can cause the very defects they are employed to eliminate. Inserts of too heavy a section in comparison with the mass of the casting at the point where they act, are only loosely held by the solid metal, and leak badly under water pressure. Machined surfaces of importance must also be avoided or the inserts may be revealed as a discontinuity causing wearing trouble at a later stage. Chaplets and studs used to hold cores in position must be considered as coming under this heading.

The Léonard Effect

Any factor tending to maintain metal fluid in a mould at various odd places, after the bulk has become solid, is a potential source of defects. One such factor arises when portions of the mould become excessively heated, forming " hot spots." Sand walls of little thickness may separate two heavier walls of metal, and small cores and projections are often nearly completely surrounded when the mould is cast. Prolonged passage of hot metal past a given point can have the same effect of raising the sand to a temperature approaching that of the iron itself.

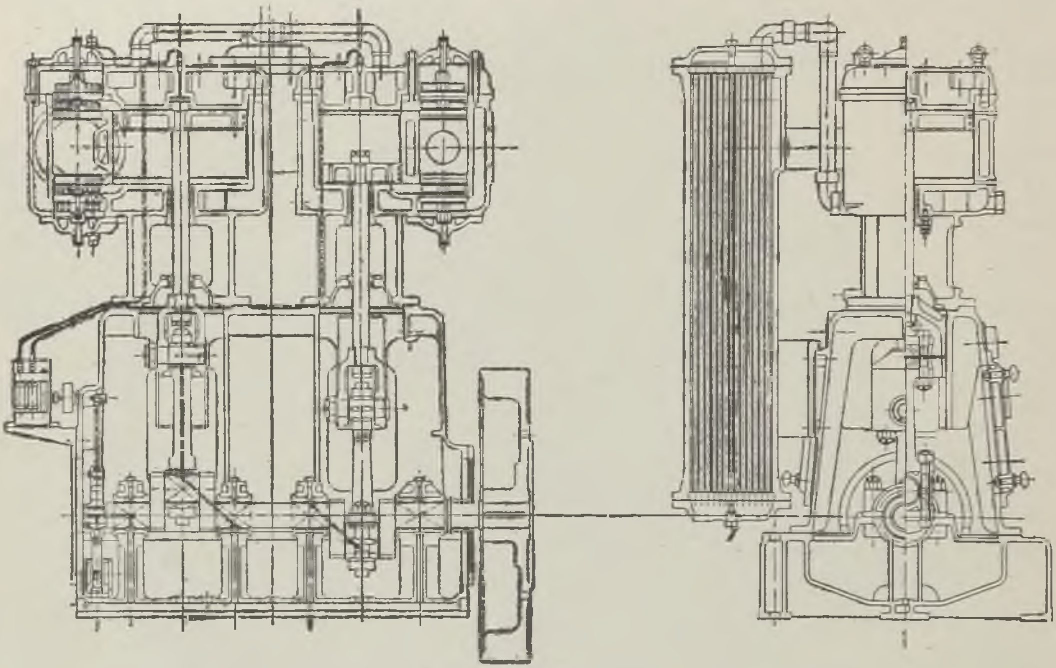


Fig. 20.—Compressor Bedplate Carrying Oil and Cast-in Bearings.

Once part of the sand forming a mould or core has become so heated it not only greatly retards cooling in the metal adjacent, but most likely itself evolves gas which, finding no other exit, remains trapped in the casting. The sponginess, porosity or definite holes revealed on machining are due entirely to the sequence of events forming the " hot spot," which has also been termed the " Léonard effect."

Replacement of the sand by a densener, at the point where the hot spot occurs, removes the cause of the trouble. Ribs and webs, where they adjoin the body of a casting, often mark an area of porosity generally ascribed to drawing away of the liquid metal. When the cross-sections involved are disproportionate the cause mentioned may be correct, but the defect occurs where sections are uniform and not excessive. At rib junctures there invariably exists a wedge of sand heated from several sides and, in consequence, more fiercely. Avoidance of the rib or more rapid cooling at the junction eliminates the sponginess.

Another instance of the Léonard effect occurs where two cylinder bores come close to each other. It is also developed by moulding castings such as liners or bushes too near to one another in the same box. An unsuspected cause of the defect follows the placing of a down-sprue too near the casting. In all these cases the sand may be heated strongly enough to retard cooling, and evolve gas which is forced into the metal during solidification. The use of a very open sand and ample venting at these congested places greatly assists to overcome the trouble.

Flanged castings as illustrated in Fig. 22 often weep, under hydraulic test, at the radius under the flange, especially if the recess made to take the bolt heads cuts into the radius. A densener applied as shown is a sure remedy, or a well-dried and well-vented loam cake will prove effective. Thick masses of metal, resulting from abrupt sectional changes, enclosing thin parts of sand mould or cores, greatly aggravate trouble under this heading.

Design of Castings

A number of the methods and devices utilised by founders to overcome and avoid defective castings have been outlined. Much towards attainment of success is possible by these or similar means, but badly-designed castings, from the founding viewpoint, are a serious handicap and increase the cost of production even if they can be made sound in spite of the hazards involved.

Often a modification to the pattern which has no effect whatever on the utility of the casting will greatly increase the chances of obtaining a sound casting and dispense with much trouble and scheming in the foundry. Neither simultaneous nor progressive solidification can prevent gas present in the liquid metal from coming off as cooling takes place, but they do ensure that no collection of it remains trapped at a spot where the metal has remained liquid.

If a thickened section is liable to contain a hidden defect, it may be not stronger but weaker than the other parts of the casting. In any case it is not proportionately stronger because cooling is retarded, with consequent increase in grain and graphite size and quantity of the latter. These influences offset the theoretical benefits shown from the calculations of the draughtsman who thickens sections to give a greater factor of safety.

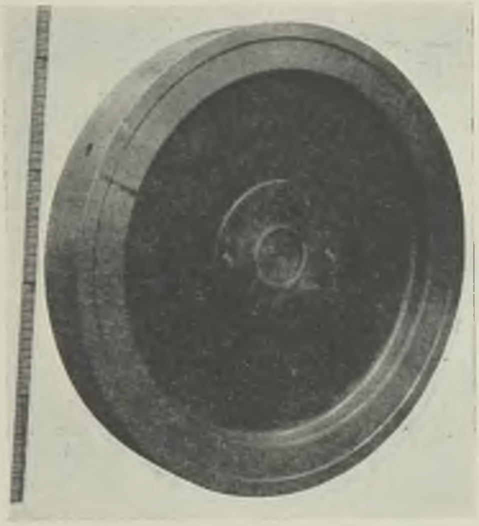


Fig. 21.—Flywheel Weighing About 20 cwts.

Warping of castings can also be attributed to extremes of section thickness. Indeed, the stresses so imposed by differential cooling become so large occasionally as to cause severing or cracking of the parts. Hence design as applied to sectional thicknesses, changes, and the radius of fillets is of the utmost importance apart from considerations of ease and economy of production.

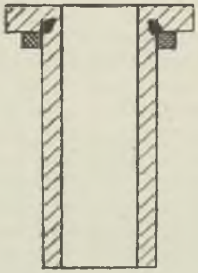


Fig. 22. — Leonard Defect in Flanged Casting.

Coring is also a subject not always fully understood or appreciated by the designing staff. All holes and spaces in castings have to be formed by sand cores or equivalent projections from the mould surface. Wherever a core is used provision must be made to hold it securely in place, vents must be taken off from it to outside the mould, and a means found for extracting it after the casting is made. Besides all this the manufacture of cores is a charge on the job. Therefore, although cores reduce the weight of a casting, they do not necessarily lessen its cost of production.

Re-entrant cores, by extending the surface into the heart of a casting, may set up the Leonard effect already mentioned. Friendly co-operation between designing, patternmaking and founding departments can prevent waste of time and misplaced effort on all sides. Foundrymen often attempt the production of a casting which they know from experience will lack freedom from defects, rather than have their skill or ability called in question. General, sympathetic consideration of the difficulties of all concerned will help tremendously to smooth the path and further mutual interests.

Finally, the writer wishes to acknowledge the permission granted by Reavell & Company, Limited, and Mr. H. A. Hartley to present this

Paper. He is also indebted to his colleagues, Mr. A. F. Hammond, Mr. R. J. Bartholomew and Mr. R. Leeks, for assistance in its preparation.

REFERENCES.

[1] J. L. Francis, "Foundry Trade Journal," June 15, 1933, p. 416.
[2] A. L. Norbury, "Foundry Trade Journal," Aug. 1, 1929, p. 79
[3] H. H. Shepherd, "Metal Industry," Feb. 5, 1926, p. 138.
[4] P. A. Russell, "Foundry Trade Journal," Jan. 26, 1928, p. 56.
[5] H. W. Dietert, "The Foundry," March, 1930, p. 129.
[6] A. E. McRae Smith, "Foundry Trade Journal," Dec. 13, 1928 p. 429.
[7] E. Longden, "Iron and Steel Industry," May, 1936, p. 271.

WRITTEN DISCUSSION

MR. E. LONGDEN wrote:—

The Paper prepared by Mr. J. L. Francis is of outstanding merit, both by its common sense and its completeness in summary of complementary data. I would recommend foundrymen to keep this work of Mr. Francis as a reference. The Institute of British Foundrymen should not miss recognition of the very helpful, practical contribution to the manufacture of castings.

May I, however, just refer to certain sections of the Paper which need to be noted?

On page 30 (second column) the author has stated:—"Pressure-tightness and good wearing qualities are main characteristics striven for in the castings described. For these properties nickel alone, or in combination with copper, *suffices* to render thick sections dense and *sound* and maintain thin sections grey and machinable. Alloying is accordingly restricted to the use of these two metals in the majority of cases."

I suggest that if the word "suffices" (enough) be replaced by the word "tends" (to contribute) one can agree with the beneficial effects of nickel and copper when due consideration is given to the balancing of the elements normally present in cast iron. The selective graphitising effect of nickel and copper, so that the pearlite carbide tends to remain as carbide but in a more refined condition, and the graphitising influence of the added alloys on the free carbide will produce stronger and more wear-resisting metal than in metal without the added elements and its adjustment in other elements. Apart, however, from the slight effect of small amounts of nickel on the freezing point of cast iron, section differences and the contingent defects are not at all completely appeased by employing nickel, copper or other element. If alloying elements eliminate defects why use denseners which Mr. Francis uses so effectively?

Effect of Densening

When referring to the production of heavy coupling castings illustrated in Fig. 9, it is stated that "The amount of liquid shrinkage which takes place can be seen from the sunken condition of the extended solid boss." I would suggest that the sunken condition of the head does not expose real fluid shrinkage, but rather does it indicate a condition resulting from the pouring of cast iron, of grey iron composition, into normal sand moulds. If Mr. Francis will pour the heavy coupling in an iron mould, or in a mould almost completely faced with denseners, he will be repaid with the evidence obtained—the castings will be commercially sound. Furthermore, it will not be necessary to provide a head to take care of liquid shrinkage; it will only be necessary to add sufficient extra metal (½ in.) to take care of sullage. To obtain this result the metal should be of such a composition that it yields a grey iron throughout its sections and the runner gates should be surrounded by sand and well distributed, and a small gas outlet riser gate be located on the highest point of the mould. I do not, however, suggest it is often commercially practicable to produce castings in such a manner. It depends on the simplicity of its design and its mass.

As I have frequently stated, due to the expansive effect of precipitated graphite carbon at the point of solidification, it will be found that, in normal cast irons of grey iron composition, it is possible to produce sound castings without resort to the employment of feeder heads.

The Léonard Effect

I would suggest that the shrinkage and porosity effect of wedge-shaped portions of sand, which create gassy and hot spots, referred to as the "Léonard Effect," should be re-named the "Fletcher Effect" or the "B.C.I.R.A. Effect," or named after other men I have in mind. The British Cast Iron Research Association put the diagnosis of this phenomenon on its best-known basis long before we learned of Léonard. Fletcher afterwards referred to this aspect of porosity both inside the authority of the British Cast Iron Research Association and in his lectures to technical bodies, particularly to the Institute of British Foundrymen. I for one shall in future refer to the "Fletcher Effect." It is a trait in the British character to take too small notice of our own nationals and too much notice of foreigners in technical as in other matters.

AUTHOR'S REPLY

MR. J. L. FRANCIS wrote that, before dealing with the points raised by Mr. E. Longden, he wished to record appreciation of his kind remarks and approval of the Paper as a whole.

Alloyed Cast Iron.—The wording of the second paragraph under this heading could have been better chosen. It was intended to differentiate between the use of alloys for imparting special properties other than those mentioned, *e.g.*, high hardness, corrosion and heat resistance, and to emphasise that copper and nickel alone are sufficient to induce the necessary pressure tightness and resistance to wear. Neither nickel and copper nor any other elements singly or in combination in cast iron can give complete immunity or guarantee the entire elimination of defects, and there was no intention to convey the idea of any such foundry millennium.

Although alloy additions can effect modification of structure, they do not achieve this by any adjustment of cooling speed. Sections of varying thickness solidify under the same differential characteristics, despite the presence of alloys. Denseners, therefore, though perhaps not so necessary, can still be useful in rendering cooling more uniform and reducing the tendency towards formation of shrinkage cavities at places where feeding cannot be applied.

Coupling Castings.—Mr. Longden's method for producing commercially sound castings, such as are illustrated in Fig. 9, is interesting. The system described in the Paper also produces commercially sound castings with greater simplicity and latitude in operation. It has the advantage, moreover, of always being practicable without much limitation due to design and mass of the coupling.

Fletcher Effect.—I am perfectly willing to use this term in place of "Léonard Effect" in describing the porosity emanating from overheated portions of sand. Mr. Longden may be correct in crediting priority of diagnosis of this type of defect to British workers. I merely used the designation as being well known in the literature on the subject and because it has previously been accorded unquestioning acceptance as conveying conception of a definite condition. I would much rather be accused of ignorance than lack of patriotism or willingness to accord due recognition to British workers.

Mr. H. W. Keeble in another written contribution to the discussion wrote:—I have read the Paper with interest and profit. I developed a feeling that if all foundries on this class of work operated with the same degree of control there would be less call on the local drysalter's stock of sal ammoniac, and fewer occasions for the machine-shop people to cover their own failings to fulfil schedules by the indiscriminate use of the excuse, "trouble of weeping at pressure test."

I note that Mr. Francis works with cupolas fitted with receivers; further, that he arranges his "blow" so that he commences with ordinary grade iron which changes progressively to high-duty grades and then back again to the ordinary grades. Perhaps Mr. Francis would outline his reasons for this procedure, as from the compositional aspect it would seem more straightforward to work from ordinary grades up to the highest grade and then finishing. Presumably such factors as local floor conditions of coring-up, closing, availability of ladles and peculiarity of cupola operation, etc., affect the issue. The two sets of conditions are shown graphically in Fig. A.

The author stresses the necessity, and rightly so, of timing the charges through, and I would like to have his opinion of supplementing this control by use of the wedge chill test. Under the best of conditions emergencies arise, such as scaffolding, etc., which might render timing control alone somewhat inadequate.

Effect of 1 per cent. Manganese Additions

The use of high manganese contents by Mr. Francis (that is, around the 1 per cent. mark) for high-duty work is to be recommended and is based on sound metallurgical principles. It would be to advantage if this practice were more widely followed. Fifteen years ago the "all-pearlitic" structure was the fashion in cast-iron metallurgical circles. As was expressed at that time, the next phase of development would be the attainment of sorbitic structures, and in this manganese plays a part. The 1940 A.F.A. "Cast Metals Handbook" says: "As manganese content of cast iron is increased the matrix is successively pearlitic, sorbitic, martensitic and austenitic. In a pearlite iron, an increase of manganese from, say, 0.4 to 0.7 per cent. would affect structure very little. With an increase up to, say, 1 per cent. the matrix would be expected to appear somewhat sorbitic." High manganese facilitates use of ordinary base irons and machinery scrap for manufacture of high-duty irons.

I would like to have the author's opinion on one aspect of high-manganese practice. With pig-irons containing high manganese, phosphorus and silicon (like pig-iron A, Table I of the Paper), I have noticed that primary as well as secondary graphite is much in evidence. The author recognises the possible effect of this, for he says: "Charge materials having an excess of coarse graphite tend to retain this characteristic even after passage through the cupola." Does he have any trouble on this account from high-manganese pig-iron?

Moulding Technique

With respect to the moulding technique for the cast-iron rotor, it is noted that the shouldered portion of the machined densener rod is coated with loam. Is this shoulder portion serrated to carry the loam, or is twine, etc., used as a bonding medium? Also, is any dressing applied to the remaining length? Most foundrymen think of " blowing " troubles when metallic denseners or inserts are mentioned. One of the causes is undoubtedly the sweating of the chill, brought about by water condensate forming on the densener surface. Premature closing of warm moulds, striking back of skin-dried moulds, etc., are among causes of condensate formation. On the other hand, I feel that insufficient attention is given to the scientifically verified fact that certain compositions of cast iron will readily give off gas when heated beyond 700 deg. C. I am referring to the work of Genders and Bailey, Research Monograph of the B.N.-F.M.R.A., pages 115 to 118.

These workers demonstrate that gas is given off in appreciable quantities, the volume increasing with the combined carbon content. The reaction is vigorous at 750 deg. C. The " blowing " is due to chemical action between the usual oxide film and the carbide of the densener; surface oxidation is necessary between the heatings. White iron is the worst offender and soft grey iron the least. In practice, it is almost impossible to avoid superficial oxidation taking place, although the burnt-out dressing provides some protection against oxidation while not being used. When used in the mould, the freshly applied dressing affords some assistance against local overheating by its thermal insulating effect. A machined cast-iron densener is more liable to oxidation than is one possessing the " as-cast " siliceous skin. These facts demonstrate that denseners should be made in soft iron, *i.e.*, of low carbide content, should be used with the " as-cast " skin intact, be dressed, and the metal flow in the mould arranged (as far as possible) so that overheating (beyond 700 deg. C.) does not occur. Under these conditions " blowing " from the densener will be a straight issue relative to " sweating " only.

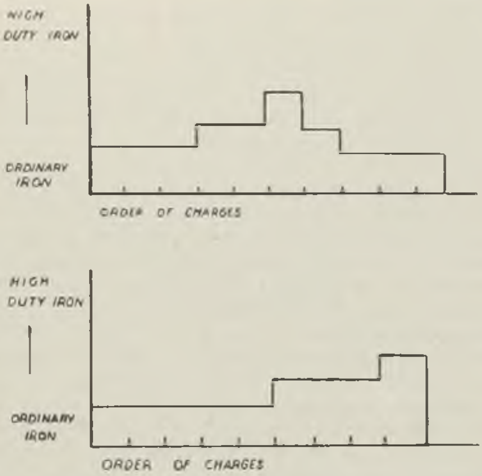


FIG. A.—AUTHOR'S CHARGING SYSTEM (UPPER) AND SYSTEM SUGGESTED BY MR. KEEBLE (LOWER).

AUTHOR'S REPLY

MR. J. L. FRANCIS replied: My thanks are due to Mr. Keeble for raising some very interesting points. Apart from his kind remarks in the first paragraph the nature of the contribution reveals that Mr. Keeble has bestowed the compliment of thoroughly studying the Paper.

Reasons for adopting the charge sequence mentioned may be stated briefly as follows:—The demand for high-duty material is usually least in quantity. Optimum melting conditions, in the cupola furnace, tend to occur over a period commencing from the end of the first three or four charges up to a point just before the stock begins to fall at cessation of charging. During this period charges are tapped with chemical composition truer to the theoretical figures calculated from the analysis of their components. Oxidation tends to increase towards the end of the blow and it is not good policy to leave all the most important castings until the last when the ladles are not so clean. In order to conserve the furnace lining as much as possible it is good practice to cease blowing before the last charge has melted and it is preferable for the metal coming down with the " drop " to be of the least costly grade.

Timing Control

Mr. Keeble brings forward emergencies of scaffolding and blast failure he could also have added run-outs. These, of course, should be of rare occurrence only and whilst needing anxious attention it is not desirable to hamper everyday routine melting practice with safeguards intended for operation at rare intervals and which ought to be applied more effectively elsewhere. Actually the timing control is supplemented and checked in practice by employing ladles which have a capacity of at least one charge unit or whole multiples thereof.

The author confirms the utility of the wedge chill test as a means of control but would again emphasise that with comparatively small amounts of high-grade metal time is a factor of vital importance.

In assessing the effect of manganese on cast iron, due consideration must be accorded to the requirements of the manganese-sulphur balance. As explained in the Paper, it is only the manganese in excess of this requirement which is available for exerting the modifications to the structure quoted from the 1940 A.F.A. "Cast Metals Handbook."

With a siliceous pig-iron, such as A in

Table I, primary graphite would be expected irrespective of the manganese content. It is intended for use in the lower-grade charges and to carry a high ratio of returns and scrap, the last two items exerting a sufficient refining influence for the purposes intended. Perhaps Mr. Keeble has in mind the tendency of high-manganese irons towards greater carbon absorption. Excess of coarse graphite in the high-duty iron is guarded against by the use of hypo-eutectic irons and running the cupola so as to obtain minimum carbon pick-up. This is explained in the Paper, but a further hint, not mentioned, consists in the charging of fused soda-ash blocks with the bed coke.

Another point with regard to manganese is its introduction to the melt in the form of low-carbon ferro-alloy. Here, because a greater proportion of the manganese is free, that is, not combined as carbide, its action is said to be more intense and the benefits derived are more easily and readily obtained.

Denseners

The points put forward on this subject are well worth studying. Dealing first with the long centre densener used for the bore of the rotor, it is produced as a casting, the shouldered portion cast vertically downwards and formed in a dried sand core. To hold the sand to this portion it is first coated with core gum or slurry. The casting skin is not removed by machining; a dressing of a proprietary anti-scab solution is applied, but a coating of ordinary creosote would do equally well. A cast stick of 2⅜ in. dia. would not cool very rapidly, so that the combined carbon would not be very high. Thus it seems that most of the requirements summarised in the quotation from the work of Genders and Bailey have been met. Finally, it is not likely, owing to the cross-sectional area of the densener, that it would attain to 750 deg. C. throughout its mass until after the molten metal had formed an appreciable solid skin around it.

Paper No. 708

Development of Some Gating and Feeding Methods for High-Duty Alloys

By C. C. BRISBOIS and A. E. CARTWRIGHT (American Exchange Paper)

The energetic development of high-duty alloys that has taken place during recent years, while being a tribute to the enterprise and ingenuity of the metallurgist, has taxed considerably the resources of the foundryman required to produce castings embodying the enhanced qualities implied by the results of metallurgical research.

The foundry and metallurgical technique requisite for the production of sound, dense castings in the modern high-duty and alloyed irons, for example, is much more exacting than that which was required in other days for the cast irons of the period. Higher pouring temperatures are the general order, and dictate the use of more refractory moulding sands. High liquid shrinkage and short freezing range of the low-carbon high-strength grey irons, "Ni-Resist," "Ni-Hard" and similar alloys, demand more generous feeding measures than the grey-iron foundryman was previously accustomed to provide.

A steadily increasing demand for castings of these types of alloys argues that they are performing satisfactory service. Whether methods of producing them are universally such as to utilise to the fullest extent the metallurgical improvements that have been demonstrated, is possibly debatable and a subject worthy of consideration by those interested in their promotion. It is not sufficient that these modern alloys should furnish some additional service value over that of material previously used; for true progress one must aim for the ultimate properties possible of attainment from the alloy concerned. That this attitude has been taken by pioneering producers of these alloys is certain; otherwise, regardless of the improved metallurgical qualities and higher properties obtainable in test-bars, such marked success, in competition with other metals and methods of fabrication, could not have so far been attained or maintained.

It is recognised that discrepancy unavoidably exists between the mechanical properties of sections of a casting and those obtained from a standard form of test-bar, owing to the diverse structural characteristics, produced by differences in cooling rates, occurring in the varying designs of castings. It is essential, however, that the foundryman should take all precautions against this discrepancy being widened by porous discontinuities produced by inadequate feeding In the authors' experience, gating and feeding proportions may be such as to provide a minimum or maximum density in a casting, above the range where rejection, due to visible defects, occurs. Minute porosities resulting from minimum feeding provision will usually be reflected in lowered strength and lessened resistance to wear, abrasion, cavitation and corrosion.

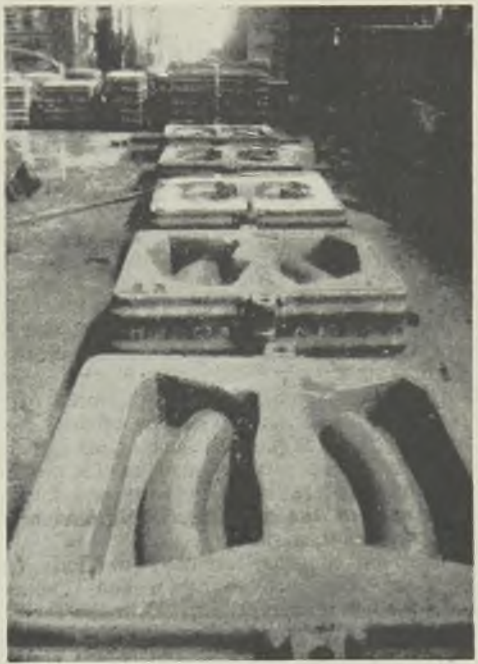


Fig. 1.—Bottom Parts for the Castings Shown in Figs. 3 and 4.

A number of variables are present when planning the proportions and location of gates and feeding heads for an unfamiliar design of casting. In foundries engaged in quantity repetition work, it is feasible to determine, on a trial basis, the most effective and economical moulding technique for a particular design, before going ahead with production. This process is not, of course, practical where the miscellaneous jobbing foundry is concerned, except in minority instances, where a large number of castings from one pattern design are required.

The methods described in the present Paper were evolved to meet the requirements of the extremely miscellaneous jobbing foundry with which the authors are concerned. Experiments were initiated about four years ago with the object of reducing the sensitivity to the variables prevalent in ordinary methods of gating castings weighing from a few ounces to two tons, made in both ferrous and non-ferrous alloys, including various tin bronzes, brasses, manganese and aluminium bronzes, silicon bronze, nickel silvers, Monel, and commercially pure nickel, as well as the alloyed irons mentioned above.

General Gating and Feeding Practice Consideration

While innumerable variations of gating and feeding of castings are practised by different foundries, the almost universal method is to run castings by introducing the molten metal through one or more gates and to take care of shrinkage by use of feeding heads. Adequate feeding is sometimes accomplished by means of the gate itself, but when heavy sections are involved and more than a very moderate amount of feeding is required, separate feeding heads usually are employed. Such heads, more often than not, represent the last portion of the mould to be filled upwards from the casting, and, therefore, must be so proportioned as to provide feeding metal of sufficient quantity and fluidity to take care of the shrinkage requirements of the casting sections.

A number of supplementary methods frequently are employed to attain and maintain the required fluidity of the metal in the feeding head, *e.g.*, (*a*) interrupting pouring through the gate at a point where the mould cavity is filled and transferring pouring directly into the riser, and (*b*) connecting the down-sprue with the base of the feeding head at a point where the mould cavity is full. Covering the head with powdered charcoal or other compounds furnishing an exothermic reaction, introducing a small amount of phosphor-copper (in the case of some bronzes), the use of feeding rods, etc., are all methods used to increase feeding-head efficiency.

The obvious method of dispensing with a separate introductory gate and pouring directly and entirely through the feeding head is seldom seriously considered. To use the last-mentioned method, it is necessary to ensure that the metal entering the mould is thoroughly free from dross or slag, and also to provide a mould surface that will resist satisfactorily the impact of falling metal. This latter condition commonly is considered sufficiently difficult of fulfilment to discourage the use of that method of introducing the metal. The methods herein described and illustrated were planned to overcome these seeming difficulties, and to render the pouring of moulds through feeding heads a practical and worth-while procedure for many designs of castings.

Existing References to Direct Pouring Methods

Dwyer[1] illustrates and briefly describes a system of direct pouring through a strainer-feeding head, attributing the original idea to an Italian foundry engineer, Brunelli. Ronceray[2] likewise credits Brunelli with the initial recommendation. However, Ronceray can be particularly identified with the promotion of the idea through several Papers[2 3 4] read before European and American foundrymen.

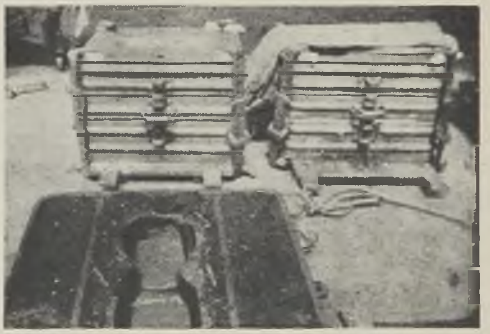


Fig. 2.—Closed Moulds for Dies, Showing Strainer Cores.

The late George Batty described a method[5] of arriving at similar results by bottom-gating into feeding heads placed at low levels and, subsequently, partly or wholly reversing the mould position, so that the hottest metal is in the correct relative position for effective feeding. This process may be practicable under certain standard conditions of production, but is a rather terrifying prospect for the average jobbing founder.

Preliminary Studies

Initial consideration was given to choice of available moulding sands best suited to withstand expected severe conditions. Practical trials were made to determine the most efficient basic form of feeding heads to accentuate the expected advantages of the method of direct head pouring.

Co-operative efforts of the metallurgist and practical foundryman were, of course, essential at every stage of the experiments. Critical comparative study of fractures and metallurgical structures was a prime means of evolving basic feeding-head designs. Laboratory and practical foundry tests of sands and bonding agents were of importance, as also were thermal tests indicating the relation between actual pouring temperatures and the temperature of the metal in the mould at the end of pouring.

These data, considered along with freezing ranges of various alloys, indicated the improvements available by lowering the degree of superheating of the molten alloys necessary for optimum results. Intelligent revision of moulding technique to suit the conditions, economical planning of existing equipment, and the addition of a minimum of new essentials, perseverance in overcoming various minor obstacles, and, not least, tact in obtaining the co-operation of the conservative moulder in efficiently handling the less usual materials and methods, were all matters requiring careful attention.

Fig. 3.—Dies Before Fettling.

Advantages Obtainable by Direct Riser Pouring

It was increasingly demonstrated that, properly applied, the principle of direct riser pouring was capable of providing the following advantages: —

(1) Much enhanced effectiveness of feeding by having the feeding head filled last with hottest metal, and maintenance of feeding head temperature by virtue of the head being covered with a heated strainer core.

(2) A moderate economy in feeding metal and gates, together with a large economy brought about by reduction in the number of defective castings.

(3) Much lessened sensitivity to feeding head proportions for different casting designs and alloys of different shrinkage characteristics; that is, the feeding head is generally of a size to compensate for a range of shrinkage wider than that provided for by the more usual methods.

(4) Generally lower requisite pouring temperatures for all alloys, with corresponding less necessity for excessive superheating of the molten alloy. The last is an especially attractive feature from the metallurgical standpoint where those alloys most susceptible to oxidation or gas absorption beyond their melting point are concerned.

Design of Direct-Pour Feeding Head

The basic design of feeding head chosen was that of a straight-sided, round-shouldered, short-necked bottle. The total height and diameter are variable, according to the size of section to be fed and the alloy concerned. The following principles of proportion are adhered to as closely as possible: —

(1) The diameter of the base (neck) of the feeding head adjoining the casting should be not less than one-half the full diameter of the head.

(2) The full diameter of the feeding head should be continued downward to a point as near the casting as is consistent with maintaining a sufficient mould strength at the junction.

The importance of an efficient feeding head proportion and the general adaptability of a few sizes and shapes were considered sufficient to warrant making and maintaining a store of patterns. The riser pattern decided upon is handed to the moulder along with the casting pattern. This eliminates uncertainties due to any misunderstanding on the moulder's part as to the required feeding provision. Some of these patterns are made of wood; others are cast hollow in scrap aluminium. Plain cylindrical or square extensions are provided for varying height, and a coreprint is provided for seating the strainer core used in all direct-pour heads. For heavy solid work having flat backs, such as die-blocks, the round bottle-shaped feeding head, unmodified in shape, is used. Varying casting designs, position and shape of cores, reinforcing bars in flask equipment, etc., frequently make necessary modification of the actual shape of feeding heads. The proportional dimensions are, however, adhered to as closely as possible.

Fig. 4.—Finished Dies Made of Nickel-Chromium Iron.

Most of the earlier experiments were carried out with dry-sand moulding. This procedure was followed because the more expensive rejections concerned this type of work; that is, fairly large castings of relatively heavy sections, and also because ordinary green-sand mould surfaces do not satisfactorily resist the impact of molten metal falling from a height. It was found desirable to use a synthetic sand for the higher melting point alloys, such as nickel alloys and alloyed irons. The fact that this sand is constantly available is the main reason that other alloys, perhaps not strictly requiring such a highly refractory sand, happen to have been cast in it. It is quite likely that, for ordinary bronzes, a natural sand would be sufficiently resistant to the pouring conditions. A fairly open sand is desirable (preferably one with a grain fineness number of 80 to 120 and with high permeability, a sand corresponding to A.F.A. coarse No. 3 or fine No. 4), and the mould should be well treated with a graphite wash to obtain good surface quality. In personal practice, the authors lean generally toward sand of high permeability rather than use of a vent wire on a less open sand.

Synthetic Sand

The synthetic sand mixture chosen for direct riser pouring consists of a pure white silica sand bonded with 10 to 12 per cent. bentonite. The heap sand gradually has been built up over a period of two years by preparation of a facing sand including about 20 per cent. of new silica sand. When no increase in the quantity of heap sand is required, it is usual to prepare a facing sand from 100 per cent. heap sand, 1 per cent. bentonite being added.

Cereal Binders

The addition of 2 to 5 per cent. cereal binder is made to the facing sand. This combats the tendency towards surface drying and crumbling generally associated with synthetic sands. The cereal binder is very efficient in maintaining plasticity without leaving behind undesirable fine material of bond destroying qualities when it burns out, a difficulty sometimes experienced when using, for example, coal dust.

Mechanical Analyses

The sand, as will be seen from the mechanical analyses of Table I, is very resistant to grain changes and to reduction to fine material. Sand losses are confined to average burning-out of bond and to relatively small amounts of sand adhering to castings going to the fettling shop. The quantity of water used throughout is about 10 per cent. A typical analysis of new silica sand and, for comparison, analyses of facing sand and heap sand are given in Table I. The analyses of Table I are of new silica as received, and of facing and backing sand after bonding material had been washed out.

Working Characteristics

The sand mixture is not readily workable for hand ramming of moulds. All moulds made of this sand are rammed with an air rammer. The sand mixture is rather sticky, and difficulty at first was experienced in withdrawing the pattern, but this was overcome by spraying the pattern with a light fuel-oil before the mould was rammed.

Table I.—*Comparison of Mechanical Analyses of New Silica, Facing and Heap Sands.*

Retained on.	New silica, per cent.	Facing sand, per cent.	Heap sand, per cent.
Mesh.			
No. 6 ..	Nil	Nil	Nil
No. 12 ..	Nil	Nil	Nil
No. 20 ..	2.7	2.9	2.6
No. 30 ..	21.5	17.6	14.1
No. 40 ..	27.6	21.6	19.4
No. 50 ..	25.6	14.8	16.5
No. 70 ..	14.1	11.4	13.2
No. 100 ..	6.1	8.4	10.4
No. 140 ..	1.4	4.5	3.6
No. 200 ..	0.3	3.2	3.4
No. 270 ..	0.2	2.2	2.1
Pan ..	0.5	3.5	4.3

Notwithstanding the coarse grade of sand used, a very fine surface is obtained on castings when the mould surface is protected by a wash of the following mixture applied by air-spray before the moulds are dried:—

Plumbago ...... 15 quarts.
Glutrine .... 1 quart.
Diluted with water to 24 deg. Be.

Strainer cores perform the very important function of providing clean metal to the moulds and are used in the top of the feeding heads. These cores are made of a strong oil-sand mixture and in standard diameters ranging from 2 to 10 in. They vary in thickness from $\frac{1}{2}$ to $1\frac{1}{2}$ in. as the diameter of the core increases. The number and size of the holes in the strainer cores vary according to the job, generally from 4 to 12 holes of $\frac{1}{4}$ to $\frac{1}{2}$ in. diameter being used. Except when it is required to avoid striking a centrally-located core, the gate holes are arranged near the centre of the strainer core. Care is exercised in all cases to avoid metal striking directly on the protruding sand section at the riser-casting junction.

For the past two years, direct riser pouring has been successfully adapted to Sandslinger moulding and much of the work previously made in dry sand has been transferred to the Sandslinger. The sand mixture, both heap sand and facing sand, used for Sandslinger practice, is identical with that described for dry-sand moulding, with the exception of moisture content, which is controlled in this case between 4 and 6 per cent. All this work is skin-dried with a portable fuel-oil torch. It should be noted here that, owing to restrictions of space and sand handling and preparing equipment, the amount of bentonite used is rather larger than would be necessary without these limitations.

Fig. 5.—Coil-Wire Annealing Pot Showing Gating Arrangements.

Figs. 1 to 13 will serve to give a fair idea of the method of application of direct head pouring methods and to exemplify the variety of designs for which it has been found useful. A brief description of each follows:—

Fig. 1 illustrates the bottom parts of moulds for the dies of Figs. 3 and 4. The vents appearing at one end of each mould are not to be mistaken for ingates. Fig. 2 shows the closed moulds for the same dies with strainer cores in place, and Fig. 3 the dies before fettling.

Fig. 4 illustrates a group of feeding head-poured dies of high-tensile nickel-chromium iron having a tensile strength of 25 tons per sq. in. The Brinell hardness number of the 1.2-in. dia. transverse bar was 278, while that of the die sections varied only from 269 to 278 on any part of the 4- to 6-in. cross-section of these dies, indicating a very satisfactory density throughout the casting. Incidentally, the surface of these dies was obtained suitable for easy file-finishing as-cast, demonstrating the adequacy of moulding technique and materials.

Fig. 6.—Sludge Pump Castings in Ni-Hard.

Fig. 5 illustrates the method used to produce a coil-wire annealing pot in a heat-resisting nickel-chromium cast iron. It is also typical of the procedure for moderate wall-size bushings. Fig. 6 shows a group of direct-head poured sludge pump parts in Ni-Hard (martensitic white iron), and Fig. 7 a refrigeration pump that had been a constant source of heavy loss due to leakers when gated by other methods. The internal design is complicated with abrupt changes of section. The direct-pour heads admit metal dropping directly on the complicated oil-sand core, which adequately resists this severity.

Fig. 8 is a two-ton bushing with 6-in. wall in high-tensile nickel-chromium iron using two bottle-design direct-pour heads. Steel ingot moulds have been produced satisfactorily in like manner. Fig. 9 shows a valve section in high-tensile alloyed iron, and Fig. 10 large gears in high-tensile iron, using unmodified bottle heads for casting. Fig. 11 shows some oil refinery castings in " Ni-Resist " (austenitic nickel-copper-chromium cast iron); Fig. 12 a group of solid and cored bushings in Monel metal; and Fig. 13 a commercially-pure nickel pump-casing, direct-head poured; the small impeller at the left has conventional gating.

In utilising these methods of direct pouring into feeding heads over a four-year period, some limitations in their applicability have, naturally, come to light in various forms and degrees. The more important of these limitations are described and some notes of caution included, based on personal experiences.

An attempt was made to produce the Monel centrifuge casting illustrated in Figs. 14 to 17, by means of a single direct-poured feeding head on the hub. The casting was of difficult design and dimensions and the result, by this method, was serious cracking in one arm and outer section, caused by too long maintenance of high temperature in the hub by the pouring head.

The authors were recommended, from an outside source, to mould the centrifuge as shown in Fig. 14, with the hub extension down in the drag and surrounded with external chills. Chills also were to be placed under the outside rim. A separate gate entering the hub was to be used, the remains of which are visible in the picture. Between the arms a loose mixture of sawdust, sand, and ashes was rammed and as soon as it was deemed safe after pouring, the cope was lifted and the hub and arms freed. However, the result was very similar to that of the first effort in regard to strain cracks.

Following this experience, it was decided to adopt a rather radical procedure for a third trial. It is thought that this procedure, in view of the result obtained, may be of interest and assistance to others faced with a similar problem. A skeleton insert of the design shown at the bottom of Fig. 15 was cast in Monel. The mould for the main casting was designed with gating shown in the two upper sketches of Fig. 15. The skeleton, after thorough cleaning by sand blasting, was placed in the mould as indicated in the diagram, the extensions on the bottom and arms of the insert being firmly bedded in the main sand mould.

FIG. 7.—REFRIGERATION PUMP CASTING WITH "BOTTLE" FEEDING HEADS.

The relative section sizes were such as to leave at least from ¾ to 1 in. between the insert and every part of the adjacent mould wall and core, with the exception of the supporting points. It was considered that the insert would so function as to accelerate cooling in its locality, that it would either completely melt into the mass of molten Monel or, on the other hand, if it retained its form, would act as a reinforcement against possible, though doubtless lessened, contraction strains in the arms.

FIG. 8.—TWO-TON BUSHING MADE IN NI-CR CAST IRON USING "BOTTLE" DIRECT-POUR HEADS.

The casting so produced was apparently perfectly sound and satisfactory. As will be seen, the only points at which an examination of the effects of the inserts was possible were the supporting prints in the hub and on each arm. Figs. 16 and 17 show this casting before cleaning, and the protruding ends of the insert are visible. Each protrusion was examined minutely; chipping, grinding, filing and subsequent machining failed to reveal the outline of the insert below the surface so treated.

The use of internal chills has been criticised by some authorities; Batty,[5] for example, refers to their being "potentially dangerous as isolated foreign bodies in what should be a homogeneous structure." The authors do not agree wholeheartedly with this view, believing that, in common with many other foundry procedures, their usefulness depends on the judgment used in proportioning. Relation between the dimensions and bulk of the parts carrying the internal chill, and those of the chill itself, must be carefully considered, as well as the location of gates and requisite pouring temperature of the metal to come into contact with the chills. Too large a chill, in proportion to the size of the casting section, will certainly result in a dangerously heterogeneous structure; on the other hand, one too small will be ineffective for its purpose.

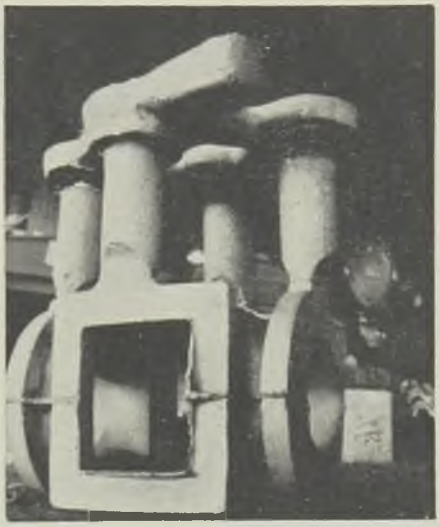


FIG. 9.—VALVE SECTION IN HIGH-DUTY ALLOY IRON.

Turbine Castings

Figs. 18 and 19 show two designs of turbine castings, made in a 4 per cent. silicon bronze, that were successfully produced by direct top pouring through feeding heads, without the use of internal chills. Figs. 20 and 21 show one of a design in a similar alloy that was not successfully made by this method, owing to excessive temperature in the locality of the pouring heads resulting in cracking of the blades. For this particular pattern, silicon-bronze internal chills were cast and inserted in the cores, forming the central heavy ring section as illustrated in Figs. 22 and 23. Fig. 22 shows the upper core (which should be viewed inverted), while Fig. 23 is a half core of the complementary underside of the central heavy ring. The casting was gated as shown—the metal first entering at the bottom of the casting at a number of points and, subsequently, entering the top ring-section through separate branch gates to ensure ample temperature of the metal encountering the internal chills. Protruding points of some of the internal chills are visible in the inner ring of Fig. 21. The initial pouring temperature was 1,150 deg. C., while for direct top pouring without chills the pouring temperature was about 1,090 deg. C.

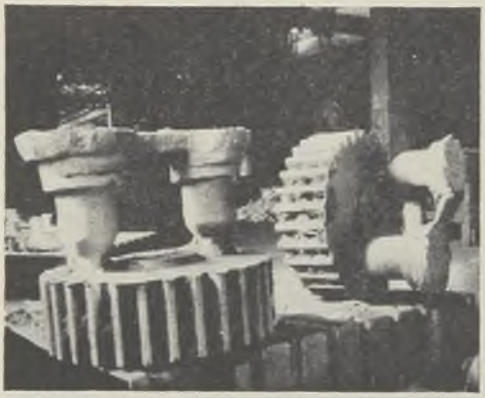


Fig. 10.—Large Gears Made in High-Tensile Cast Iron With "Bottle" Heads.


Fig. 11.—Oil-Refinery Castings in Ni-Resist Iron.

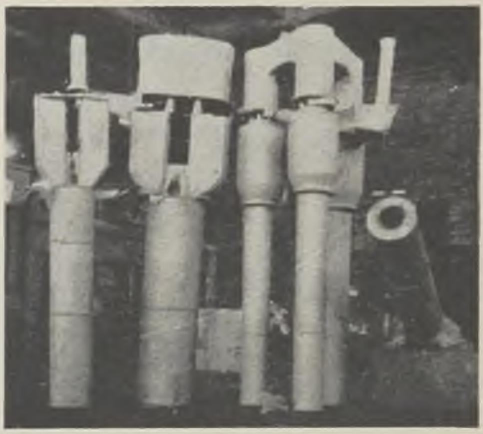


Fig. 12.—Solid and Cored Bushings in Monel Metal.

With regard to strainer cores, it is not as efficient to use a single relatively large hole to clean the metal stream as to use a sufficient number of small holes of approximately the dimensions recommended earlier in this Paper. There is too much tendency for a single large hole to form a vortex into which slag and dirt may be drawn, particularly when the metal is on the hot side and very fluid. In an emergency,


Fig. 13.—Pump Casing Made in Commercially-Pure Nickel.

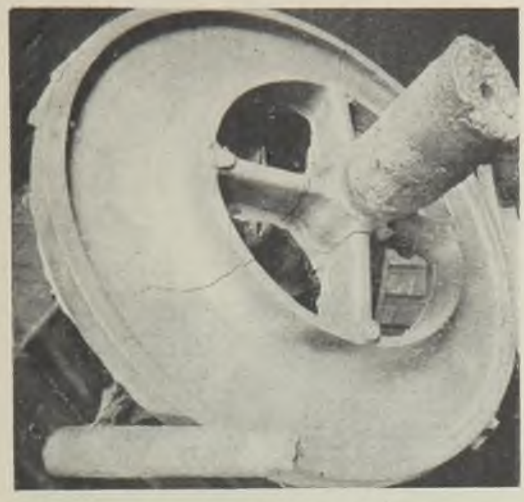


Fig. 14.—Wrong Method of Moulding a Monel Centrifuge Casting.

where metal is so cold as to freeze and block the small holes of the strainer, it may be necessary to enlarge the holes for the time being, but melting practice should be remedied to overcome the difficulty, rather than to make the use of large holes in the strainer standard practice.

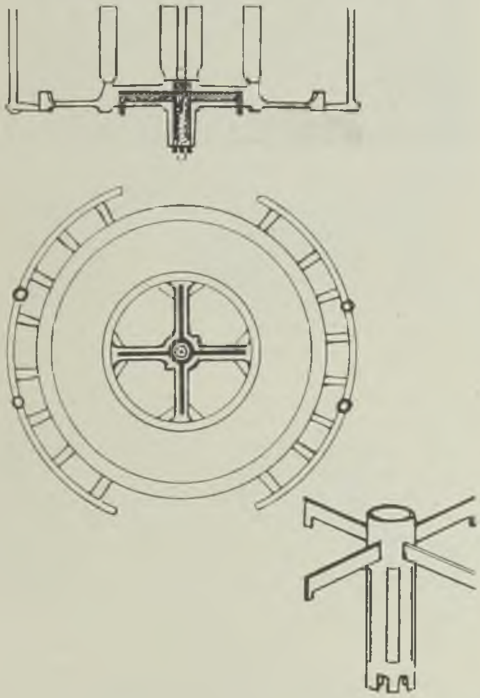


Fig. 15.—The Two Upper Sketches Show the Gating System Adopted. Below is a Monel Metal Skeleton Insert.

Indirect-filled feeding heads should not be used in close proximity to direct-filled feeding heads. It is frequently necessary to use indirect-filled heads to feed sections isolated from the direct-poured heads by thinner sections. If, however, both kinds of heads are used on the same heavy section there is a tendency for the indirect-filled heads to be themselves fed sound at the expense of the casting section. For example, the outer ring of the turbine in Fig. 19 is separated by a relatively light section from

Fig. 16.—Showing the Centrifuge Casting Made by Changing Gating Method.

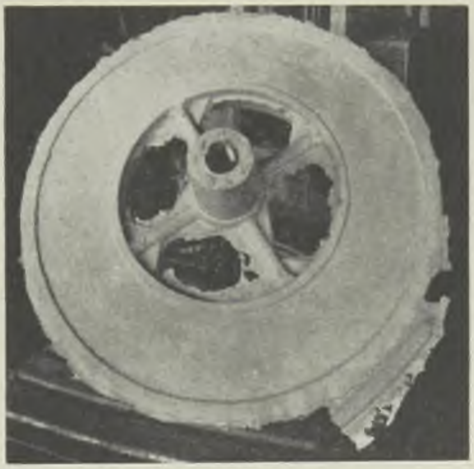


Fig. 17.—Monel Metal Centrifuge Casting Successfully Made.

the inner ring carrying the direct-filled heads, and is served by indirect-filled feeders. On the other hand, the heads of a Ni-Hard dredge pump liner in Fig. 6 were all directly filled by two nearly semi-circular pouring basins. The temptation to cut down the size of the pouring basins, allowing two or more of the heads to be indirectly filled would result, experience has shown, in shrinkage from the castings into the heads and a worse condition in the casting than if the fewer direct-filled heads only were used.

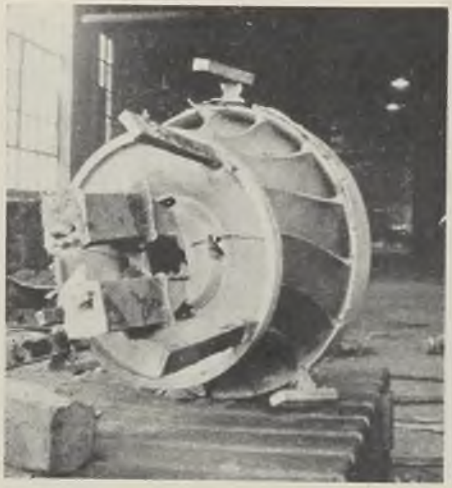


Fig. 18.—Turbine Casting Made in Silicon Bronze With Direct-Pour Feeding Head.

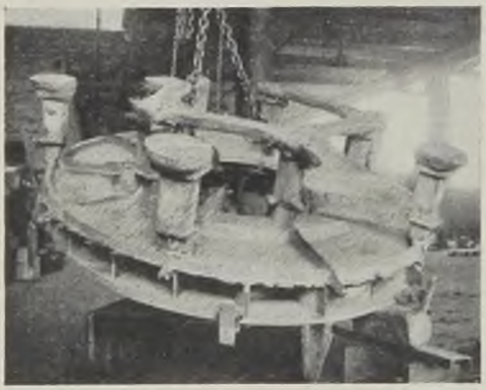


Fig. 19.—Another Turbine Casting Made Like Fig. 18. In Both Cases, No Internal Chills Were Used.

Non-Ferrous Applications

Light aluminium alloys have not been successfully produced by these methods owing to their tendency to occlude mould gases and trap oxide dross. Manganese and aluminium bronzes are not satisfactorily handled by these methods owing to extreme drossing at the pouring temperature. The high zinc alloys (including nickel silvers) not containing aluminium were satisfactorily so produced, as also the silicon bronze.

For alloys of moderate liquid shrinkage and relatively long freezing range, there is usually not much to be gained by direct pouring through feeding heads. Tin bronzes, especially those carrying appreciable quantities of lead or phosphorus, are more liable to segregation, particularly if poured too hot. Even with some of the more suitable alloys, particularly a complex alloy such as nickel silver, too high a pouring temperature will result in segregation, large weak crystal zones and porosity. Soft grey irons of high silicon and total carbon content should not, in any event, be used for castings of heavy section, but when direct-poured through feeding heads they are increasingly liable to porosity due to coarse graphitisation and tendency to kish formation.

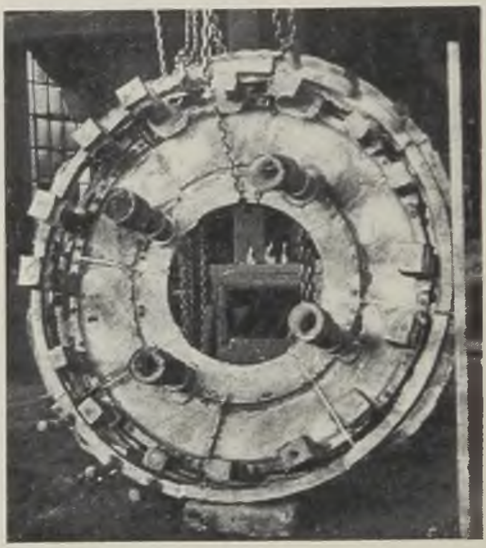


Fig. 20.—A Casting Which Does Not Lend Itself to Direct Pour and Internal Chills Were Used.

Conclusions

It will be gathered from the above description that the authors believed that there was room for research into moulding and gating practices for the purpose of keeping in step with progress in metallurgical developments. The ever-increasing diversity of casting designs and special characteristics of various high-duty alloys developed and being developed makes unreasonable the horizontal continuance of production methods good enough in times past for alloys contemporary with those times.

In consideration of the fact that such methods of introducing molten metal into moulds as those herein described have been, generally speaking, universally avoided, the illustrations included purposely consist mainly of photographs taken from routine production in the foundry with which the authors are associated. These, it is assumed, will appear more convincing and informative to the practical foundryman than would mere diagrammatical illustrations of what might be thought an abstract theory. The number of illustrations included, while being more than enough to illustrate the method of application, may be excused on the ground that they serve to convey an idea of the extent in number and variety of designs for which the methods have been found useful.

Fig. 21.—The Casting Shown in Fig. 20. Note the Protruding Internal Chills.

It is not meant to imply that direct feeding head pouring is uniformly applicable to all designs other than the exceptions discussed; for many castings, particularly those having no complications in sectional design, it is freely admitted, and indeed emphasised, that the more ordinary gating methods are adequate and more economical. Nevertheless, a large proportion of the varied designs passing through the foundry have most profitably been adapted to this method of production, and the resultant castings have, in many instances, shattered standing records of service life. Therefore, it is hoped that the information contained in this Paper will be of interest to foundrymen generally and a stimulus to further investigation into methods directed toward the still greater prestige of foundry products.

Fig. 22.—Core for the Silicon-Bronze Casting Shown in Fig. 20.

Fig. 23.—Setting of the Monel Metal Internal Chills in Half-Core.

Acknowledgments

The authors desire to thank their principals, the Robert Mitchell Company, Limited,

Montreal, Canada, for permission to present this Paper and for their encouragement throughout the development of the methods herein described.

REFERENCES.

[1] Dwyer, P., " Gates and Risers for Castings," Penton Publishing Co., Cleveland.

[2] Ronceray, E., " The Making of Castings Without Feeding Heads," Proceedings, Inst.B.F., vol. 15, 1921-22.

[3] Ronceray, E., " Facts About Sound Castings, Feeding Heads, Runners, and Venting," Proceedings, Inst.B.F., vol. 16, 1922-23.

[4] Ronceray, E., " Some Considerations in Gating and Pouring Castings," Transactions, A.F.A., vol. 38, pp. 41-64, 1930.

[5] Batty, G., " Controlled Directional Solidification," Transactions, A.F.A., vol. 42, p. 237, 1934.

WRITTEN DISCUSSION

MR. FRANK HUDSON wrote: One must compliment the authors on this excellent Paper which, on the whole, imparts sound practical advice and accordingly should be most helpful to many foundrymen. There is one matter, on which some criticism might be levelled, namely, in connection with the remarks on producing the Monel centrifuge casting as outlined in Figs. 14 to 17.

Admittedly, this casting is of difficult design, and the writer considers that satisfactory results could be obtained without having to resort to the use of a skeleton insert as a strengthening device in the arms to prevent hot cracking. The gating and feeding methods shown in Figs. 14 and 15 are both good, and one would imagine that either should normally result in the production of sound castings. If cracking persists one will begin to wonder if metal quality is satisfactory and if hot-shortness is not playing a major part. It is noted that the authors give no indication as to whether they checked up on this point.

Composition plays a very important part in the strength of cast Monel at elevated temperatures and if care be not taken during melting to exercise careful control in this direction, trouble through hot cracking can quite readily arise. The effect of lead for example, is particularly marked. As little as 0.08 per cent. of this element will reduce the tensile strength of cast Monel from about 26 tons down to 9 tons per sq. in. at 430 deg. C. (800 deg. F.) and the elongation from 34 per cent. down to 3 per cent. Accordingly, in castings of awkward design, where hot cracking is liable to occur, it is particularly important to see that no lead contamination takes place. Carbon, when present over 0.35 per cent., and sulphur constitute other dangerous impurities from the point of view under discussion, and these must also be carefully controlled along recognised lines in order to obtain the best results in the foundry.

In the absence of any evidence by the authors as to whether or not detrimental compositional effects have been present in connection with the production of the centrifuge casting, one can be pardoned in thinking that the use of Monel of satisfactory quality used in conjunction with proper gating and feeding methods should completely eliminate the need for the skeleton insert, which is after all something of a makeshift.

Paper No. 709

The Extended Uses of Cast Iron, with Special Reference to War Conditions

By J. G. PEARCE, M.Sc., F.Inst.P., M.I.E.E., M.I.Mech.E. (Member)

Introduction

Too often and for too long has the history of cast iron been one of replacement by other materials more aggressively investigated, developed, manufactured and marketed, and too often have other industries profited at the expense of an unorganised foundry industry. In recent years, however, a new spirit of cohesion has been evident in the industry, showing itself in part through the steady growth of institutions, each of which has a special function to perform and which are becoming increasingly representative: trade associations, the Research Association, the Institute, and the technical Press.

One of the results of this new spirit is the gradual extension of the uses of cast iron, a process which is accelerated, but not created, by war conditions, and rendered possible largely on account of intensive research and development during the past twenty years. Those who assume hopefully that, because cast iron was used to some extent for munitions during the last war, it will be used again in this, completely overlook the higher standards called for to-day.

Evidence of the new spirit is the growing recognition that those who supply a bad or unsatisfactory material injure the whole industry, for to a dissatisfied user, cast iron is cast iron from whatever branch of the industry it comes. Such material, unfortunately not superficially distinguishable from good, is bad only because it is unsuitable for the purpose for which it is used. A low-cost material, cheaply made, is not necessarily bad; indeed, the industry still offers many opportunities for economy in design and production costs.

Reversion and Replacement

The ironfounding industry is concerned as a whole with the wider uses of cast iron. New work resulting from fresh applications directly benefits the foundries undertaking it, together, of course, with the equipment and supply houses, themselves users of iron castings, while, since the total load on the industry increases, other foundries benefit indirectly.

The object of this Paper is not so much to give a list of replacements as to provide those in the industry with an opportunity to describe new uses of cast iron since war broke out and the degree of success or otherwise which has attended them, and to invite suggestions for further extended uses.

History Repeating Itself

As the earliest metallic material to be widely used industrially, few uses for cast iron can be regarded as novel, for most products have been tried in it at one time or another. For example, a few years ago an American journal published an article on the wider uses of cast iron, advocating as its main suggestion the use of cast-iron tombstones. Yet the oldest casting extant in this country is frequently said to be a gravestone in Burwash Church, although there seems little doubt that cast-iron guns, replacing the more expensive bronze, were made at an earlier date, 1543, and firebacks before that. Paradoxically, the new uses for cast iron are in the main for products which themselves are new compared with cast iron itself. Thus, while the use of cast-iron crankshafts strikes many engineers as a revolutionary step, it was at one time normal procedure.

The term "substitution" has been used to imply the replacement of other materials by cast iron, but, partly because the process is frequently one of reversion rather than of substitution, and partly perhaps because the word "substitute" now so frequently implies an inferior article, the phrase "extended uses" or the word "replacement" is to be preferred, either term covering both new uses and reversions to prior practice, and both having a significance beyond that of increased output of an article already made in cast iron.

The wider use of cast iron not only enables the industry to make its contribution to the national need, but it assists in securing supplies of material and equipment and in the maintenance of essential labour, staff and plant as far as possible intact for post-war development. The relief offered thereby to other productive resources enables a more balanced national economy to be obtained. That the industry is justified in anticipating such extended uses arises from its remarkable development since the close of the last war, especially in continuous and mass production, with respect to plant and equipment, technical control, labour skill and management. The industry can also offer greater precision of form in dimensions and design of castings, as well as much better quality and strength and greater uniformity. To suit requirements a wide variety of structures, special processes of manufacture and finishes are now available. Even under the difficulties which might arise in a prolonged war, due to deterioration of raw materials, etc., the scientific knowledge available will enable high standards to be maintained, and the resources of the industry are very largely derived from the United Kingdom itself.

If little is said regarding malleable castings, it is because the pressure on malleable foundries renders unnecessary any attempt to find fresh markets by replacement. Indeed, the possibility of replacing, as a war emergency measure, both steel and malleable grey iron castings by high-duty cast irons, is one which should be carefully studied.

Suggestions for Replacement

The preparation of suggestions for the wider uses of cast iron may be dealt with in several ways. The most wearisome and difficult would be to build up a catalogue of parts which have been or which could be produced in this material. Such a list of replacements since war broke out would assume formidable dimensions, and could only be fully appreciated from drawings of the parts in question. At the other extreme, a few broad principles might be laid down, based on the extraordinary demand at the present time for steel and non-ferrous metals, especially aluminium and brass. Thus, the replacement by cast iron of all-welded structures which formerly were made in cast iron or which were initially designed as weldings could be considered, and also the replacement of castings in aluminium alloys, magnesium alloys, bronze, gunmetal, and other non-ferrous metals, where they can be dispensed with, and which have to be conserved for purposes for which they are indispensable. The wider use of austenitic irons and martensitic irons in place of certain ferrous and non-ferrous alloys might also be mentioned. It is assumed that under present conditions the steel and non-ferrous industries will appreciate the assistance cast iron can give in relieving pressure on production.

The author has chosen an intermediate plan and has classified the field of replacement available into four sections, as follows:—

Section 1.—War and defence purposes.

Section 2.—The building industry and domestic castings, *i.e.*, castings used on, in and about buildings of all descriptions, including civil engineering and public works generally.

Section 3.—The engineering industry.

Section 4.—Other industries for which lists such as that given in Section 3 might be prepared.

For obvious reasons it is not proposed to give any details in Section 1, but it can be said that the war and defence demand affects both sides of the industry, that is, the light or builders' castings side and the heavy or engineering castings side. In some cases cast iron is being used because it is the most suitable material for the purpose, while in others it is used in part because of the strain on the productive resources of other materials. It is in this field that foundries normally catering for the building and domestic trade can make good deficiencies due to the decrease in normal demand. In addition, there is a considerable amount of replacement to be done in the building industry itself, as is shown in Section 2.

The building industry is separately sectioned, partly because of its importance as a consumer of foundry products, and partly because it is catered for by a large and highly organised section of the industry, normally producing about one-fifth or one-sixth of the total output.

The engineering industry itself naturally forms a great field for replacement and very conveniently so, because many works have foundries on which they can rely for castings. On the whole, however, the other industries mentioned in Section 4 do not operate foundries, but have to rely on existing sources of supply.

No attempt is made to list the literature of extended uses. Mention has been made of the cast crankshaft, not only because it is important in itself, but because engineers convinced of the practicability of this change are likely to be open to further suggestions. The Paper by Gough and Pollard ("Properties of Some Materials for Cast Crankshafts"), presented to the Institution of Automobile Engineers in 1937, forms an excellent basis for the study of this subject. The work of the automobile industry in the wider uses of cast iron is well illustrated by the Paper by Toghill and Dowle to the same Institution this year. For substitution in engineering work wide use has been made of the First Report of the Research Committee on High-Duty Cast Irons, under the Chairmanship of Dr. Gough, reported in 1938 by the present author, for the Institution of Mechanical Engineers.

The list given in the Appendix is based on one originally prepared by the British Cast Iron

Research Association for the Ironfounders' National Confederation, and elaborated from suggestions received by the latter body from a number of firms following on the issue of a circular to the industry by the Confederation. It is impracticable to give the suggestions made in detail; naturally many suggestions are made more than once, some many times; some suggestions are very general, others apply to such special cases or small outputs that they lack general interest. The list has been prepared on the basis suggested above, that is, one which is sufficiently detailed to be suggestive to and stimulate readers without being unduly extended. Contributions are invited in the discussion and suggestions relating to war and defence are invited, but will not be printed.

The above assumes, as is often the case, that the user applies to the founder for assistance. Much useful work for the foundry, however, requires to be done among engineers and users who are not yet alive to the possibilities of such assistance. What is to be done to influence buyers before a contract is placed and before the maker is faced with the necessity of seeking advice on substitution under the most difficult conditions, *i.e.*, when the design is already determined in some other material? The author would be glad to hear suggestions. One obvious method is by public advertisement, or advertisement in the technical Press, or circulation of leaflets. Thus one foundry group advertised nationally a cast-iron trench lining for A.R.P., while another large foundry advertised in a national daily cast-iron housing and hutments. Another company has done most enterprising work in broadcasting the use of cast-iron valves in place of non-ferrous metal, but the problem is not yet satisfactorily solved of how to reach the department engineer, buyer, purchasing agent, who does not specifically ask for advice on substitution. Yet there are probably dozens of components in, for example, the machine-tool industry alone, that could advantageously be made in cast iron.

Many small applications can be conveniently machined from cast-iron stick or rod, while for others centrifugal casting is very suitable.

A Technical Problem

The question of providing an article in cast iron to replace another material is essentially a technical one. It involves design, manufacture, frequently under controlled conditions, testing and results of service life, showing a comparison of ratio of cost to life for the two materials. While the cheapest and most readily available materials for the purpose should be used, the copy of a part in common cast iron may prejudice the material if trouble ensues, and where other conditions prevent any modification to design, special cast irons may be called for.

For these reasons users of castings requiring replacements in cast iron should be invited to supply a print of the part to be replaced and indicate whether, and to what extent, redesign is possible. Hence the most complete co-operation should exist between the casting designer, founder and metallurgist. The success of replacement largely depends upon this co-operation. Many foundries do not possess all the elements of this, and some competing products, such as plastics and cement, offer the kind of information required by would-be users, through a central body. The B.C.I.R.A. possesses the nucleus of a design section capable of advising on this aspect of substitution, and with its expert services relating to foundry production, experimental foundry and laboratories, enabling any property of interest to users to be determined, is in a position to aid those who are interested in extended uses. The existence of national specifications for cast iron, 309/1927, 310/1927, 821/1938, and particularly 321/1938 and 786/1938, in the formulation of which the Institute played no small part, has been of the very greatest assistance in replacement work.

It is hoped that this brief note, prepared under great pressure of other duties, will serve to focus the interest of the industry in this matter and provoke suggestions and comments.

APPENDIX

Extended Uses of Cast Iron

Section 1. Military, Naval and Defence Purposes.

Section 2. Building Industries.

(*a*) *Structures.*

Columns, struts, beams, stanchions, girders, standards.

Roof members, bracing bars, etc.

Staircases, internal and external.

(*b*) *Fittings* (*internal to buildings*).

Window frames, roof-lights, sills, door frames, ventilators, air bricks, etc.

Bench and table and shelf supports for all types of furniture.

Gutters, gratings, manhole covers, pipes and all rainwater goods.

Stoves, cookers, ranges, boilers, calorifiers, hollow-ware, sinks, baths, bowls, basins, washers, wringers, lawn mowers.

Builders' ironmongery (keys, locks, fastenings, brackets, hooks, etc., some in malleable iron).

Switch covers and boxes.

Heaters, slow-combustion stoves, radiators and their heating pipes.

Floor plates, chequer plates, roofing plates.

(*c*) *Civil Engineering* (*external to buildings*).

Railings, rail posts, fencing, grills, gratings, gates

Signs.

Pipes.

Tanks.

Lamp and electric tramcar or trolley standards, traffic posts, islands.

Pit props.

Linings for A.R.P. trenches.

Supports for basement shelters, cellars, etc., baseplates and screwed unions for same.

Floor plates, grids, scraper mats, ventilator grids, etc.

Roads, road curbs.

Tunnel segments.

Section 3. Engineering and Shipbuilding.

Railway axleboxes and axlebox guides, sleepers.

Machine-tool bedplates and frames.

Bearings and bearing housings, for slower speeds and lighter loads.

Automobile and compression-ignition engine crankshafts, camshafts, brakedrums, flywheels, pistons, valves, tappets and guides, engine frames, cylinder heads, timing wheels, rear axle castings.

Gears and bushes, spur rings, pinions, worm and bevel wheels.

Drawing and pressing dies, jigs, bolsters, press tables and punches for hot pressing, drop-stamp slides and rods.

Bedplates for fans, pumps, compressors, conveyors, etc., and for prime movers of all kinds.

Valves and valve fittings.

Case-hardening boxes, annealing boxes and pans, salt baths, pickling tanks.

Propellers, ship and dock capstans, bollards, cleats, fairleads, mooring pipes, winch barrels, etc.

Electrical starter frames, switch boxes, motor starter pillars.

Conveying machinery, wheels, brackets, rollers, trays.

Pipes of all kinds.

Crane bearings, housings, brakewheels.

Section 4.—Other Industries.

Agriculture and horticulture.

Chemical.

Clay, building materials and refractories, glass, cement, pottery.

Colliery, mining, coking and quarrying.

Food, drink and tobacco.

Gas and electric power and water supply.

Iron and steel.

Paper, printing.

Rubber.

Textile and clothing.

Timber.

Paper No. 710

Design of Test-Pieces for Carbon Steel Castings[*]

By C. H. KAIN and E. W. DOWSON (Members)

The design of test-pieces which are truly representative of the metal employed in the manufacture of carbon steel castings has not received the attention merited by its importance to the steel castings industry. For many years a block or coupon of the rectangular tongued type from which two test-pieces could be cut in a plane parallel to the axis was generally employed. This design is open to the serious technical objections involved in a square section prone to the formation of cleavage planes from the corners at 45 deg. to the faces. In spite of this objection, this method usually produced two test-pieces of reasonably uniform properties.

When however the tongue of the block was extended to provide a third bar (either as a spare or for a third test), it was found that the three bars did not possess uniform properties. In previous Papers,[1 2 3] it has been shown that the bottom bar had the best properties, the bar immediately under the head the next best, whilst the centre bar was slightly inferior. These results are independent of the position of the gate, similar results being obtained whether the gate is in the base or the head. This is illustrated in Table I taken from the Papers cited.

An explanation was offered that the bottom bar consisted entirely of primary crystals, whilst the two above it had centres of secondary crystals, the formation of which in the narrow space between the primary crystals prevented the effective gravitational feeding of the middle bar. This is shown diagrammatically in Fig. 1.

Table I.—*Tensile Properties of Continuous Test-bars.*

Position.	Y.P.	M.S.	E.
	Tons per sq. in.	Tons per sq. in.	Per cent.
A	20.48	31.80	34.0
B	21.06	31.48	24.0
C	20.28	31.18	28.0
A	20.28	33.64	31.0
B	19.72	33.52	22.0
C	19.40	33.04	26.0

The growing tendency of inspecting authorities to demand three tests (usually tensile, bend and impact) has made imperative the use of a block which will yield three test-pieces of exactly uniform properties. The present Paper describes the steps taken in the foundry with which the authors are connected to evolve such a test-block.

A block was designed to employ the principle of directional solidification by making the casting taper from the base to the feed head. This is illustrated in Fig. 2.

Table II shows the results obtained on three bars cut from this type of block (in the normalised condition).

Table II.—*Results obtained from Re-designed Form o Test-block.*

Heat No.	Position.	Y.P.	M.S.	E.	R.A.
		Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
A.1221	A	20.84	33.68	26	30.4
,,	B	20.20	33.16	22	23.2
,,	C	20.00	31.52	12	16.0

As before, the bottom bar A gives the best results, but the properties of bars B and C are reversed. The elongation and reduction of area are considerably affected, whilst the maximum stress shows an appreciable drop from B to C. It seems clear that directional solidification and adequate feeding alone will not produce three test-pieces having identical properties, since in these tests all three bars were cut from solid metal below the feed head and pipe.

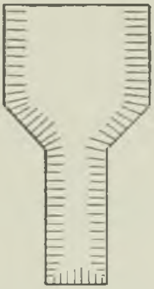


Fig. 1.—Effect of Primary Crystallisation in Usual Form of Test-Block.

A further test was made on a block sliced horizontally as shown in Fig. 3, two bars being taken from the two upper portions, as far as

---

[*] Mr. Dowson was awarded a Diploma for this Paper. Mr. Kain was already a Diploma holder.

possible from the centre line. The results are shown in Table III.

In all cases the yield point and maximum stress are fairly uniform, but the elongation and reduction of area are again affected by the position of the bar in the block, although the effect is not so pronounced as when the tests are taken from the centre of the block.

Bars B and B1 and C and C1 give identical results, showing that, providing the bars are cast in such a position as to allow identical freezing and feeding conditions, they will give uniform results with one another.

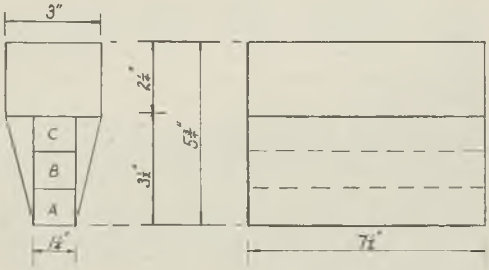


Fig. 2.—Block Designed to Incorporate Directional Solidification.

In all these experiments, the bottom bar A has yielded the best results. As previously suggested, this bar freezes from three sides and consists entirely of primary crystals, the greatest possible surface being available to produce this condition. If the bars cut as shown in Fig. 3 are considered as each having four sides, it is seen that B and B1 have one side from which primary freezing takes place, one side in contact with the early freezing bar A, whilst one side is in contact with the delayed freezing bars C and C1. Again, bars C and C1 have one side from which primary freezing takes place, one side in contact with the comparatively slow freezing bars B and B1, and one in contact with the large body of molten metal in the head. Thus, it appears that bar A owes its superiority to its position for primary freezing conditions, and since the order of freezing, A, B and C, is also the order of superiority of mechanical properties, it seems definite that delayed freezing, even when subject to direct feeding conditions, is not conducive to the best mechanical properties.

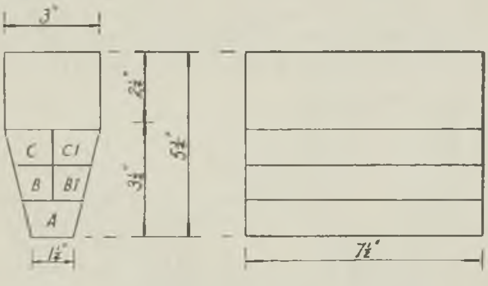


Fig. 3.—Showing Revised Method of Sectioning Test-Block.

Fig. 4.—Test-Block Used for High-Shrinkage Alloys.

From the above considerations, it appears possible to formulate rules to be observed in the design of a test block to yield three test-bars having identical properties:—

(1) The bars must solidify under the same freezing and feeding conditions.

(2) As large an area as possible must be provided from which primary solidification can proceed.

(3) The test-pieces must be isolated from large bodies of metal which cause delayed freezing, even though these provide direct feeding influences.

Table III.—*Results obtained from Revised Sectioning of Test-block.*

Heat No.	Position.	Y.P.	M.S.	E.	R.A.
		Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
A.1248	A	20.20	33.32	28	37.7
..	B	20.44	33.64	26	35.2
,,	B1	20.68	33.64	24	30.4
,,	C	21.12	33.04	20	26.4
..	C1	20.52	33.44	20	24.8

At first sight it would appear that a test coupon with an elongated tongue from which bars could be cut vertically would fulfil these conditions. The results given in two of the previous publications,[2 3] however, demonstrate that such a method is not satisfactory.

Non-ferrous and certain Continental steel foundrymen seem to have given more attention to the production of satisfactory test-blocks than steel-foundry investigators in this country. Fig. 4 is an illustration of a test-block which is sometimes used in this country for high-shrinkage alloys, such as manganese bronze, and is used in Continental foundries even for metals like stainless steels. It is claimed[4] that this block gives very good results.

After consideration, certain modifications were made to this design, although the basic principle was retained. It was decided to use three bars or tongues instead of four and to employ a circular head with the diameter of the inscribing circle. In order to avoid the danger of cleavage planes, it was decided to investigate the possibility of a rounded section and a block was evolved as shown in Fig. 5.

Table IV.—*Results given by Test-pieces Machined from Block shown in Fig. 5.*

Heat No.	Posi-tion.	Y.P.	M.S.	E.	R.A.
		Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
A.1272	1Square	20.64	33.32	25	33.5
,,	2	20.48	33.52	31	44.9
,,	3	30.36	33.40	30	43.3
,,	4Centre	20.84	28.40	10	12.0

In addition to the avoidance of cleavage planes, the rounded section has the advantage of requiring slightly less metal and being somewhat easier to machine. The first results are shown in Table IV.

The inferiority of the bar cut from the centre demonstrates clearly the advisability of adhering to the first two rules enunciated. Also, the slight superiority of the rounded bars over the square section justifies the adoption of this section.

Table V.—*Results obtained from the Design of Test-block shown in Fig. 6.*

Heat No.	Posi-tion.	Y.P.	M.S.	E.	R.A.
		Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
A.1285	1	19.32	31.04	33	46.0
,,	2	19.32	31.08	34	42.0
,,	3	19.08	30.92	34	47.2
,,	4 centre	18.68	29.24	15	16.8

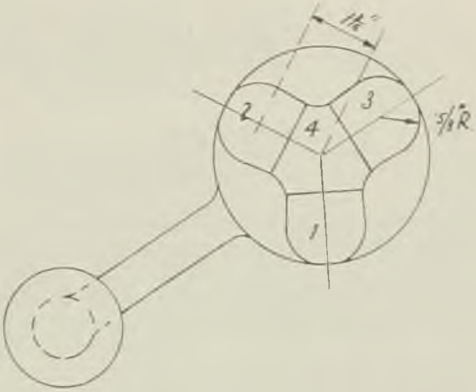


Fig. 6.—Final Design of Test-Block Evolved.

A final design was then adopted as shown in Fig. 6, to conform with all three rules. The bars freeze under identical conditions; they have

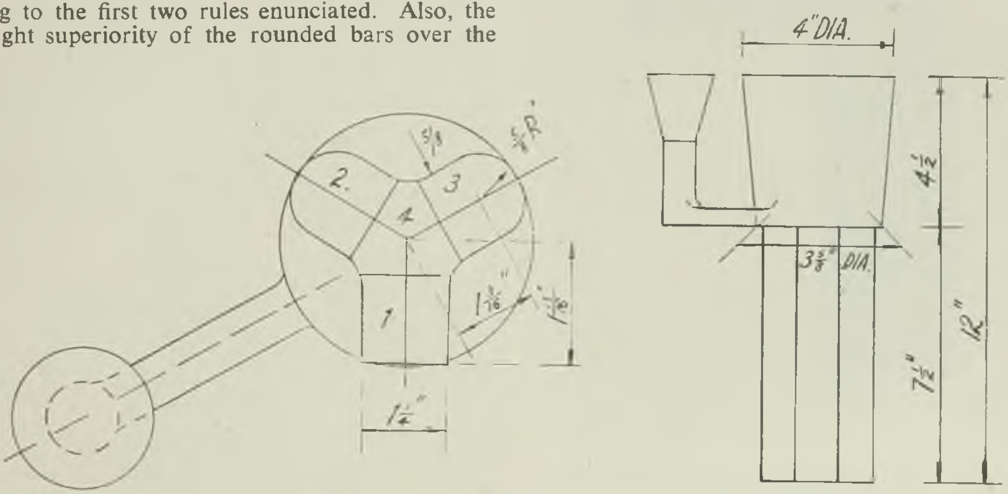


Fig. 5.—First Type of Vertically Disposed Test-Block.

a uniformly large surface for primary freezing and as the feed metal is introduced from the side, the section of the bar subject to stress during testing is remote from any large body of feed metal to cause delayed internal freezing.

The results from this type of bar are given in Table V, which shows clearly the degree of uniformity obtained. The properties of a bar cut from the centre are shown as an item of interest. Table VI shows comparative results obtained on the "clover-leaf" type of block and the tongued type.

Table VI.—*Comparison of Results obtained from the Tongued and Clover-leaf Types of Blocks.*

Heat No.	Position.	Y.P.	M.S.	E.	R.A.
		Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
Tongued. B.2372	A	18.08	29.46	35	47.2
,,	B	18.20	29.24	27	35.2
,,	C	17.84	28.96	27	35.2
Clover leaf. B.2372	1	18.44	29.56	32	44.9
,,	2	19.04	29.48	32	44.9
,,	3	18.52	29.56	32	43.3
,,	4 centre	18.40	27.60	18	23.2

Fig. 7.—Clover-Leaf Type of Test-Block Finally Evolved.

Table VII.—*Further Examples of Results obtained from New Type of Test-block.*

Heat No.	Position.	Y.P.	M.S.	E.	R.A.
		Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
B.2870	1	23.75	41.85	27	33.5
,,	2	23.15	41.30	27	35.0
,,	3	23.60	41.40	26	33.5
C.9910	1	21.10	35.10	30	39.5
,,	2	21.50	35.75	31	41.0
,,	4	21.70	35.65	29	38.0
A.1301	1	19.64	29.84	34	50.0
,,	2	18.84	29.64	35	51.1
,,	3	18.96	29.68	35	50.0

These results are typical of many dozens obtained in daily practice, further examples being shown in Table VII.

All the results given are from carbon steels in the normalised condition and from blocks designed for a 0.564-in. dia. bar.

Table VIII.—*Results from 2-in. sq. Test-pieces from Clover-leaf Type of Test-block.*

Heat No.	Position.	Y.P.	M.S.	E.	R.A.
		Tons per sq. in.	Tons per sq. in.	Per cent.	Per cent.
B.2562	1	23.9	35.5	30	47.0
,,	2	23.0	35.8	31	46.46
,,	3	23.5	34.9	31	47.95

It was thought that equally good results might not be obtained from a block designed to yield the 2-in. square test-piece sometimes specified. It was, however, found that the same uniformity persists when a clover-leaf block of three tongues, capable of machining to 2 in. square and tested at 0.798 in. dia., was used. Table VIII shows one such result but no comparison with a three-bar tongued block of similar dimensions is available.

Table IX.—*Impact Tests.*

Heat No.	Position.	Energy required to fracture notched bar. Ft.-lbs.		
A.1310	1	55.0	58.0	55.5
,,	2	52.0	55.5	57.0
,,	3	51.0	55.0	53.0
A.1310	A	49.0	47.0	54.0
,,	B	47.0	48.5	40.0
,,	C	31.0	40.0	55.0

Although the impact test is not as yet fully understood and has not been accepted by steel founders for general use, comparative tests were made as shown in Table IX.

In every case examined, the clover-leaf type of bar yielded slightly higher and very much more uniform results.

Summary

(1) The freezing phenomena of test-blocks designed for the provision of test-pieces for steel castings have been considered.

(2) Rules governing the design of an ideal test-block are suggested and a section resembling a clover-leaf recommended.

(3) Data are given in support of this recommendation.

Acknowledgments

The authors wish to record their thanks to the directors of Lake & Elliot, Limited, for permission to publish these results.

REFERENCES.

[1] Proc. I. Brit. F., vol. XXIII, p. 507.
[2] ,, ,, ,, vol. XXVI, p. 501.
[3] ,, ,, ,, vol. XXVIII, p. 661.
[4] "Foundry Trade Journal," vol. 62 (8940), p. 7.

WRITTEN DISCUSSION

Mr. F. W. Rowe, M.Sc., wrote:—This design of test-block is a matter to which the writer has devoted a certain amount of time, but without the successful results which appear to have attended the authors' efforts. It is thought that answers to the following queries would be of general interest:—

(1) Is the clover-leaf type of test-block equally satisfactory with a 9-in. length of test-bar as with a 6-in. length?

(2) Is the comparative gross weight with head available as against the ordinary type of tongue block usually used, providing the same length of test-bar?

(3) At first sight it looks as though the clover-leaf test-block might be more expensive to cut up than the ordinary one. How is the block cut? Are the head and runner burnt off and then the three test-pieces milled out, or how? On the usual tongue block the writer cuts his test-pieces from the block with a hacksaw.

(4) In the majority of cases even now only two test-pieces are needed, either tensile and bend or tensile and impact, but a tongue block about the same proportions as are shown in the Paper is called for, because the "C" portion is, as the Paper proved, usually rather poor.

(5) Could another Paper be written on the best design of test-block where only two test-bars are needed?

AUTHOR'S REPLY

The Authors answered Mr. Rowe's queries as follows:—

(1) The clover-leaf test-block has been found to be perfectly satisfactory for test-bars as long as 15 in.

(2) The clover-leaf type of bar is a few pounds lighter than the equivalent tongue type of block made for three bars.

(3) The question of cutting off the bars is an awkward one, and it is usual to slit down the three tongues with an oxygen cutter before heat-treating. The bar can then easily be cut off with a hacksaw.

(4) Even where only two test-pieces are required, it is the practice always to provide three in case a spare is required or in case of dispute

(5) There can be no doubt that the time will come when the impact test will be much more generally used than it is to-day, and it is really advisable to be prepared to produce three good test-bars, when required. No great difficulty is thought to arise in the production of three test-bars of reasonably uniform properties.

Paper No. 711

Gas In Liquid Cast Iron

By Wm. Y. Buchanan (Associate Member)

Although the possible practical application of results of the work done has always been kept in mind, it is thought that the subject of this Paper may form a suitable basis for discussion and, further, though the subject is still in a preliminary stage, it is hoped that its presentation will result in some definite lines being indicated along which additional worth-while investigations may be pursued. The Paper, however, is intended mainly to promote discussion. The subject is rather difficult to approach owing to the many experimental difficulties, and the procedure adopted should receive due consideration initially. The many variables entering into ordinary cupola melting make the direct application of this research to the cupola in everyday practice lengthy and sometimes confusing.

Apparatus Used

In order to improve the conditions of the tests a new ladle was made and drilled all over the sides and bottom with $\frac{1}{4}$-in. diameter holes to facilitate the escape of steam during the drying of the lining. A block pattern was made to form the lining 1 in. thick all over the bottom and sides and used for ramming up. Prior to this, there was a tendency to make the bottom of the old ladle too thick and the sides too thin, and any variation in thickness of the refractory altered the cooling rate of the metal. This cooling rate was always checked by plotting a time-temperature graph for each test. With the new system a very smooth, even lining was obtained and this was dried very thoroughly with the "Aurora" burner used for lighting the cupola, by applying the heat to the outside as well as the inside of the ladle. The ladle was knocked out after each day's tests and made up afresh before the next in order to ensure reasonably identical conditions; no black-wash was used on the surface of the lining.

The burette with the two-way glass stopcock, as illustrated in the previous Paper,* was found unsatisfactory when very high rates of evolution were encountered as the bore of the stopcock gave a "wire" effect which hindered the registration of sudden increases in rate, and at the same time 50 ml. capacity was in some cases found to be inadequate. A burette was therefore constructed from glass tubing of 15-mm. bore and 42-in. length, having a capacity of 200 ml. without running out and reading in $\frac{1}{10}$ in., equivalent to 0.5 ml. Care was taken to keep the inlet at the bottom end as large as possible, and by this means sudden fluctuations in gas evolution were easily recorded. One particular increase in evolution appears to coincide with some change, such as perhaps the separation of primary graphite. This point, although interesting, is evidently not of much practical importance.

It is interesting to note that the introduction of cold material appears to liberate large quantities of gas from liquid cast iron. This is shown in the case of steel additions referred to later in the Paper. The use of the bell which constitutes a cold addition may have the same effect. This would explain why the large evolution takes place immediately on placing the bell in position in the surface of the metal, irrespective, within limits, of the initial temperature.

The Measurement of Temperature

It is said that molten cast iron varies in its emissivity, and that this gives conflicting results where the variable is measured against temperature change, as for example in the study of fluidity by casting tests. Different methods of melting are said to give different emissivity values for the same temperature. The emissivity is also held by some workers to change even from furnace to ladle. With temperatures taken by optical pyrometer in the open-hearth or electric furnaces, where (1) the angle of the telescope of the pyrometer to the metal surface is very oblique; (2) the surface is covered with slag of a glassy or smooth type with highly reflecting surface; (3) the furnace gases are luminous and continually changing; (4) the atmosphere contains fine limestone dust at high temperature, or (5) on tapping, a very heavy fume (red or white) covers the launder,

---

* See page 227.

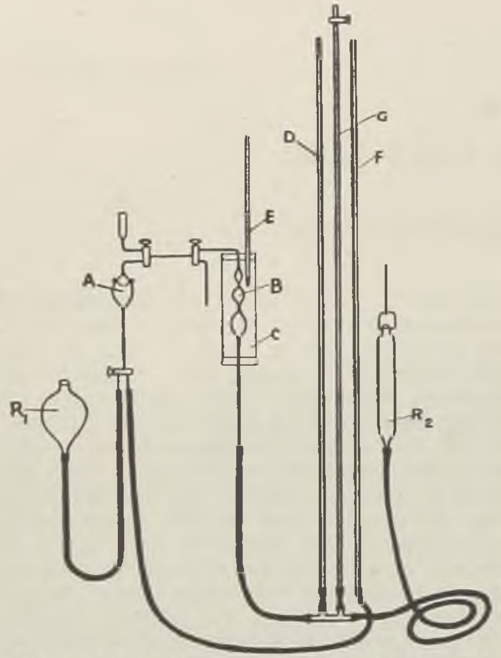


Fig. 1.—Form of Gas Analysis Apparatus.

the emissivity, as recorded by the optical pyrometer, must be subject to great and constantly varying errors. The substitution of thermocouples for optical pyrometers is the obvious solution, and it is said to have been the means of turning a rather doubtful set of results into a highly successful piece of research. The measurement of temperature by optical pyrometers is, however, not necessarily always wrong, and has much to recommend it owing to its relative freedom from trouble when making large numbers of daily readings. The immersion of thermocouples usually results in rapid wearing of the thermocouple wires, but couples of suitable materials for use on steel and cast iron are said to have been developed a number of years ago, although these have not become generally available as yet.

Ladle additions are said to change the emissivity value, considerable errors mentioned in this connection being of the order of 190 deg. C., although this is rather difficult to accept without substantial proof. The emissivity value for molten metal is likely, or perhaps certain, to be entirely dependent on the type of surface film. This film is usually an oxidation product diluted by non-metallic inclusions separating from the molten metal. The additions can and do modify the film radically, and so also the emissivity, as, for example, in the case of traces of soda-ash slag and similar fluxes.

Apart from the question of degree of emissivity, the condition and appearance of the surface film seem to be an indication of the metal conditions, and it may have some relation to the quantity and character of dissolved gases. There are, however, some difficulties in recording the appearance of the film in any systematic investigation owing to the state of constant motion in the metal surface. The surface films were constantly under observation, but no detailed record was made in the course of the investigations described here. However, in the case of cast iron, unless the oxide film is modified radically by ladle additions, the emissivity is not likely to vary as much as the cases quoted. In all the gas experiments for this research, the surface of the metal was constantly being raked over to expose a fresh surface for temperature measurement by optical pyrometer. There seems no reason why a thickening medium cannot be used to assist in raking off this film unless it interferes with the normal measurement of temperature. There is, however, no doubt that a study of this question of temperature measurement is highly desirable and perhaps long overdue. The use of the immersion thermocouple pyrometer as a check would no doubt be helpful in ordinary foundry conditions, where the optical pyrometer is regularly used.

Gas Analysis

On first considering the type of gas apparatus required for the analysis of small volumes of gas collected from liquid cast iron, several points had to be considered. For example, the volume of gas collected may be extremely small, especially if an attempt is made to separate fractions of the volume given off, and to allow of repeat tests the apparatus must be capable of handling small samples accurately. The use of mercury seemed advisable and so the various forms of the Orsat type were ruled out. The cost of types like the Bone and Wheeler was deemed prohibitive, and the apparatus selected and described here is designed by Ambler. The arrangement and simple design show an intimate knowledge of the subject by the designer and considerable practical experience in gas analysis. The apparatus which is shown in Fig. 1 consists of:—

A.—A combined explosion and absorption pipette of about 25 ml. capacity.

B.—A measuring vessel consisting of three bulbs of volumes 1, 3, and 6 ml. respectively, which allows the use of samples from 0.25 ml. to 15 ml. at N.T.P.

C.—A water jacket and thermometer E for measuring the temperature of the sample.

R_1 and R_2.—Reservoirs for applying or reducing pressure.

G.—A barometer for taking readings required in the calculation.

D.—A manometer for reading pressures of the sample during analysis.

F.—An additional manometer for indicating the rate of and completion of solution of gases.

The barometer G and manometers D and F are mounted on a mirror engraved with a common scale which makes accurate readings easy and prevents parallax errors. The complete apparatus with the exception of the barometer and manometer consists of capillary tubing, and all rubber connections are eliminated from the main part of the apparatus.

The samples of gas were always collected over mercury, and when retained for any length of time were kept under a slight pressure so as to prevent any contamination of the sample by air. The accuracy of results is shown by the three following consecutive percentage analyses of the same sample of town gas:—

CO_2	3.47	3.36	3.42
O_2	11.13	9.88	10.16
CO	8.78	9.97	9.84
H_2	65.32	65.32	65.34
CH_4	9.44	9.24	9.31

The volume of the sample used for analysis in each case was about 10 ml.

From previous work carried out, moisture was found to have a pronounced effect on the quantity of dissolved gases, and, besides the case of moisture in the ladle lining, there is a similar possibility of the supply of moisture from the cupola itself.

Primarily there is the case of insufficiently dried patching material giving off free or uncombined water, and, in addition, the moisture or water of combination driven off at elevated temperatures. The moisture contained in coke on charging is generally supposed to be driven off completely in the upper part of the furnace; the sand bed, however, is composed of green sand. In the case of the 45-in. cupola (balanced-blast) on which the following study of blast conditions was carried out, the quantity of green sand would be over 10 cwts., which would be equivalent to about 90 lbs. of free water. This must be a potential source of moisture to enter the metal, and it is difficult to see how it can be eliminated if this were necessary. Ample ventilation of the drop bottom is essential to prevent any tendency for this water to rise through the metal, especially where, as in the continuous running systems, the whole of the bottom may not be covered with liquid metal. It is, of course, not possible to dry out the bottom completely or the risk of breakout would be greatly increased. Another source of moisture is the atmosphere, and this aspect was studied in detail.

Measurement of Moisture Content of the Atmosphere

Some difficulty is encountered in determining the actual weight of water in the atmosphere. The wet- and dry-bulb hygrometer is well known, and there are many similar instruments in attractive bakelite mountings for general indoor use. These are, however, supplied with a table giving the percentage humidity at the observed temperature, and sometimes this scale is built into the instrument case and operated in position. This percentage humidity is unfortunately of no direct value in the study of blast conditions.

A standard wet- and dry-bulb instrument was used, and for observation was housed in a small suitably-ventilated cupboard on a post situated in the open where the readings were made at the time of blast-on and blast-off.

The local observatory advised the use of formulæ set out in M.O.421, "Averages of Humidity for the British Isles," and the method of computation is as follows:—

The determination of vapour pressure (x) and relative humidity from readings of dry-bulb temperature (t) and wet-bulb temperature (t^1) has been effected using the formula

$$x = f - A\,(t - {}^{1})$$

where f is the pressure of saturated vapour at the temperature of the wet bulb (t^1) and A is a constant. For readings of temperature in degrees Fahrenheit and vapour pressure in millibars, A has the value 0.444 when t^1 is 32 deg. F. or above 32 deg. F. and 0.400 when t^1 is below 32 deg. F. The values of moisture content have been computed from values of temperature and vapour pressure by means of the formula $\delta = 216.7\,\frac{x}{T}$ and are set out in Table I, where x is the vapour pressure, T is the dry-bulb temperature in absolute Centigrade scale, and δ is the moisture content in grams per cubic metre.

For calculation of the weight of water delivered in the blast, a constant delivery of air was assumed, namely 4,500 cub. ft. of air per minute to the cupola, and the figure was adhered to for comparative estimations from day to day.

Table I sets out the weight of water delivered per hour to the cupola, calculated to lbs. It will be observed that this figure varies very considerably, *i.e.*, from 36 lbs. to over 100 lbs. per hour on what are virtually consecutive days. These figures will no doubt be a source of surprise to many foundrymen, and on their face value justify serious research into possible means of control or elimination of this excessive moisture from several points of view—namely (*a*) fuel economy, (*b*) possible maximum temperature obtained in the furnace combustion zone, and (*c*) gas in the molten metal, as it has

Table I.—*Daily Variations in Atmospheric Moisture related to Water Content in Blast.*

Day.	Temp. Deg. F.	Lbs. water per hour to 45-in. cupola.	Remarks on weather conditions.
Mon.	46.8	84	—
Tues.	45.3	77.5	—
Wed.	49.3	71	—
Thurs.	49.0	109	Overcast—Raining
Fri.	37.3	65	Overcast—Raining
Sat.	39.8	59	Clear—Bright—Sunny
Mon.	45.3	70	Clear—Bright—Sunny
Tues.	49.5	56	Bright—Sunny
Wed.	42.5	39	Bright—Sunny
Thurs.	43.0	36	Bright—Sunny
Fri.	43.8	53.5	Dry—Slightly overcast
Mon.	46.0	99	Overcast—Raining
Tues.	47.8	106	Heavy rain. Dull
Wed.	34.0	64.5	Snowing
Thurs.	39.2	48	Overcast but dry
Fri.	42.6	36.5	Clear—Bright
Sat.	46.4	42.5	Clear—Bright
Mon.	54.0	112.5	Slight rain—Cloudy
Tues.	43.0	72.5	Overcast—Slight rain
Wed.	48.3	91	Overcast—Slight rain
Thurs.	52.3	88	Clear—Bright
Fri.	53.9	77	Clear—Bright
Sat.	46.9	74	Dry—Heavy rain earlier
Mon.	47.3	67	Clear—Bright
Tues.	50.0	79.5	Raining
Wed.	54.5	62	Dry—Bright
Thurs.	49.8	69	Dry—Bright
Fri.	51.6	65	Dry—Bright
Mon.	46.0	85	Overcast but dry

been already shown that moisture is a serious source of dissolved gas in cast iron.

Dry Blast

The idea of drying the blast has been debated and the subject of experiment in connection with blast furnaces for a long time with the object of (*a*) fuel economy and (*b*) increasing the temperature and regularity of melting, and it has been under discussion more or less continuously since 1800. Since the findings with regard to the blast furnace may be directly applicable to the cupola, the following notes will not be out of place, and since the question of drying blast for the cupola now arises it is as well to review the possible methods, and how these have stood the test of experimental application to the blast furnace. While the question of economy of fuel and regularity of melting in the cupola might be important, the main object, so far as this Paper is concerned, is the relation of moisture content to gas in the melted metal.

Historical Notes on Dry Blast (from Lewis's Paper)

1800.—J. Dawson, of Lowmoor, in a Paper read at Dartford, pointed out the difference between winter and summer practice.

1853.—Prideaux's "Economy in Fuel" gave suggestions for drying blast.

1869.—The Duke of Devonshire, at the inaugural meeting of the Iron and Steel Institute, mentioned this difference as an important problem to be solved.

1880.—The Fryer process used solid calcium chloride. The liquor formed was to be collected and concentrated, and the solid so obtained dried and fused, but the process was not worked commercially.

1885.—Cremer process used solid calcium chloride and sulphuric acid. The medium was to be placed in double-bottom trays, thus allowing for regeneration *in situ*. (Cremer was Gayley's predecessor, and the process was a failure.)

1890.—Gayley's experimental work began.

1901.—Notes on experiments were made in

Table II.—*Summary of Data obtained by E. H. Lewis*

	1925	May, 1927	June, 1927	July, 1927	August, 1927
Moisture in atmosphere, grains per cub. ft.	3.5	3.08	3.41	4.85	4.77
Moisture in blast, grains per cub. ft.	3.5	1.09	1.20	1.61	1.50
Output per furnace per week in tons	356.5	418.5	400	417.6	412.9
Percentage increase in output	—	17.39	12.20	17.14	15.82
Total carbon per ton of iron	2,055	1,961	1,938	1,956	1,947
Percentage saving in fuel	—	4.57	5.69	4.82	5.55
Carbon burnt at tuyeres per ton of iron, lbs.	1,705	1,611	1,588	1,606	1,597
Percentage saving in fuel burnt at tuyeres	—	5.51	6.86	5.81	6.33
Balance of available hearth heat per lbs. carbon burnt at tuyeres. B.Th.U. (by Johnston's calculation)	1,585	1,724	1,717	1,694	1,700
Theoretical percentage saving in carbon burnt at tuyeres (according to Johnston)	—	8.06	7.69	6.43	6.79
Theoretical balance of available hearth heat per lb. of carbon burnt at tuyeres for actual atmosphere moisture for month	—	1,609	1,590	1,509	1,514
Theoretical percentage saving in carbon burnt at tuyeres for actual monthly conditions	—	6.67	7.39	10.92	10.94

U.S.A. with a view to drying by refrigeration; a plant was to be installed at one of the Carnegie blast-furnace plants.

1904.—Gayley's Paper to the Iron and Steel Institute giving the first month's figures from Isabella No. 1 furnace.

1906.—In a discussion of a Paper by Moissner, Gayley stated that the saving to be expected directly from drying was normally about 3 per cent., with a maximum of 7 per cent., and that the remainder of the saving actually made was due to greater regularity in blast-furnace operation.—In the Elsner process using solid calcium chloride, the regeneration was carried out in a lower drum and the regenerated calcium chloride then elevated to the upper or "drying drum."

Johnston's Theory.

Grains per cub. ft. of water in blast.	B.Th.U. available per lb. of carbon burnt.
nil	1,788
1	1,729
2	1,671
3	1,613
4	1,557
5	1,501
6	1,446

1907-9.—Refrigerating plant was installed at Dowlais-Cardiff plant and a considerable saving quoted. The Harbord process using calcium chloride, sulphuric acid and peat or pumice stone was impregnated with the medium, thus giving an increased surface area of the latter. Refrigerating plant was installed in South Chicago to deal with 122,000 cub. ft. per min.

1909.—Experiments were undertaken at Clarence Ironworks to determine the effect of uniformity of moisture. It was shown that considerable quantities of steam could be added to the blast to attain regularity without materially increasing the coke consumption.

1910.—Daubine and Roy described calcium-chloride process in which the blast was drawn through calcium chloride which was water-cooled and arranged for regeneration *in situ.* A plant was installed at Differdange Works, Luxemburg.

1911.—An ammonia refrigerator plant to be driven by exhaust steam was installed by the Brymbo Steel Company. The moisture was to be maintained below 1.5 grams per cub. ft.

The Wiles process, a modification of Gayley's, whereby the air was cooled in contact with sprays of cold liquid in the outlet side of direct-acting blowing engines.

1913.—Ehrenwerth stated that the Gayley process at the Deutscher Kaiser Works, Bruckhausen, and the Daubine and Roy process at

TABLE III.—*Showing Negative Influence of Atmospheric Moisture on Cupola Conditions.*

Lbs. water per hour to cupola.	Blast pressure. Ozs.	Temp. range during sampling.	Metal composition.					Gas analysis.					
			T.C.	Si.	Mn.	S.	P.	CO_2	O_2	CO	H_2	CH_4	N_2
59	16	1160–1110	3.25	2.62	0.88	0.085	0.40	Nil	0.4	16.8	20.0	0.7	62.1
74	16	1130–1110	3.15	2.43	0.95	0.082	0.41	0.4	0.9	10.5	6.7	1.4	80.1
56	15	1140–1110	3.28	2.58	0.855	0.091	0.43	0.8	0.3	20.9	17.7	1.1	59.2
39	16	1140–1110	3.10	2.13	0.70	0.105	0.46	0.4	0.6	11.1	12.0	0.5	75.4
36	16	1220–1170	2.94	2.25	0.75	0.111	0.505	1.8	0.1	13.6	15.7	2.2	66.6
53.5	15	1190–1160	3.00	2.19	0.735	0.104	0.51	2.2	0.2	8.5	13.0	0.8	75.3
99	15.5	1180–1120	3.05	2.32	0.71	0.106	0.52	1.0	0.4	16.2	9.2	1.3	71.8
106	15	1160–1130	2.98	2.22	0.735	0.103	0.48	5.2	0.4	6.4	13.6	1.0	73.4
65	15.5	1160–1110	3.03	1.84	1.03	0.098	0.48	0.4	0.4	18.6	14.8	0.7	65.0
48	15.5	1170–1110	3.11	2.30	0.745	0.103	0.46	2.8	0.4	10.8	14.5	0.5	70.9
36.5	15.5	1170–1090	3.21	2.01	0.745	0.098	0.48	1.3	0.4	11.6	7.3	0.6	78.8
42.5	15	1190–1130	3.26	2.04	0.85	0.099	0.47	1.1	0.7	21.0	6.8	0.9	69.5
112.5	15	1180–1120	3.17	2.25	0.80	0.105	0.48	1.9	0.3	23.1	8.0	2.3	64.4
72.5	15.5	1180–1110	3.08	2.18	0.725	0.097	0.48	2.2	0.3	8.4	18.0	2.0	59.1
91	16	1200–1150	3.12	2.26	0.735	0.107	0.435	2.1	0.6	5.7	16.2	1.5	73.9
88	13	No record	3.27	2.24	0.81	0.097	0.47	1.3	0.7	17.0	11.5	1.4	68.0
77	12	No record	3.25	2.47	0.785	0.097	0.435	1.9	0.6	20.5	9.6	1.3	66.1
No record	15.5	1210–1150	3.20	1.84	1.07	0.107	0.415	0.5	0.5	18.2	7.1	Nil	73.7

Differdange were out of operation and reported unsatisfactory.

1917.—Cammen described a process using calcium-chloride solution in which the brine flowed counter-current to the blast and was then taken to an evaporator and subsequently cooled.

The only Paper consulted giving the results of direct practical trials of the application of dried blast was that of E. H. Lewis describing results obtained at Wishaw. This was particularly interesting because these furnaces were in the Clyde area and would operate under related climatic conditions. The material used in drying the air was Silica Gel and the following quotation is from this Paper, which was written in 1927, describing the application of this material in a suitable system of driers to a blast-furnace plant.

Readings at Wishaw of moisture in the atmosphere in grains per cub. ft. (Lewis).

1927.	Maxima.	Minima.
April	4.70	1.11
May	5.88	1.47
June	5.57	1.33
July	6.51	3.62
August	6.56	3.26

A factor—0.5 grain per cub. ft. equals 10 lbs. of water per ton pig-iron made—was used.

In Scottish blast-furnace practice, the weight of air used per ton of pig-iron is about 10 cwts. more than the total weight of all other materials charged into the furnace, hence if care be taken with the selection of other materials it seems only logical to get the air in the best possible state. Many attempts have been made to obtain constant blast conditions by freezing or by absorption of water with calcium chloride, sulphuric acid, etc., as already described. The conclusions from Mr. Lewis's trials were:—

(1) That absorption methods have proved impracticable.

(2) That freezing is too expensive in maintenance and running costs in comparison with results obtained.

(3) That in all cases the money spent would have been better spent in improving other conditions, such as increasing blast temperature.

Properties of Silica Gel.—It absorbs up to at least 20 per cent. of its weight of water from the air with an efficiency of 99 to 100 per cent., and, by raising the temperature, the water can be driven off, leaving the Gel ready for another cycle. It is not advisable to reduce the moisture content of the Gel below 5 per cent. A matter of 2 lbs. of Gel is required for each cubic foot of air treated per min. Filters are required, to extract dust from the air, otherwise this may adversely affect the Gel beds. A 2-in. water gauge suction is necessary to draw the air through the Gel trays. Air was used to dilute the activating gases in order to reduce the temperature to 338 deg. C. The gas necessary for activating at 135 B.Th.U. per cub. ft. uses about the equivalent of 7 tons coal per day. In cold weather the dehydration is very complete.

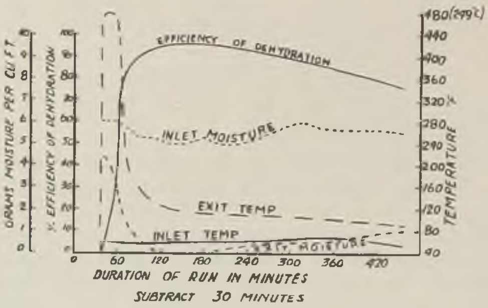


Fig. 2.—Cycle of Operations of a Silica Gel Drying Unit Used at Wishaw Blast-Furnace Plant (Lewis).

The saving in fuel in the blast furnace is not so important as in the cupola because any gas leaving at the top of the blast furnace is used, whereas in the cupola it is lost. In connection with the blast furnace regularity of quality is said to be more important than fuel economy.

It seems likely that this Silica Gel process would be the most promising for application to the cupola, but an experiment of this magnitude would naturally make an individual foundryman think twice. It is an experiment which ought to be undertaken after due consideration of its cost and probable advantages, because the cupola is now developed to a state of perfection when such an improvement as dry blast would not be out of place.

Fig. 2 shows graphically the cycle of operation of a drying unit, working on Silica Gel, as used at Wishaw (taken from Lewis's Paper).

To study the effect of moisture in the air and ultimately the effect of its removal from air blast, gas analyses were taken on successive days showing changes of atmospheric moisture content. The examples recorded in Table III give moisture contents from 36 lbs. to 112 lbs. per hour, and a prolonged study of the gas analyses does not reveal any relation to the moisture content of the blast.

It is true that the metal composition varies somewhat, but a study of this question did not justify the assumption that variations of analysis of the magnitude shown here resulted in any marked difference in solubility of the gases.

Then again, the range of temperature of collecting the gas shows some variation but no decided difference was found between gas collected at varying temperatures. The same remarks apply to variations in pressure of blast which can be taken to indicate large variations in volume of blast going through the cupola although not necessarily through the fusion zone of the cupola.

The conclusion is that the normal variations of furnace condition throughout the blow have more influence on the gas composition than the moisture content of the blast itself.

The collection of samples for gas analysis was accompanied by measurements of volume of gas evolved during cooling. Some of these are set out in Table IV along with metal analysis, moisture content, blast pressure, temperature range. In all the cases graphs were made of time-temperature and temperature-rate of evolution, and these graphs are really the best method of presenting the data, but large numbers of graphs cannot be reproduced here. The same remarks as applied to the case of the gas analyses may be applied to the volume and rate of evolution of gas. No definite relationship is shown between total volume, or maximum rate of evolution of gas from liquid cast iron and the moisture in the blast.

Addition of Water to the Blast

In spite of the conclusions drawn from the work done on the possible relation between gas content and atmospheric moisture it was thought that the presence of water in the blast must have an important effect on the nature and quantity of dissolved gases, and it was decided to introduce water into the blast and observe the effect. This was done using a Pitôt tube, with one tube attached to the top of a large bottle and the other to a tube leading from the bottom. By this means water was fed in at a regulated rate against the blast pressure. It was deemed unwise to apply this to a cupola on normal production owing to the risk of producing defective castings, so the trial was made on a 32-in. cupola melting metal for pigging only.

The conditions before the addition of water were:—

Analysis of gas in metal: CO_2, 0.94; O_2, 0.82; CO, 23.92; H_2, 13.72; CH_4, 2.92, and N_2, 57.68 per cent.

Composition of ladle metal: T.C., 3.17; Si, 1.67; Mn, 0.595; S, 0.228, and P, 0.445 per cent.

After the addition of water the following changes were recorded:—

Analysis of gas in metal: CO_2, 0.10; O_2, 0.40; CO, 7.58; H_2, 23.68; CH_4, nil, and N_2, 68.24 per cent.

Composition of ladle metal: T.C., 2.89; Si, 1.29; Mn, 0.60; S, 0.27, and P, 0.43 per cent.

This test showed some changes of the gas analysis, the water addition being accompanied with an increase in hydrogen in the metal. The change in the composition of metal is not due to the presence of additional moisture in the blast, but due to changes in composition of the cupola charge.

The measurement of volume of gas evolved from the metal before the addition of water gave a maximum rate of evolution of 32 ml. per min., while after the addition of water to the blast it gave a maximum rate of evolution of 90 ml. per min.

TABLE IV.—*Gas Evolution related to Atmospheric Moisture.*

Date.	Lbs. water per hour to cupola.	Blast pressure, ozs.	Temp. during evolution. Deg. C.	Total volume evolved, mls.	Max. rate of evolution, mls./min.	Metal composition.				
						T.C.	Si.	Mn.	S.	P.
29.2.40	59	14	1180–1090	No record	96	3.29	2.46	0.91	0.075	0.41
1.3.40	74	16	1190–1060	49.5	34	3.22	2.40	0.92	0.082	0.40
4.3.40	56	16	1220–1060	57	27	3.14	2.25	0.91	0.103	0.43
5.3.40	39	16	1200–1080	43.75	24	3.05	2.05	0.71	0.106	0.46
6.3.40	36	16	1160–1020	63	44		No sample taken			
7.3.40	53.5	15	1200–1070	47	33	2.97	2.16	0.745	0.103	0.51
8.3.40	99	15.5	1170–1030	44	43	2.98	2.22	0.735	0.103	0.51
11.3.40	106	15	1170–1050	60.5	56	3.04	2.55	0.785	0.097	0.47
12.3.40	65	15.5	1150–1060	48.5	44	2.96	2.04	1.08	0.098	0.44
13.3.40	48	16	1190–1080	67.75	66	3.02	2.28	0.77	0.105	0.44
14.3.40	36.5	15.5	1170–1040	52.5	39	3.13	2.02	0.81	0.098	0.47
15.3.40	42.5	15.5	1210–1070	49.5	38	3.09	2.12	0.83	0.100	0.435
18.3.40	112.5	15	1140–1020	49.25	36	3.12	2.16	0.785	0.102	0.435
19.3.40	72.5	15.5	1220–1140	35	52	3.12	2.08	0.84	0.098	0.46
11.3.40	91	16	1210–1090	49	31	3.05	2.18	0.765	0.098	0.425
12.3.40	88	14	1230–1130	49.25	38	3.29	2.26	0.775	0.104	0.445
25.3.40	77	13.5	1180–1080	53	38	3.28	2.26	0.795	0.090	0.435
27.3.40	No record	16	1270–1080	50	42	3.32	1.82	0.96	0.100	0.425
20.4.40	100	16	1290–1110	37	25	3.38	2.12	0.84	0.087	0.515
21.4.40	106	16	1250–1140	35.25	28	3.51	2.08	0.795	0.098	0.49

This experiment showed that the presence of water in the blast had a pronounced effect on the quantity and composition of the dissolved gases. It is also possible that other types of cupolas, *e.g.*, the single-row Rapid type, will react differently from the experiment recorded, and that charges containing large percentages of scrap in a Rapid type of cupola may be more adversely affected by high moisture conditions owing to the high concentration of the blast in certain parts of the cupola.

Owing to the unusual set of conditions prevailing in the 32-in. cupola remelting for pigging, it was thought advisable to duplicate the experiments in an 18-in. cupola running on 100 per cent. pig-iron, using a coke of 4 per cent. ash content and no limestone. The volume measurements were made on the gas as before.

The maximum rate of evolution of gas from metal normally melted in this small cupola was 15 and 17 ml. per min., while after the addition of water to the blast the maximum rate of evolution was found to be 24 and 28 ml. per min. on two series of tests. In this case a relatively large quantity of water was added, but this could not be said to produce any very obvious signs of lower temperature in the metal. This, however, need not be taken to disprove the theory that water absorbs heat and lowers the available calorific value of the fuel as indicated by Johnston's theory.

This experiment represents a well-heated coke bed receiving a water addition of relatively short duration, which it would conceivably be able to stand without much fall in temperature. The case of the steady supply of water throughout the entire run, including lighting-up time, would be much more effective. It is well known that a cupola improperly lighted never really recovers during the entire run, but continues to melt in an unsatisfactory manner, giving metal colder than usual.

It is also well known to foundrymen that the cupola works better on some days than on others. Even the ordinary domestic fire in an open fireplace may be observed to burn much brighter on days when the weather is frosty and clear. There is to be found some support for the view that the atmosphere is related in some way to gas in metal, for example, in the discussion on a Paper " Hydrogen in Solid White Cast Iron," J. L. Cawthorn, jun., said that in an attempt to eliminate porosity in steel castings made from cupola-direct-arc electric furnace iron " the incidence of porosity was checked up against humidity of the atmosphere, and although the curves were not qualitatively analogous, there was some quantitative analogy between the curves."

Experiments concerned with the elimination of gas from the liquid cast iron are much more easily carried out than any attempt to limit or

Table V.—*Showing Marked Reduction of Gas Evolution on Adding Steel.*

Date.	Time.	Blast press. Ozs.	Metal analysis.					Temp. range. Deg. C.	Total volume. Mls.	Max. rate of evol. Mls./min.	Remarks.
			T.C.	Si.	Mn.	S.	P.				
26.3.40	4.10	16	3.32	1.82	0.96	0.100	0.42	1270–1080	50	42	As tapped
,,	4.20	16	3.32	1.95	0.96	0.102	0.43	1210–1090	44	29	4 per cent. steel added
,,	4.25	16	3.30	2.06	0.78	0.103	0.42	1230–1150	76	134	As tapped
,,	4.35	15.5	3.25	1.97	0.72	0.105	0.43	1200–1160	41	62	4 per cent. steel added
,,	4.45	15	3.18	2.21	0.78	0.098	0.42	1210–1130	71	90	As tapped
,,	4.55	13	3.37	2.16	0.78	0.101	0.44	1210–1140	36	56	4 per cent. steel added

Table VII.—*Showing the Slight Influence of the Addition of Steel Turnings on the Transverse Properties of the Metal.*

Date.	Blast press. Ozs.	Cast. temp. Deg. C.	Metal analysis.					Transverse test. 1.2 in. dia. 18 in. centres.		Remarks.
			T.C.	Si.	Mn.	S.	P.	Load. Lbs.	Def. Ins.	
28.3.40	16	1260	3.35	1.80	0.74	0.098	0.41	2,380	0.25	As tapped
,,	16	1260	3.35	1.85	0.77	0.097	0.40	2,480	0.25	4 per cent. steel turnings
29.3.40	15.5	1260	3.34	2.06	0.75	0.103	0.41	2,492	0.25	As tapped
,,	15.5	1260	3.37	2.16	0.73	0.104	0.39	2,576	0.25	4 per cent. steel turnings
1.4.40	14.5	1260	3.33	2.02	0.94	0.107	0.48	2,184	0.25	As tapped
,,	14.5	1260	3.30	1.97	0.92	0.095	0.46	2,100	0.25	4 per cent. steel turnings

control the amount of water going in with the blast. The effect of direct oxidation either by scale alone or by mixtures of scale and soda ash has already been described in the previous Paper* showing a decided reduction of the volume.

It was intended to test the effect of various additions on the gas content of the metal in the ladle, using such additions as are likely to be made, including alloys, but this field was not covered.

Addition of Steel Turnings

The addition of steel to the cupola has always been associated with oxidation, sulphur pick-up, and heavy lining wear. This applies more particularly to thin steel scrap which presents large surface area. The introduction of steel as a ladle addition is free from the excessive oxidation, sulphur pick-up and lining wear taking place in the cupola, and on that account has much to recommend it. Steel cuttings and turnings are available in large quantities from machine shops, and while the material is produced in various forms from large spirals to small compact chips these can be rendered uniform in size by suitable "chip breakers" now on the market or specially selected for foundry use. For example, a group of circular saws for cutting bars produce small curled-up cuttings less than $\frac{3}{8}$ in. diameter, which can be shovelled readily in small quantities, and these melt readily in cast iron.

A decrease in temperature is to be expected with the introduction of cold material to the ladle, and this factor will limit the quantity which can be used in particular cases. A quantity of 4 lbs. per cwt. of liquid cast iron can be used regularly without serious decrease in temperature. This addition is useful to metal for casting heavy pieces requiring close grain and good finish, as for example slides and saddles for lathes. The slight decrease in temperature is in this case an advantage rather than otherwise. With *good melting practice* the temperature of the liquid cast iron will effect immediate solution of the steel cuttings or turnings, and there seems little or no chance of solution being incomplete even with rather heavy turnings.

Using nickel or nickel-chromium turnings a corresponding percentage of these valuable alloys may be introduced in a relatively economical manner with improvement in the general properties of the metal. Since the introduction of steel in this form is responsible for a dilution effect only, the resultant change in chemical analysis figures for the cast iron is known beforehand. However, the experiments with steel additions to the ladle were undertaken to find

TABLE VI.—*Influence of Steel Additions on the Composition of the Gas from the Metal.*

Time.	Blast press. Ozs.	Temp. range. Deg. C.	Metal composition.					Gas analysis.						Remarks.
			T.C.	Si.	Mn.	S.	P.	CO_2	O_2	CO	H_2	CH_4	N_2	
4.40	15.5	1210–1150	3.20	1.84	1.07	0.107	0.417	0.5	0.5	18.2	7.1	Nil	73.7	As tapped
4.45	15	1170–1110	3.26	2.11	0.82	0.098	0.43	0.1	0.7	20.0	Nil	19.7	58.5	4 per cent. steel turnings

TABLE VIII.—*Brinell Hardness Readings on Untreated Metal and with Scale Additions.*

Casting temp. Deg. C.	Brinell hardness.							Metal analysis.					Remarks.
								T.C.	Si.	Mn.	S.	P.	
1250	168	196	179	89	187	202	207	3.35	1.78	0.86	0.103	0.49	Untreated
1220	202	179	159	74	179	192	207	3.29	1.91	0.905	0.094	0.525	1½ lbs. scale to 2 cwt. metal added
1200	202	192	174	68	156	183	196	3.26	1.98	1.11	0.083	0.49	Untreated
1200	207	196	170	68	163	179	202	3.26	1.97	0.96	0.088	0.51	1½ lbs. scale to 2 cwt. metal added
1220	207	187	170	68	166	179	202	3.10	2.17	1.11	0.084	0.47	Untreated
1190	207	187	163	68	159	187	207	3.08	2.16	1.11	0.089	0.45	1½ lbs. scale to 2 cwt. metal added

---

* *Loc. cit.*

what effect, if any, this had on the volume and analysis of the dissolved gases. The procedure used was to take a ladle of metal direct from the furnace for gas volume measurement and then, for comparison, place steel turnings in the bottom of the next ladle and tap the metal on this, and after this was dissolved to make a volume measurement. In order to eliminate any variables from one day to the other a number of volume measurements was made on the same day and alternately with the steel additions and "as tapped" whilst recording the blast pressure in the wind belt. The last reading of this pressure set out in Table V shows that a larger volume was being taken by the cupola, and this might tend to increase the quantity of dissolved gases. Graphs of temperature and time and temperature and rate of evolution were made as in all other cases, and these show very clearly the considerable reduction in gas content brought about by the steel addition; but these graphs are not reproduced, as a large number of graphs would overload the printed Paper. The figures included in Table V, however, prove the case clearly.

The conclusion is that the gas content is reduced, in the case of low initial content, by about 30 per cent., and in the case of high initial gas content by 54 per cent., as shown in the examples.

The effect of steel-turning additions on the composition of the gas in solution is shown in the examples in Table VI and seems to confirm the conclusion already reached, namely, that no very definite chemical selection takes place in the removal process. The solution of steel in cast iron probably disturbs gas equilibrium conditions, resulting in the liberation of a quantity of gas of mixed composition.

The fractional boiling off, that is the separation of one gas before the other, has not been observed so far, but the point might require more careful and extended tests. Whether oı not it would lead to any useful conclusions, or have any bearing on the elimination of gas defects in practice, is doubtful.

An addition of steel would be expected to alter the physical properties of the iron and probably to some extent the microstructure (Table VII). Some transverse bars cast from metal with and without steel addition show, where the analyses before and after are substantially the same, an increase in strength of about 5 per cent. for a 4 per cent. addition of steel to an iron of the composition shown in Table VII. It is uncertain whether the gas elimination has contributed to the change in strength, and it must be understood that small variations of elements such as silicon, sulphur and manganese may produce variations in strength of sufficient magnitude to mask the effects being measured.

It has been suggested that a certain quantity of dissolved gas might retard or control the shrinkage of cast iron. In order to test this point a number of casting tests were made on a standard pattern to cast blocks 8 in. by 4 in. by 4 in. with a cut in the gate at one end and a riser taken off through a cut gate at the other end. No risers were used for the purpose of feeding the casting. These blocks were cut through the centre and polished for Brinell measurements diagonally across the centre section.

Table VIII gives the results of tests made on blocks cast as tapped, and degasified by scale addition. As is shown in the table, the tendency to porosity is not increased by degasification and from similar experiments there is no reason to support the idea that dissolved gas in anv way influences porosity or shrinkage.

The author wishes to thank John Lang & Sons for permission to place the results of these investigations before the Institute.

Paper No. 712

Some Observations on Contraction in Grey Cast Iron

By E. LONGDEN, A.M.I.Mech.E. (Member)

The term "contraction in cast iron" is used in this Paper to define the reduction in volume which operates from the point of solidification to atmospheric temperature. Reduction in volume from casting temperature to the point of solidification might well be defined as "shrinkage," although both terms are used to describe a diminution in volume.

The amount of contraction and degree of distortion in a casting will have relationship to the chemical and physical properties of the metal, design and method of manufacture. Factors influencing contraction include:—

(1) Chemical composition of the alloy.

(2) Melting conditions, pouring temperature and superheat of the metal.

(3) Design, section and volume related to section.

(4) Size, shape, location and distribution of runner and riser gates.

(5) Character of the mould and core materials and their condition when the metal is poured into the mould.

(6) Method of moulding and coremaking.

It is not intended to detail the influences stated above, but to offer further information about the behaviour of castings during cooling. In the past, standard contraction has been laid down for cast iron irrespective of its very varied constitution, or size and design of the casting.

It is well understood that the composition of an alloy should be suitable to the class of casting, but control of composition for the majority of castings will not eliminate, substantially, the vagaries of contraction with its incidence of distortion and stress. The design, size and mass of castings must command consideration.

Little attention has been paid by investigators to the effect of volume changes on castings of a commercial character. Consideration has been given to cast iron as an alloy. One has to turn back to the experiments of Prof. T. Turner, carried out in 1906, and even earlier investigators such as Mallet and Keep, for any definite findings on contraction. All such experiments, however, were carried out on test-bars of simple form.

Because a large casting offers a wider and bigger field for observing movements during cooling than small castings, or test-bars, the author's attention has been directed to following the movements of large castings during cooling.

Volume Changes

Arrests in the rate of contraction, or an expansion at critical temperatures, are quite pronounced in the general run of cast irons. Such volume changes would appear to be largely due to the liberal amount of carbon present in cast iron, and its condition. The precipitation of primary graphite on solidification, and secondary graphite at lower critical temperatures, will account for expansions.

According to Prof. Turner, phosphorus is responsible for an expansion, if present in appreciable quantities. Generally, it has been considered that there are two distinct arrests in low-phosphorus irons, and, in alloys with appreciable phosphorus content, three arrests.

The final amount of contraction will be influenced by the ratio of free carbon to combined carbon in the completely cooled casting, but the data presented in this Paper will indicate that final contraction and the absence or presence of stresses in many classes of castings are also due to the conflicting expansion and contraction influences operating together in the same casting. In lengthy castings, mould and core

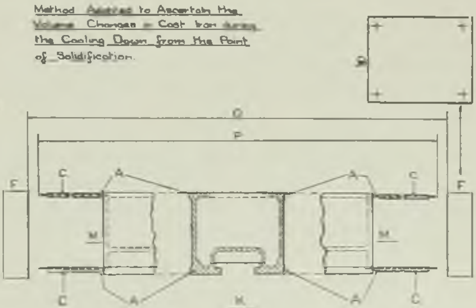


Fig. 1.—Method Used for Ascertaining Volume Changes.

resistance will tend to reduce contraction and create stressed material.

Test Procedure

A method devised by the author for ascertaining the behaviour of large castings during cooling, from the point of solidification to atmospheric temperature, is illustrated in Fig. 1. The movement of the casting is followed by frequent measurements between fixed points outside the mould and rods held by the metal of the casting. Whenever practicable, temperature readings are associated with the volume changes.

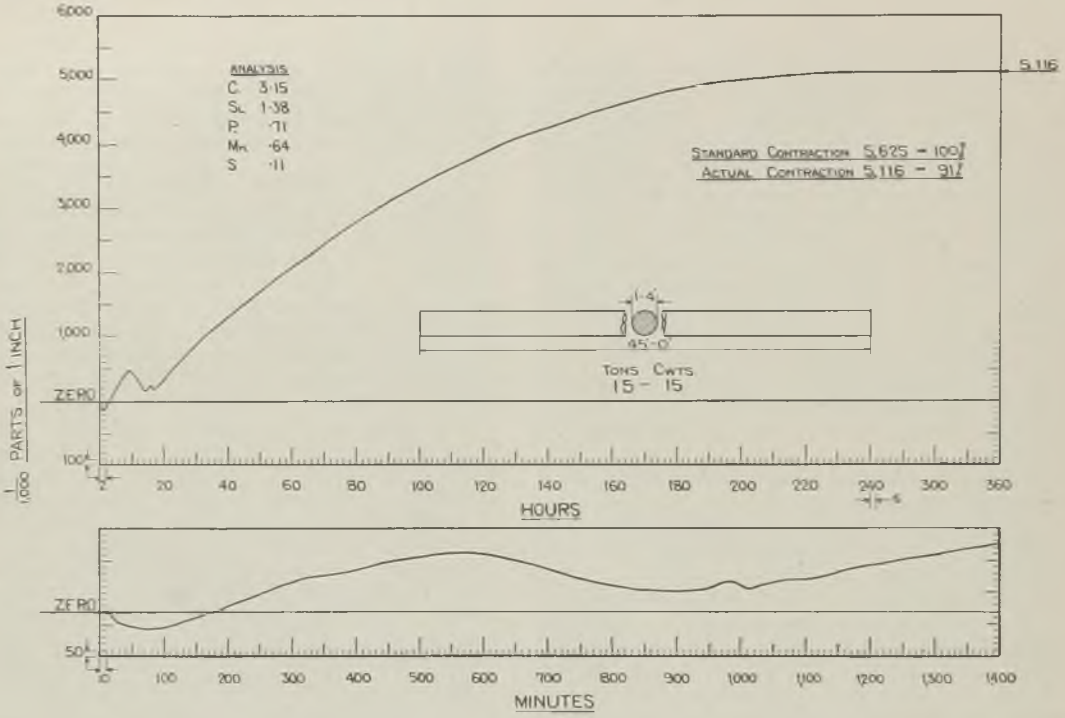


FIG. 2.—VOLUME CHANGES OF THE SOLID BORING BAR SHOWN IN FIG. 3.

The example chosen to describe the procedure is that of a lathe bed. A cross-sectional elevation, K, and two end portions of the longitudinal elevation, M, are outlined in Fig. 1.

The test procedure is as follows: During the ramming of the moulds, heavy weights, F, Fig. 1, are located soundly below the floor level, outside the ends of the pattern, at a suitable distance (in this example 3 ft.). Wrought-iron tubes, C, 2 ft. 8 in. in length, are also positioned and rammed around with the rest of the mould. The tubes are placed with ends within 1 in. of the vertical faces of the casting, and the opposite ends about 4 in. away from the machined vertical face of the weights, F. Four tubes are located at each end of the mould, two opposite the heavy slideways and two 2 in. from the top face of the mould. Each tube is fixed opposite the vertical walls of the casting. There are, thus, eight tubes.

Following the withdrawal of the pattern and the finishing operations, the moulds are broken through to the tubes and ½-in. wrought-iron rods, A, are pushed forward to within about 3 in. of the face of the heavy weights, F, at each end of the mould. About 1 in. of the rod, A, made jagged to hold fast to the metal of the casting, penetrates into the mould cavity. The opposite ends, which have been ground perfectly flat, correspond with crossed centre-lines scribed on a polished section of the weight opposite (see Fig. 1, F). The spaces between the ends of the tubes and the mould face are well sealed and secured by ramming sand around the rods, now leaving, as before stated, the ends of the rods protruding into the mould cavity, to be gripped by the metal of the casting.

Just before pouring the casting, careful measurements are taken, by inside micrometers, of the gap between the ends of the rods, and the centres marked on the weights. Provision is made to begin taking measurements within 3 minutes after pouring the mould. In the case of a large casting, similar to the bedplate illustrated in Figs. 6 and 7, repeated measurements proceed at intervals of 3 minutes for about 3 hours, when the measurements are slowed down to every 15 minutes for a further 5 to 6 hours, then every half hour for about 6 hours, every 3 hours for 24 hours, and checking is continued four times daily until contraction is complete. The total contraction is shown by the final gap distance between the faces, P, of the rods, A, and the faces, O, of the weights, F, less the original gap dimensions before pouring the casting. The sum of the net dimension at each end equals contraction.

The alterations between the points, O, P, indicate, with a closing of the gap, expansion, and, with a widening of the gap, contraction. The records of the movement of the casting, with associated times, are plotted on graphs. The early behaviour of the casting is expressed in minutes and the complete movements in hours.

A line, zero, on the graphs identifies the condition of the molten metal in the mould. The penetration of the curves below the zero line indicates expansion beyond the size of the mould. Above the zero line the curves register contraction and any further volume change, such as expansion or arrests. Note is taken of the expansion of the test rods due to absorption of heat from the casting. The temperature variations of the rods are checked at intervals. Later, the same class and length of rod is heated to a similar temperature as obtained during the cooling of the casting. The length of the rod, cold, as against the rod heated to the particular temperature required, gives the amount of extension of the rod, which must be cancelled from the early movements of the casting as recorded. A further adjustment is needed in castings which are cambered. On the total contraction, an allowance is made for the difference in length that a curved line will give when straightened out.

TESTS ON LARGE BORING BAR CASTINGS

18-in. dia., 45-ft. long Solid Boring Bar

The volume changes of a large solid boring bar, 18 in. dia. and 45 ft. in length and weighing 15 tons 15 cwts., is illustrated by the cooling curves in the graph, Fig. 2. The casting is shown in Fig. 3.

The casting, on account of its great length, is poured in a horizontal position. A description of the moulding technique would be too lengthy to include in this Paper. Briefly, the mould was metal-faced and of special construction, which produced an excellent quality casting. The composition of the metal is shown in Fig. 2.

Fig. 3.—Solid Boring Bar Weighing 15¾ tons.

A record of the movements of the casting was obtained in a similar manner as by the general method of obtaining volume changes described earlier in these notes. Two readings were obtained from two rods located one on each end of the mould; the sum of the movements was plotted in the graph, Fig. 2. All allowances have been made in the curves for the expansion of the test rods due to rise in temperature. This adjustment also applies to the curves of the 22-in. cored bar, a description of which follows the first example.

The minutes' curve shows an arrest at 10 minutes when the casting is substantially solid. Expansion is indicated for about 65 minutes. Zero is reached in 170 minutes. Contraction proceeds for a period until 570 minutes is reached, when a very decided arrest and expansion is registered which lasts for 330 minutes. A further arrest follows at 980 minutes, but it is of short duration and lasts about 25 minutes. From this point the curve indicates only small fluctuations and a steady rate of contraction. The curve in hours shows the complete behaviour.

Finally, on cooling to room temperature, the total contraction is found to be only 91 per cent. of standard allowance at 5,116 thousandths against 5,625 thousandths. The casting had taken up 96 per cent. of its contraction in 10 days.

22-in. dia., 47-ft. long Cored Boring Bar

A second test, applied to a cored boring bar, 22 in. dia. and 47 ft. in length, and weighing 19 tons, confirmed the tests applied to the 18-in. solid bar. Fig. 4 shows the design and dimensions of the bar, and the cooling behaviour of the casting by the curves plotted on the graph. The casting is shown in Fig. 5.

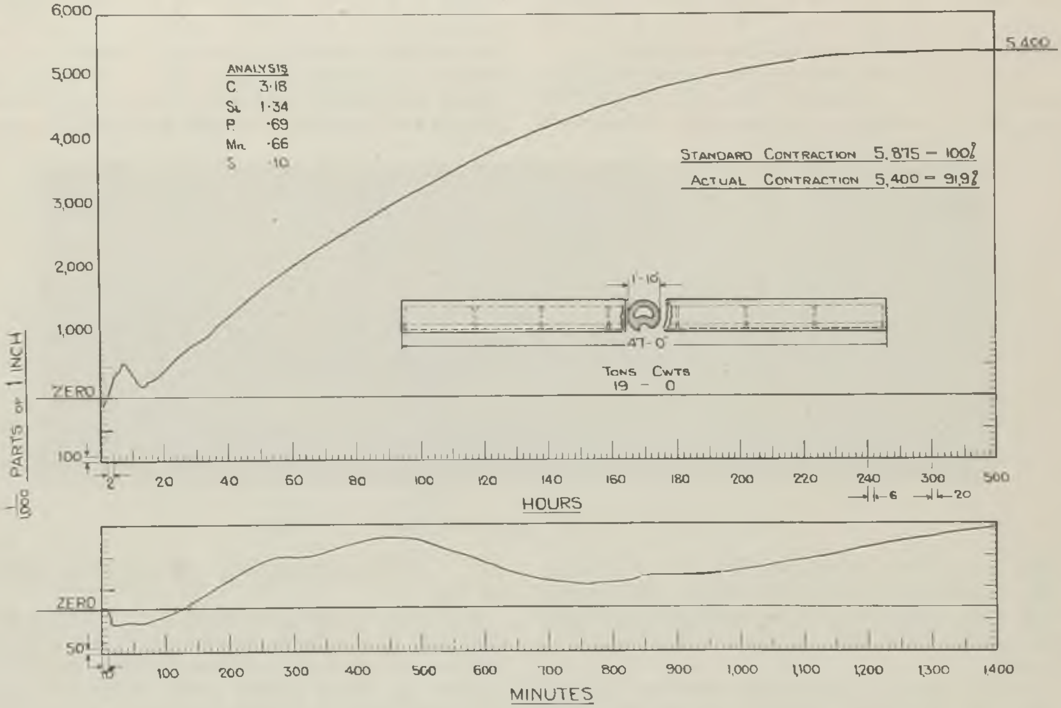


FIG. 4.—VOLUME CHANGES OF THE CORED BORING BAR SHOWN IN FIG. 5.

The casting was made and poured in a similar manner as practised for the solid bar, but with the added complication of a series of kidney-shaped cores, which were almost completely surrounded by metal. Again, a truly sound and satisfactory casting resulted from the technique employed. The composition of the metal is set out in Fig. 4.

The minutes' curve indicates an arrest and expansion at 10 minutes when solidification of the metal is well advanced. Expansion continues for about 60 minutes. Zero is reached in 130 minutes. A short arrest is disclosed at 285 minutes. After further contraction, a most marked arrest and expansion is registered in 440 minutes. This volume change lasts for 320 minutes, until 750 minutes is reached. A further small arrest can be noted at 850 minutes. From this point the rate of contraction is very uniform. The hours' curve shows the completion of the cooling process of the casting. After cooling down to atmospheric temperature, the total contraction of the casting was 5.400 thousandths against 5,875 thousandths for the standard allowance. Contraction equalled 91.9 per cent. of standard allowance. The casting had taken up 94 per cent. of its contraction in 10 days.

Test on Long Bed Castings

Figs. 6 and 7 illustrate the cooling behaviour of a 41 ft. 6 in. long bed casting for a roll-grinding machine. The design and dimensions of the bed are outlined by the inset in Fig. 7. A cross-sectional elevation of the bed, across the points, AA, of the portion of the longitudinal elevation, L, is shown at E.

The casting is poured in the reverse position to that which is shown in the sketches, Fig. 7, with the slideways on the bottom face of the mould. The cooling behaviour is followed and checked, as previously described. In this case, however, four curves were formed. All allowances have been made in the curves for the expansion of the rods due to heating, and also for the curvature of the casting consequent upon the camber necessary to produce a straight casting. Camber is required downwards (in the centre as poured) and sideways (in the centre) in the direction indicated by the arrow, K, in Fig. 7.

The early volume changes of the casting are expressed in minutes in the graph, Fig. 6, and the complete movements, in hours, are shown in Fig. 7. The letters A, B, C and D identify, in the graphs, Figs. 6 and 7, the curves taken of the cooling casting, on the lines indicated by A, B, C and D in the sketch E, Fig. 7. The line of contraction, A, carries the heaviest mass of the casting—the vee slideway. The line, B, holds the flat slideway, being the second heaviest line of contraction. The line, C, influenced by the extra metal at H, thereby takes the third position in order of mass influence, and D the lightest and most quickly cooled and contracting line.

FIG. 5.—CORED BORING BAR WEIGHING 19 TONS.

Referring to the minutes' curve in Fig. 6, the following movements are indicated:—

Curve D.—At 7 minutes an arrest and expansion of 25 thousandths occurs and lasts for 28 minutes. At 68 minutes a second arrest is shown covering a period of about 30 minutes. A third and fourth slight arrest may be detected at 140 and 220 minutes respectively. The curve then indicates a steady contraction with only small fluctuations.

Curve B.—At 9 minutes an arrest and expansion of 46 thousandths is noted, lasting for about 30 minutes. At 130 minutes, a second arrest, for 65 minutes, occurs. At 207 minutes a third arrest appears lasting for about 30 minutes. The remainder of the curve records only small fluctuations.

Curve C.—At 8 minutes the record shows an arrest and expansion of 55 thousandths, lasting for about 25 minutes. At 180 minutes, a small arrest occurs for 15 minutes. At 240 minutes a third small arrest can be identified. The curve following is steady until final cooling.

Curve A.—At 10 minutes an arrest and expansion of 75 thousandths is shown over a period of 40 minutes. A second arrest is indicated at 150 minutes, lasting for 20 minutes. At 195 minutes a third, sharp arrest is recorded, lasting for 15 minutes. A fourth arrest occurs at 265 minutes, which covers a period of 65 minutes. A fifth slight arrest is indicated at 395 minutes. After 430 minutes the curve shows a steady contraction rate.

The standard contraction allowance for a 41 ft. 6 in. casting is 5,188 thousandths. The actual final contraction of the bed is as follows:—A, 4,978 thousandths, which is 96.0 per cent. of the standard allowance; B, 4,904 thousandths, which is 94.6 per cent. of the standard allowance; C, 4,251 thousandths, which is 82.0 per cent. of the standard allowance; D, 4,182 thousandths, which is 81.0 per cent. of the standard allowance; average contraction, 87.4 per cent. of the standard allowance. Between the lowest contraction of D and the highest contraction of A there is a difference of 796 thousandths. A, C side has contracted an average of 72 thousandths more than B, D side. A (bottom heavy vee slideways) has contracted 74 thousandths more than B (bottom flat slideway). A, bottom, has contracted 727 thousandths more than C, top. B, bottom, has contracted 722 thousandths more than D, top. The average contraction of A, B (bottom face) over C, D (top face) is 725 thousandths.

Camber Allowances

These varied contractions, recorded on the four extremes of the castings, confirm the camber allowances needed to counteract distortion due to the differing heat gradients and the hinderance, by design, to free contraction. The camber allowance, downwards, was 2¾ in., which must be associated with the excess contraction of 725 thousandths of A, B (bottom face) over C, D (top face). The camber requirements on the A, C (heavy) side was ⅝ in. This allowance must be associated with an excess contraction of 72 thousandths of the A, C side over the contraction of the opposite side, B, D.

Without the heavy facing, S, on the A, C side, it is necessary to allow approximately ¼ in. more camber on the A (heavy vee slideway) line than on the B (flat slideway) line. The influence of the heavy side facing, S, was to reduce slightly the downward camber, but to create, along with the heavy vee bottom slideway, a side distortion if not counteracted by camber allowance.

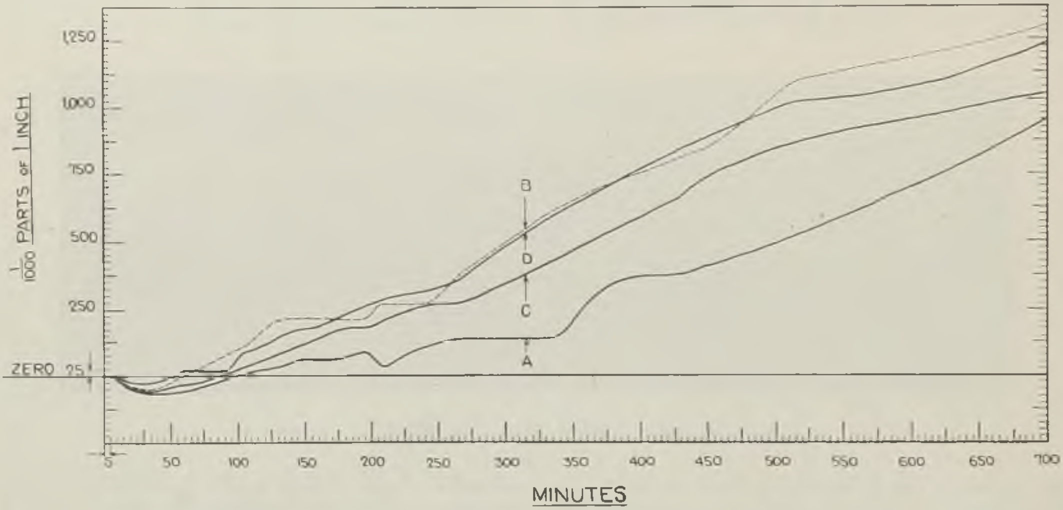


Fig. 6.—Cooling Behaviour of a 41-ft. 6-in. Roll-Grinding Machine Bed.

It will be noted, on close examination of the cooling curves, that B (bottom flat slideway) contracted slightly ahead of C (top with side facing) and then later falls behind to take its place in order of mass cooling. This may be due to the early effect of the denseners, on the B slideway, and the acceleration of the cooling rate immediately after solidification of the metal. The C (top side), however, is influenced by a heavy facing, carrying nearly as much metal as B (bottom) which is also densened. Since the side facing is subjected to a sharper cooling, by virtue of its outward position in the mould, cooling and contraction are, subsequently, more rapid than B, which is located in the bottom of the mould. Again, much of the heat absorbed by the denseners is retained by the densener to slow up the rate of cooling at a later period.

Adverting to the arrests in the cooling curves, it is possible that the influences, when cooling has reached a stage when a considerable difference in contraction stress is upon the casting, cause a late arrest which is not actually due to an expansion, but may be attributed to distortion of the casting.

Test Castings

Fig. 8 illustrates, by sketches, the design of a test casting 10 ft. by 2 ft. by 7 in. and, graphically, the cooling curve and final contraction of the casting. The sketches show that the casting consists of a series of bars of varying sections making one unit. The outside longitudinal bars carry a 4-in. flange, 1 in. thick, forming, with a vertical ½-in. bar, a tee section. The inner bar is heavier, having a 5-in. by 2-in. flange mounted above a ¼-in. vertical bar, again forming a tee section. The cross bars are plain bars of ½-in. section.

The test is arranged to create an exaggeration of the cooling conditions present in certain types of castings, particularly of bed designs. The composition of the metal poured into the casting was such as to yield a grain structure as might obtain in a much larger casting, with a lower silicon content. The analysis is set out in Fig. 8.

The volume changes were checked on three contraction lines, indicated by the letters X. The behaviour of the two outside longitudinal bars was so similar that it became unnecessary to draw a curve for each bar. They were, therefore, merged and are plotted together in the curve C, in the graph, Fig. 8. The curve traced for the movement of the centre bar is identified by the letter B.

The curve C shows that an arrest occurs at 4 minutes with an expansion of 28 thousandths. A second mild arrest and slowing up of the rate of contraction occurs at 20 minutes. With B curve an arrest is recorded at 5 minutes with a 32 thousandths expansion. A third arrest and slowing up of contraction occurs at 28 minutes. A steady contraction follows. The heavy centre, B, passes and exceeds the contraction of the outer lighter bars, C, at 375 minutes.

The final contraction of the casting came out at 1,246 thousandths for the heavy centre bar, B, being only 4 thousandths below standard allowance, and 1,164 thousandths for the outer lighter bars, C, which represents only 92.5 per cent. of standard allowance. The casting was bent (down in the centre as poured) by $\frac{5}{8}$ in., along the line B, and $\frac{3}{16}$ in. on the lines C. The casting was also fractured at six points indicated by F, in Fig. 8.

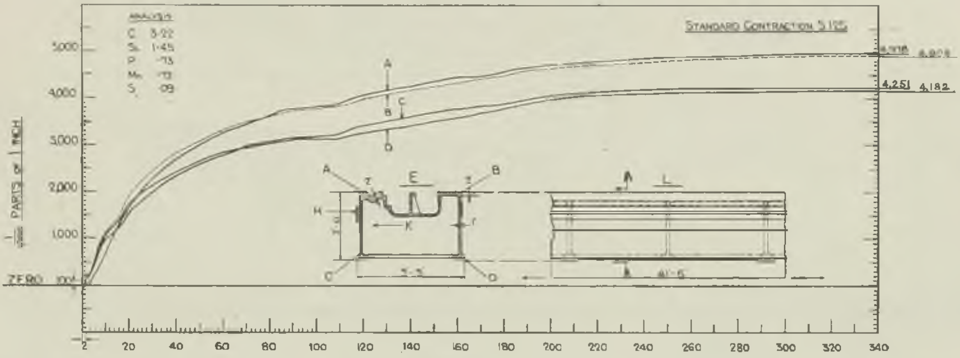


FIG. 7.—COMPLETED COOLING BEHAVIOUR OF THE ROLL-GRINDING MACHINE BED.

The usual allowances were made in the final figures for the expansion of the rods due to heat and the curvature of the distorted casting.

A further test was taken, but with the middle bar, B, split by a core, as described at S, Fig. 8. The behaviour during cooling is interesting. The lines, C, contracted 1,252 thousandths (close to standard allowance), against 1,164 thousandths for the same dimension of bar in the first test casting. This means that the bars in the first casting contracted 88 thousandths less than the bars in the second casting.

The two middle bar sections, B, together contracted 1,238 thousandths, which is 12 thousandths less than standard. The gap, S, severing the bar in the centre had, after cooling, widened by 187 thousandths.

The distortion in the second test, with the heavy centre bar split into two sections, was less pronounced than in the first test, where the casting is not split across the centre bar. The lines C and B cambered $\frac{7}{16}$ in. Furthermore, no fractures appeared at the points F.

Conclusions

All of these tests offer substantial support to the previous experiments carried out by the author and presented to the Institute over a number of years.

The conclusions are that, on the classes of iron castings surveyed, thick bars, or sections, contract more than thinner bars, or sections, where such varied sectioned members are linked together, as a single-piece casting, in a proximity to be affected by mutual influences. If, however, the same contrasting sections are cast as simple uniform and separate items, contraction is in line with standard allowance and knowledge—that a thin section of grey iron contracts more than a thicker section for the same analysis, because of the more rapid freezing of the lighter section and the effect of this more rapid cooling on the grain size and graphite formation.

A probable explanation of the two contrary degrees of contraction referred to is that, in the case of a one-piece casting, the thin or comparatively light sections are subjected to an extensional stress, during freezing and cooling of the metal, created by the resistance of the thicker sections which are not ready to contract. The frictional resistance of the mould and cores, and the expansion of cores on being heated up by the molten metal, will also tend to subject the cooling metal to extensional stress. Again, a study of the very clear arrest and expansion periods noted on the cooling curves, especially those of the heavy and large boring bars, indicates that a thick section of a casting may be undergoing an expansion at a time when a thinner section has passed its expansion phase and is in a state of contracting. Under these conditions the thin sections will suffer extensional stress.

Conversely, the thicker sections will be subjected to a compressional stress by the effort of the earlier cooled members to contract. Finally, the heavy sections, on cooling, must take up a shorter length by bending certain sections of the casting, or by fracture in the weakened or most highly stressed sections.

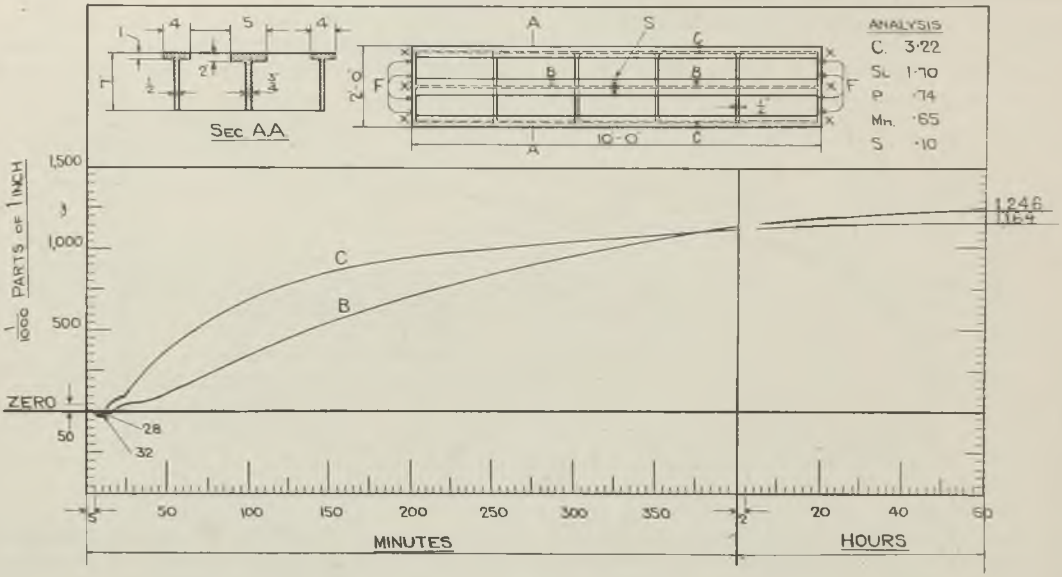


Fig. 8.—Design and Thermal History of Test Casting.

The author's thanks are tendered to Mr. J. R. Greenwood (chairman) and the directors of Craven Bros., Limited, machine-tool engineers, for facilities to obtain information for this Paper.

WRITTEN DISCUSSION

Mr. V. C. Faulkner (Past-President of the Institute) wrote: A really valuable contribution has been made by Mr. Longden's researches, not only to the practical adjustment of contraction allowances to be made when making patterns and moulds for large castings, but also to the theoretical aspects of the subject. In connection with the test procedure, it is conceivable that improvements might be effected by using bars of Invar metal, as that metal does not expand, instead of mild steel and by inserting balls between the rods and the tube, to act as a bearing. The author's view of these aspects would perhaps be of general interest.

Mr. E. Longden wrote in reply:—The suggestions put forward for implementing the test procedure are very welcome; they afford an opportunity to explain phases not yet disclosed.

The possibility of employing a metal with a low coefficient of expansion exercised my mind very early in the experiments—some five years back. With this object in view, I later tried an alloy of nickel and iron, of similar composition as compounded for Invar metal, but I abandoned the use of this special alloy because the temperatures dealt with went beyond the range at which the alloy reactions caused a cancelling of volume increase. It was also found that the alloy test rod became embrittled, resulting in partial fracture at the juncture where the rod entered the metal of the casting, indicating intercrystalline failure. This failure would be due to subjecting the nickel alloy to the very high temperature of the face of the molten cast iron of the casting.

The peculiarities of Invar and similar alloys are that, while steel expands and contracts normally, the special alloy shows little or no volume increase over a restricted and comparatively low range of temperature. This range of temperature appears to correspond with the magnetic transformation period, which is complete at about 220 deg. C., depending upon the composition of the alloy. Thus the volume change is neutralised by the magnetic transformation. But at lower and higher temperatures both expansion and contraction are experienced.

It was, therefore, decided to revert to the use of mild-steel rods, which could be relied upon to give the consistency of a regular expansion rate, according to the temperature gradient, which would be identified and allowed for when committing figures to the curves on the graph.

The second suggestion, by Mr. Faulkner, "that balls be inserted in the space formed by the outside of the rods and the inside of the tubes to act as a bearing," will receive attention in future tests. At the same time there was no evidence that the frictional resistance of the rods in the tubes had affected the results obtained. The rods are quite loose in the tubes and free to move, without hindrance, at the behest of the casting.

It may be of interest to outline a simple method adopted to take an additional automatic record of the movement of the casting. This record was taken at the same time as the measurements outlined in the Paper. The sketch (Fig. A) illustrates the scheme adopted:—

(A) Casting.

(B) Rod tube.

(C) Rod for recording movements of the casting.

(D) Socket holder for the black lead pencil (E), which is welded to the rod (C).

(E) Lead pencil.

(F) Slide, fastened to the rod (C).

(G) Weight, fastened to the rod (C).

(H) Baseplate.

(I) Slideway for slide (F).

(J) Recording paper, gummed to the baseplate (H).

(K) The weight for measuring the variations in the gap (L).

(L) Gap which discloses expansion and contraction movements as described in the Paper.

The movements of the casting were recorded by the pencil on the paper. When the pencil moves away from the mould an expansion is recorded, and when towards the mould contraction. Since the pencil must traverse a section of the pencilled line more than once, however, because of the expansion and contraction phenomena, the changes could only be detected by the density of the pencilled line, along with the attention paid by the person recording the times of the changes on the paper on which a measuring scale was drawn. An example of a record so obtained is shown in Fig. B.

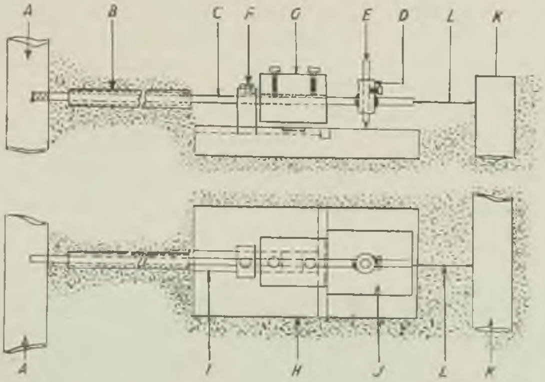


FIG. A.—METHOD OF OBTAINING ADDITIONAL AUTOMATIC RECORD OF MOVEMENT OF CASTING.

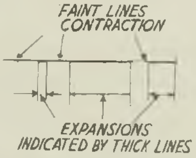


FIG. B.—EXAMPLE OF RECORD USING METHOD SHOWN IN FIG. A.

The method outlined was used on several occasions to check the general method of following the volume changes, as explained in the Paper.

There is no doubt that clockwork mechanism could be devised to record the movements automatically, although the period over which a large casting cools is of long duration; but, whatever mechanism is employed, the records would be no more reliable than those obtained in the simple and, perhaps, empirical manner explained in the Paper and in these notes.

PAPERS PRESENTED TO BRANCHES

Scottish Branch **Paper No. 713**

Design in Relationship to Contraction and Distortion*

By E. LONGDEN, A.M.I.Mech.E. (Member)

It is not intended to enlarge greatly on the associated phenomena surrounding contraction of metal and its effects on distortion and strength in castings generally, but briefly to refer to design as it affects a certain class of castings only within the ambient of this essay. Although the author has devoted considerable time to the study of distortion during the past 10 years, he is only just beginning to understand a little and realise that only the fringe of the subject has yet been explored by anyone connected with the scientific or practical aspects of the foundry.

New Thoughts on Design

Any consideration of design by a designer to help the foundrymen is fraught with some difficulty. There is much that can be done by

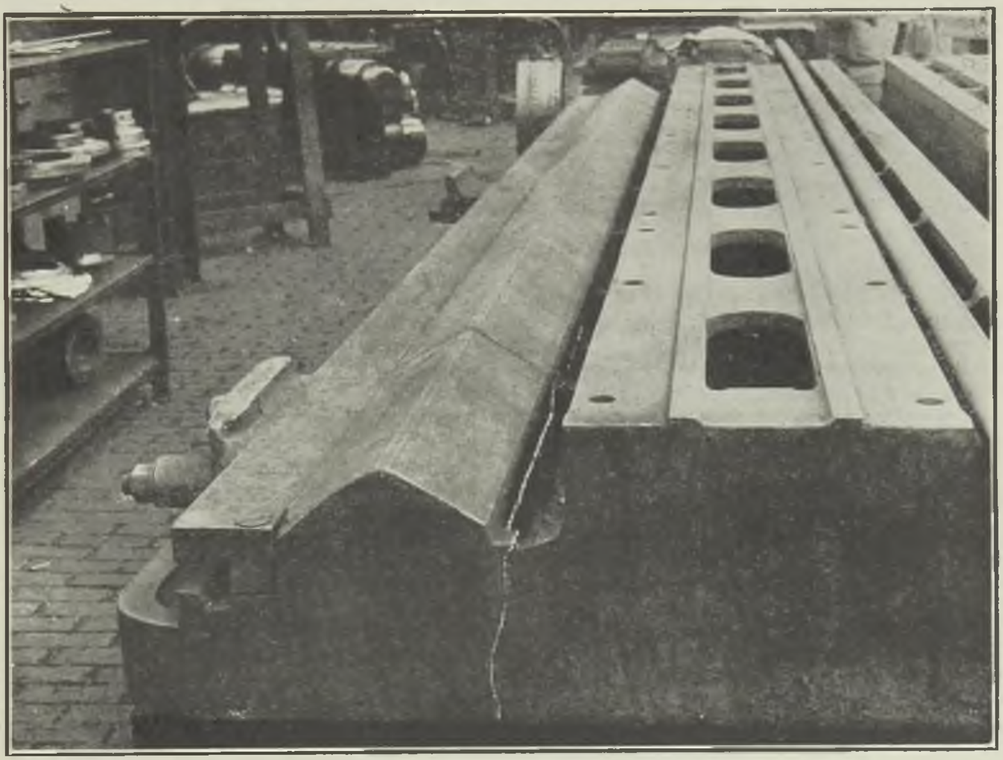


FIG. 1.—VERTICAL FRACTURE IN A PLANING MACHINE BED.

---

* This Paper, together with Paper No. 714 (p. 99 present volume) were presented to the Scottish Branch during the Session 1937–38. Following the preparation of the Author's Conference Paper (No. 712) and that which he presented to the Lancashire Branch during the 1939–40 session (No. 715), it was thought that the inclusion of all these Papers in the same volume would be of interest. It is also for this reason that Papers Nos. 713, 714 and 715 have been placed adjacent and not published amongst the other Papers presented to the Branches for which these were prepared.—EDITOR.

rational co-operation between the designer and the foundry through the medium of the patternshop to eradicate many obvious errors of design. In this connection, tribute must be paid to designers in general. They are always ready to change a shape or re-design a section to suit the metallurgical and manufacturing difficulties of the foundry. Within their knowledge they often anticipate foundry difficulties. Without " whitewashing " the designer, it is emphasised that if foundry manufacture was covered by mechanical operations as in engineering, executives would have fewer hazards and responsibilities in the foundry. The more the experience of the modern machinist and fitter, the better the appreciation of the designer.

Can one always state clearly to the designer what one needs to secure the best results in a casting? Founders are all familiar with the parrot-cry of " the design is not uniform." A uniform design is not the solution to foundry difficulties in relationship to fluid shrinkage, contraction and distortion, because one cannot secure a uniform cooling rate in a mould. External parts of a casting will cool before the inner parts for the same section of metal. The admission of metal to any particular part of a mould will create differing temperature gradients and cooling rates, although the same section may exist all over the mould. Nor can the designer help much in overcoming the resistance met by the contracting metal on enclosed cores and its effects on contraction and distortion.

One could design and make a casting which would conform to a safe cooling rate, but would this design suit the duty of the machine? Of course not, in most cases. However, one must impress on designers two fundamental rules:—(1) *Wherever permissible, allow thicker sections on the outer body of a casting than on the inner sections;* and (2) *avoid changing a section abruptly.*

Fig. 1 shows the two halves of a heavy-duty planing machine table weighing about 35 tons, which failed in service due to distortion and fracture because of faulty design or ill-usage, or both. The table, by the way, had not been made by the author's company, but they were commissioned to replace the table.

Fig. 2 illustrates how each half-table fractured during service. The upper half-table shows that the fracture extends longitudinally for about half the length of the casting along and below the vee box-shaped slide-way. The slide-way is also fractured across the section. The other half-table is fractured longitudinally below the slide-way for approximately 95 per cent. of the total length of the casting. In addition to the fractures, the castings had distorted considerably. The centre joint of the two castings showed that distortion had taken place sideways to the extent of being $\frac{11}{64}$ in., full in the vertical middle—when together, $\frac{11}{64}$ in. feelers could be placed in the gaps between the joint at each end of the table. Each half-table was also hollow across the centre on the heavy tee-slotted side shown face downwards in Fig. 2.

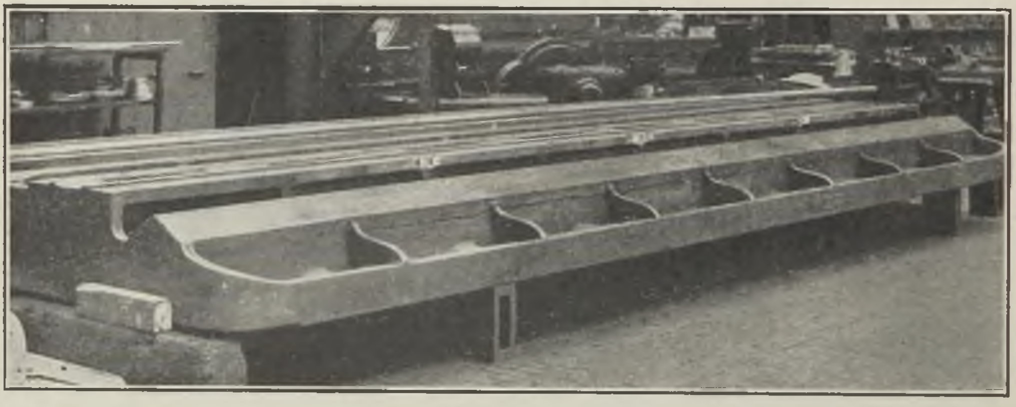


Fig. 2.—Extensive Horizontal Fracture in a Planing Machine Bed.

Why large iron castings of this class fracture in the way they do can be largely explained by reference to charts which have been prepared showing the behaviour of a bedplate and simple bars during cooling. It would appear from an examination of the fractured tables that during cooling the thinner box section forming the slide-way would cool much earlier than the very heavy reverse face of the table. The contraction of the upper slide-ways and sections would be taking place against resistance offered by the

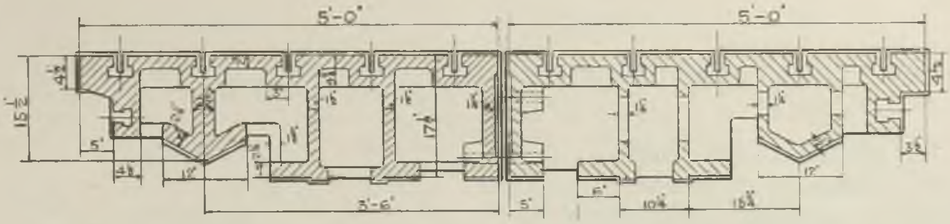


FIG. 3.—(LEFT) NEW AND IMPROVED DESIGN AND (RIGHT) DESIGN OF THE PLANING MACHINE BED WHICH FRACTURED.

much slower cooled bottom surface of the casting. Thus in the early stages the upper surface would undergo extensional stress whilst in a milder way the lower surface would undergo compressional stress. On final cooling the heavy bottom section on taking up its shorter length will now place the top in extensional stress again by an upward or bending moment. During contraction the ends move downwards so that the stresses set up are dual and conflicting. Again at an early period the top suffers extensional stress whilst the bottom is affected in return by a mild compressional stress; later the top is subjected to a further extensional stress by bending or bulging and the bottom to extensional and bending stress.

The fracture in the half-table shown in Fig. 2 is open $\frac{5}{16}$ in. in the centre, which indicates that the lower heavier face has thrust the top upwards, thus extending the face. To accommodate itself the slide-way must either break across or part from the lower face metal by ripping under the slide-way longitudinally, and bending to take up a shorter length.

Fig. 3 shows a cross-sectional sketch of the old and new design to overcome somewhat the troubles outlined. The right-hand half of the drawing shows the old and faulty design, and the left-hand side the improved design.

The light box-shaped design for the slide-way was abandoned for the heavy arrow-head shaped design on the left. The extra metal introduced

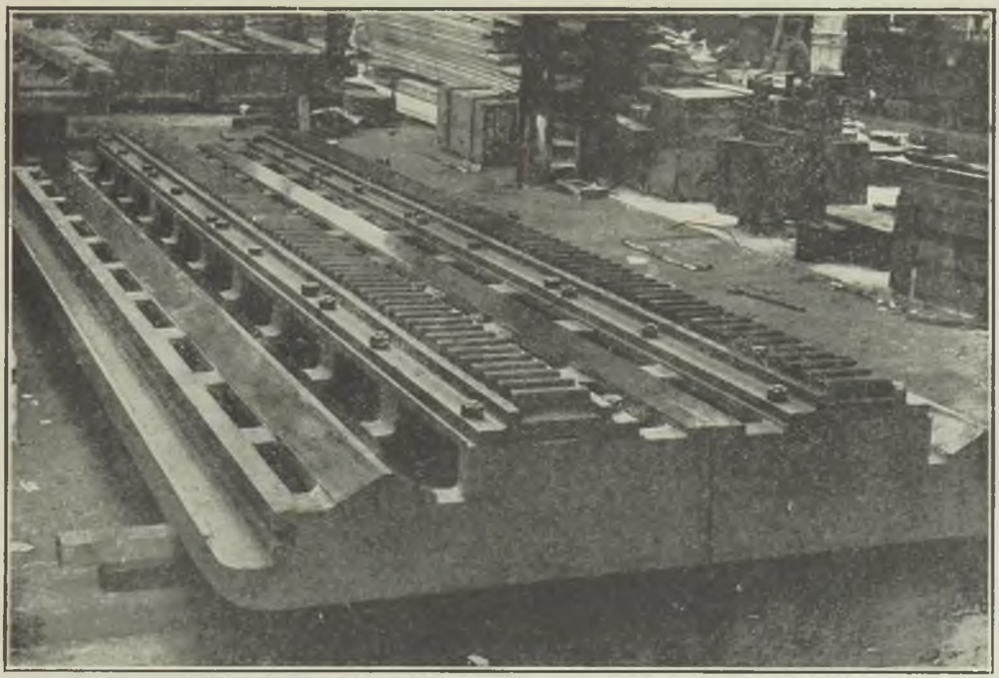


FIG. 4.—REDESIGNED PLANING MACHINE BED.

into the upper slide-ways and inner vertical walls was counterbalanced by a reduction in the metal forming the opposite face of the table. Fig. 4 shows the newly-designed and assembled table ready for despatch.

CONTRACTION TESTS

Simple Bar Castings

Contraction phenomena encountered in castings holding contrasting sections disclose in the type of casting investigated by the author that the thicker sections contract more than the thinner sections. So far as cast iron is concerned, this is quite contrary to the known behaviour of the metal, that the thinner the section, the finer and closer is the structure, consequently the greater the contraction.

Referring to Fig. 5, which is a test casting holding varying sections held together in the form of a grid, contraction takes place as exaggerated in the Sketch *d*. If the bars are separated from association as a grid or frame, contraction takes place as normally understood; the thinner the bar, the greater the contraction.

The graphs of Figs. 6 and 7 shows the cooling behaviour of three bars 1 in., 2 in., and 4 in. in thickness by 8 in. in depth and 32 ft. in length. The bars were poured at the same time as the 32-ft. long bedplate described in the graph, Fig. 8, from metal of the following composition:—Total carbon, 3.22; silicon, 1.48; manganese, 0.83; sulphur, 0.11; and phosphorus, 0.79 per cent.

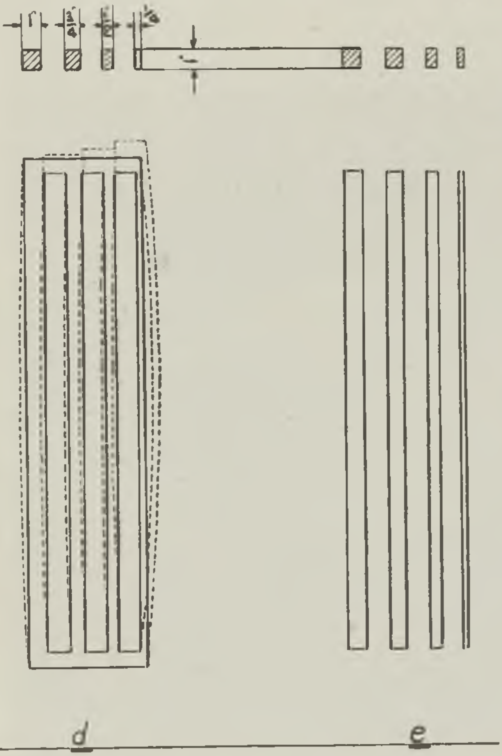


Fig. 5.—Test Grids for Ascertaining the Effect of Contraction.

Test Results

These tests are typical of a number taken by the author on the contraction and distortion in large castings of the bedplate design. The evidence amply confirms the phenomena noted in the small grid test casting.

[For details of the test procedure see Paper No. 712, p. 82 of the present volume.—Editor.]

Fig. 6 shows the early cooling behaviour of the simple bar castings. In 12 minutes the 1-in. bar, A, has taken up its maximum expansion at 106 thousandths. Zero is reached in about 23 minutes. At about 43 minutes when contraction equals 560 thousandths. a secondary expansion takes place which lasts for 15 minutes. Afterwards contraction proceeds steadily.

The 2-in. bar, B, reaches the maximum expansion of 130 thousandths in 17 minutes, returning to zero in 35 minutes. A secondary expansion is noted after 80 minutes when 540 thousandths contraction has been reached. A further and third expansion is indicated at 145 minutes when 1,125 thousandths contraction had taken place. This expansion remained very steady for 70 minutes.

The 4-in. bar C reached a maximum expansion of 268 thousandths in 50 minutes and reached zero in 117 minutes. A secondary expansion was noted in 180 minutes. This expansion took about 65 minutes to return to the original contraction point. The graph of Fig. 7 expresses in hours the complete behaviour of the three simple bars. It will be noted that the 1-in. bar A has taken up its total contraction of 4,248 thousandths in about 86 hours, which is 248 thousandths more than the theoretical standard. Similarly, the 2-in. bar, B, takes up its total contraction of 4,204 thousandths in about 120 hours. Contraction is 204 thousandths above standard. The 4-in. bar, C, takes 148 hours to reach a final contraction of 4,050 thousandths.

It will be seen that between the thinnest and thickest bar there is a difference of 198 thousandths, confirming the greater contraction of the thinner sections as against the thicker sections when poured separately. The percentage of contraction over standard is as follows:—1-in. bar, 6.25 per cent.; 2-in. bar, 5 per cent.; and 4-in. bar, 1.25 per cent. When it is remembered that the metal is of the moderately close-grained class, the results are also in conformity with the greater contraction of the close-grained iron against the softer variety. Metal of 2 per cent. silicon would correspond more with the standard contraction.

Bedplate

The graph of Fig. 8 expresses in minutes the nine hours cooling behaviour of a bedplate, also 32 ft. in length. The curve D gives the average contraction on the top side of the casting as poured, and curve E the average contraction of the bottom heavy side of the casting carrying the shears or slide-ways. It will be remembered that eight rods are employed to test a bed, four at each corner of the ends—two at the top and two at the bottom at each end.

Several beds tested which carry heavy facings along one side of the casting show a different rate of contraction on each side, both top and bottom, as well as the difference between the top light section and the bottom heavy section. The behaviour of contraction in such cases is expressed by four curves, and reveals some extraordinary stresses and crises during cooling. This Paper would be of too great a length if it included the whole of the tests.

The design of the bed under consideration was uniform sideways; therefore, as revealed by the contraction figures, it was only necessary to produce two curves, one for the bottom contraction and one for the top contraction. The curve D shows that the top area of the bed had expanded 276 thousandths in 30 minutes, and had reached zero in 122 minutes. The bottom heavy area of the bed had expanded 438 thousandths in 35 minutes, and reached zero in 188 minutes.

The graph, Fig. 9, expresses the cooling curves in hours. No clear indication of secondary expansions can be noted. Yet, if the minutes curves be examined, one can detect arrests in the curves which may be caused by expansions. The conflicting pulls in a large bed will undoubtedly mask somewhat expansions, since one part of the bed will be expanding when another area is beginning to contract. In tests on very heavy beds the secondary expansions are almost as clearly defined as on the simple bars previously outlined.

Returning to the graph showing curves in

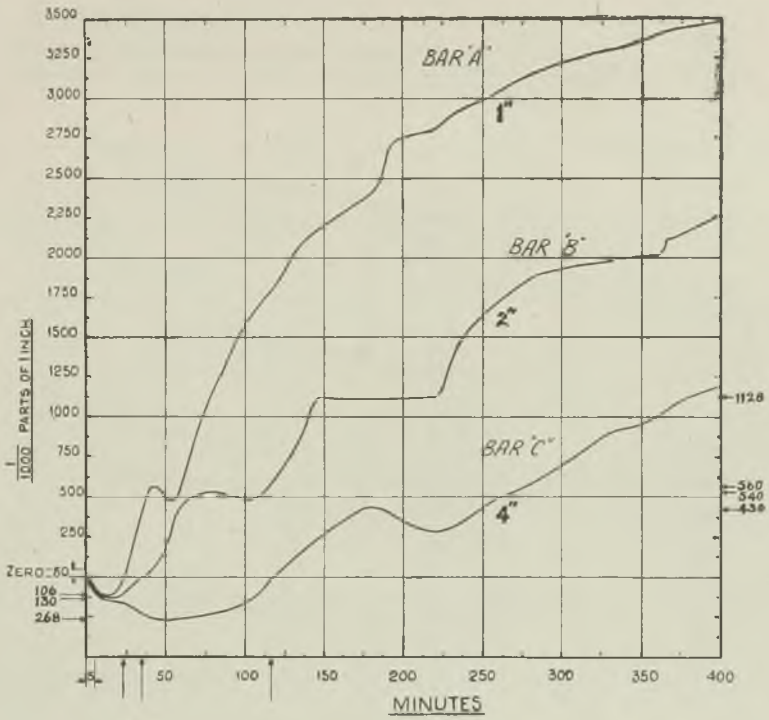


FIG. 6.—GRAPH OF THERMAL HISTORY OF SIMPLE BAR CASTINGS OF INCREASING SECTION, EARLY STAGES.

hours, it will be noted that contraction is fairly regular until at 53 hours the contraction on the top and bottom areas of the casting is equal. At this point the curve E—bottom heavy side of the casting—crosses the curve D, from which point the contraction of the bottom E begins to exceed that of the top D. Undoubtedly, it is at this stage that the severe stress and bending begins to function.

The critical period of 53 hours marks the period after which any aids in relieving the casting will be of little use. In the 53 hours, the bedplate has completed nearly 75 per cent. of its total contraction. From this point the contraction of the bottom area E steadily increases its lead over that of the top area D. In 190 hours the top area had ceased to contract and the bottom in 220 hours.

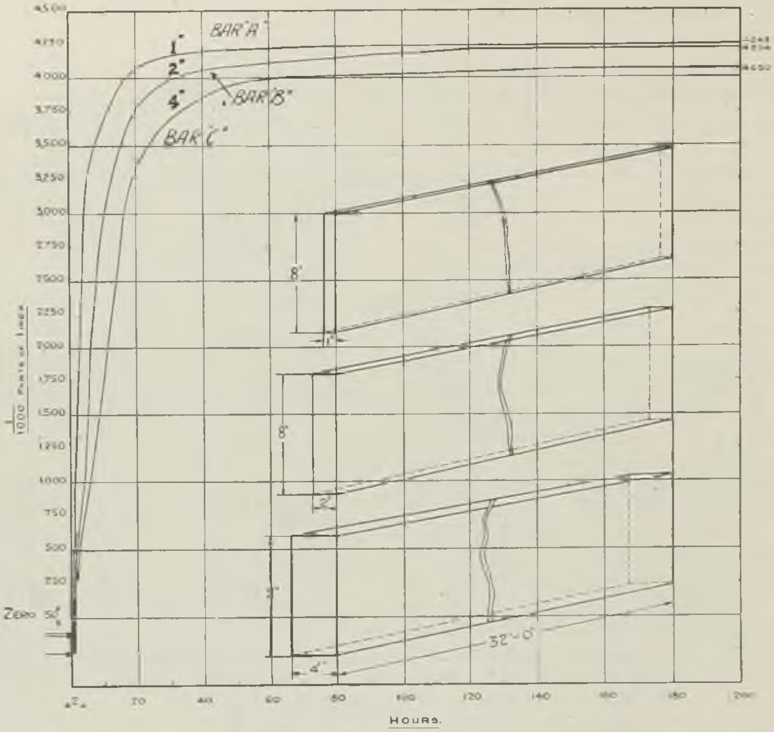


Fig. 7.—Thermal History of Simple Bar Castings, Extended to Embrace Over Eight Days.

The total contraction of the top is 3,550 thousandths or 88.86 per cent. of theoretical standard. The total contraction of the bottom is 3,746 or 93.65 per cent. of standard.

Finally, on the total contraction an allowance must be made for the difference in length that a curved line will give when straightened out. The bed on straightening from the camber given will account for approximately 30 thousandths extension of the bed. The amended figures will then read 3,520 for the top area or 88 per cent. of standard, and 3,716 for the bottom area or 93.06 per cent. of standard.

A further amendment is needed in all the curves expressed in the graphs for the extension of the testing rods, due to expansion by heat, and which is included in the total figure of expansion below the zero line. This extension of the rods will slightly affect the times stated in the curves, diminishing and disappearing as final cooling is reached. The final contraction is correctly stated as between the measurements before pouring the casting when everything is cool and after contracting when all is cool.

Tests were made by placing rods of the size as used in the major tests between fixed points on a machined table and setting the inside micrometers to a gap formed at the end of the rod. The difference between the gap with the cold rod and after heating to a similar temperature as obtains in the various sections of casting dealt with gives the number of thousandth parts of one inch to be deducted from the first expansion figures.

The amended figures will approximate to:—

For the 1-in. bar, A, Fig. 6, first expansion, 106 less 30 thousandths equals 76 thousandths net expansion.

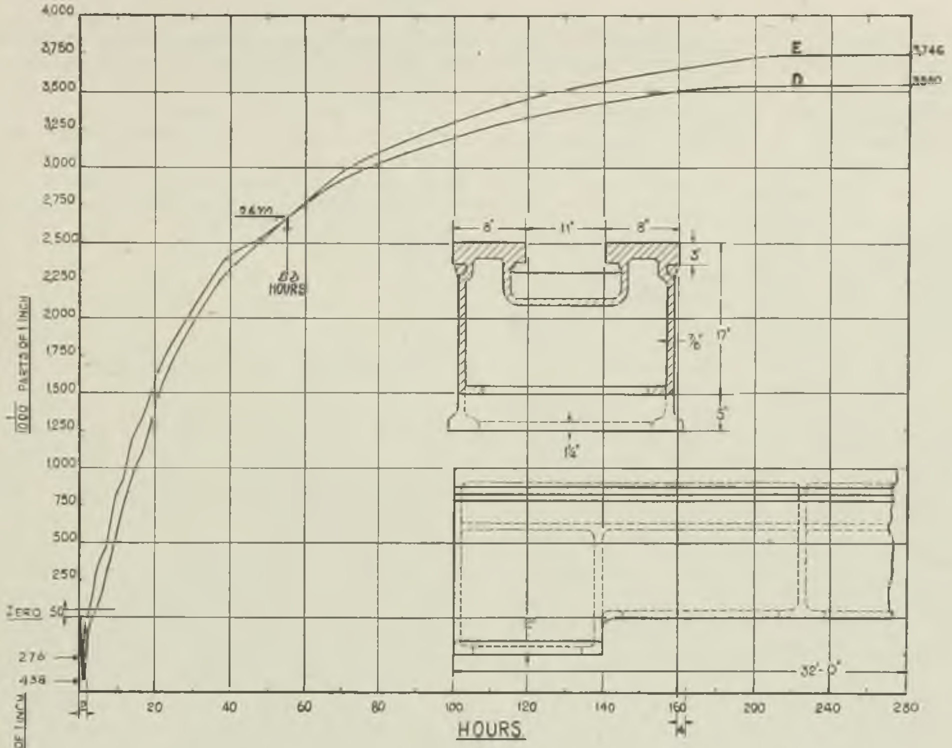
For the 2-in. bar, B, first expansion 130 less 45 thousandths equals 85 thousandths net expansion.

For the 4-in. bar, C, first expansion 268 less 120 thousandths equals 148 thousandths net expansion.

Referring to the bedplate the amended figures for the first expansion will approximate to:—

For the top area, D, first expansion 276 less 124 equals 152 thousandths net expansion.

For the bottom area, E, first expansion 438 less 266 equals 172 thousandths net expansion.



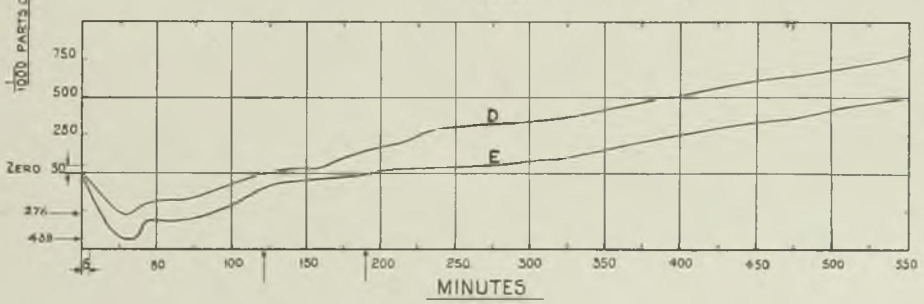


FIG. 8 (LOWER GRAPH).—BEHAVIOUR OF THE UPPER AND LOWER SECTIONS OF A 32-FT. LONG BEDPLATE.

FIG. 9 (UPPER GRAPH).—EXTENDED TIME RECORD WITH THE CROSSING OF THE LINES AFTER TWO DAYS.

Vital Comparisons

BEDPLATE—	Thousandths.
Bottom area, E, contraction	3,716
Top area, D, contraction	3,520
Extra bottom contraction over top	196, or $\frac{1}{5}$ in.
THREE BARS—	
1-in. bar A, contraction	4,248
2-in. bar B, contraction	4,204
4-in. bar C, contraction	4,050
Extra contraction on 2-in. bar over 4-in. bar	154
Extra contraction on 1-in. bar over 4-in. bar	198 or $\frac{1}{5}$ in.

In the bedplate the thick sectioned area contracts more than the thinner sectioned area, which is quite opposite to the contraction on the simple bars where the contraction of the thinner bars exceeds the contraction of the thicker bars.

	Thousandths.
The average contraction of the three bars equals	4,167
The average contraction of the bedplate equals	3,618
The average difference between bars and bed	549

These results show clearly how the contraction of large castings is influenced by design. In bedplates one learns that the conflicting expansions and contractions due to the varying sections length and its relationship to the mould frictional-resistance and the resistance set up by cores cause considerable stress and strain, so much so that the castings do not contract as much as a simple unhindered casting. The difference is contraction between the simple casting and the complicated casting is quite $\frac{1}{2}$ in. It is easy to understand from this why castings distort or even fracture.

Scottish Branch **Paper No. 714**

Cast Iron for Large Castings*

By E. LONGDEN, A.M.I.Mech.E. (Member)

The qualities required in metal for different types of large castings vary greatly; analyses are given in Table I:—

Table I.—*Analysis of Metal for Large Castings.*

	T.C.	Si.	Mn.	P.	S	Ni.
17-ton caustic pot ..	3.40	1.00	0.75	0.30	0.08	1.0
21-ton spindle casting ..	3.10	0.85	0.40	0.60	0.13	—
20-ton hydraulic cylinder ..	3.15	0.90	1.00	0.35	0.10	—
32-ton 94-in. lathe headstock	3.20	1.40	0.65	0.65	0.09	—
50-ton hammer anvil block	3.25	1.20	0.65	0.55	0.09	—

Generally, the use of alloying elements to improve the qualities of cast iron is growing. The improvements sought may be all or any of the following:—(1) Increase in strength; (2) soundness with uniformity of structure; (3) resistance to various thermal conditions promoting growth and disintegration of the metal; and (4) resistance to wear or corrosive conditions.

There are sound reasons for employing special metals to improve the flowing power of the metal and the service life of special classes of castings which enter the category of small and small medium weights. But for large and medium-weight castings, the incorporation of expensive metals in the cast iron is, to put it mildly, both unnecessary and extravagant.

Apart from the special-purpose metals containing large quantities of the expensive alloying or modifying elements, the alloy additions vary usually between 0.25 and 2.0 per cent. In such small percentages the added metals do not confer directly, to any serious extent, special properties on the cast iron. The substantial effects of alloying elements are indirect through their influence, mainly, on the conditions of the carbon and carbides, either as graphitisers or carbon stabilisers, and on the freezing rate of the metal. All these conditions can be also influenced considerably by the freezing rate of the metal, due to the section and mass of metal and the condition of the mould material.

Structural Control

The object of the author's attention has been to secure a defined structure in a particular class of casting. It may not always be possible to secure the desired structure and properties in small and medium lightweight castings, due to the rate of freezing preventing the reduction of the carbon and graphitisers to the effective percentages. In such cases the employment of modifying elements brings about the desired results. But with general heavy, medium and large castings, the thermal conditions are equally favourable to the production of the desired structure simply through the control of the elements normally present in the cast iron. The slower casting rate in heavy castings tends to level up heat gradients. The hot-mould process for the production of pearlitic cast iron may be cited as a case of control of the structure of cast iron through the normal elements present in cast iron and thermal conditions of the mould.

The metal specification for a large caustic pot which the author considered includes 1 per cent. of nickel introduced as a graphitiser in preference to about 0.3 per cent. of silicon. Although this specification was met, the author is unconvinced of the need to employ nickel in a casting carrying a uniform section of approximately 3 in. The structure desired in caustic pots is one which will not be too dense to withstand thermal conditions of expansion and contraction due to the firing on the outside of the casting, and yet be uniform in structure so as to resist the corrosive influence of the caustic fluids.

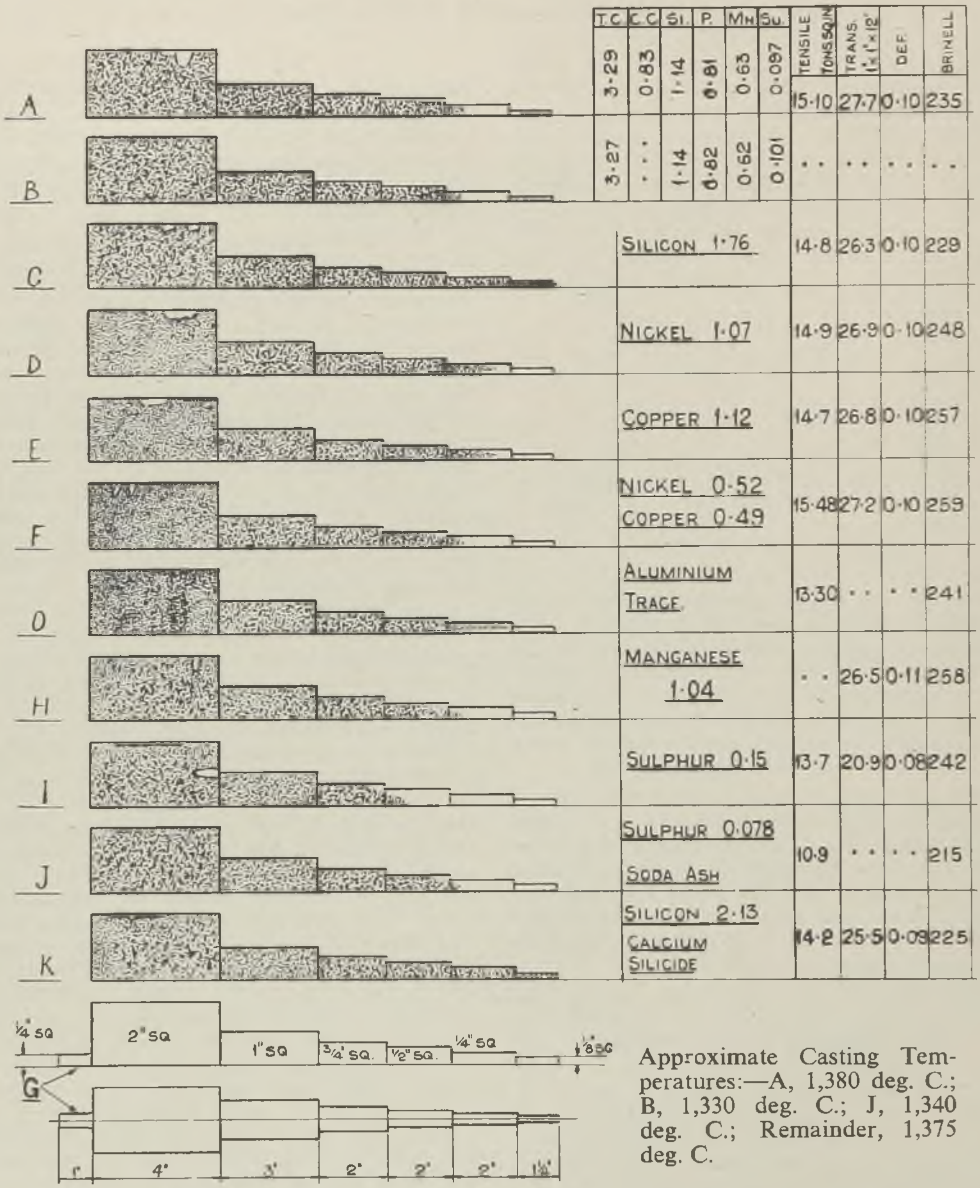
It is the author's experience to expect little trouble from fluid shrinkage in metal of the hematite class, or with metal containing over 3.30 per cent. total carbon and phosphorus below 0.3 per cent. The analysis for the caustic pot altered by raising the silicon by 0.25 to 1.25 per cent. and omitting the nickel would be equally effective in producing the desired structure.

---

* See footnote to Paper No. 713.

Many years ago it was the practice to pour such pots in No. 2 hematite iron, because of the need to withstand thermal shocks. At the same time, the maximum life was not obtained so far as resistance to the caustic solution is concerned, because of the open grain structure common to hematite irons containing silicon above 1.50 per cent. The remedy lay in reducing the silicon content to about 1.20 per cent. and the total carbon to about 3.20 per cent. along with more exact control in the operations of heating up the pot in service.

Of far more importance than one or two points in silicon or carbon is the question of pouring metal into a mould in such a way as to avoid the collection of sullage at any particular



	T.C.	C.C.	Si.	P.	Mn	Su.	Tensile Tons sq. in.	Trans. (1"×1"×12")	Def.	Brinell
A	3·29	0·83	1·14	0·81	0·63	0·097	15·10	27·7	0·10	235
B	3·27	· · ·	1·14	0·82	0·62	0·101	· ·	· ·	· ·	· ·
C	Silicon 1·76						14·8	26·3	0·10	229
D	Nickel 1·07						14·9	26·9	0·10	248
E	Copper 1·12						14·7	26·8	0·10	257
F	Nickel 0·52 Copper 0·49						15·48	27·2	0·10	259
0	Aluminium Trace.						13·30	· ·	· ·	241
H	Manganese 1·04						· ·	26·5	0·11	258
I	Sulphur 0·15						13·7	20·9	0·08	242
J	Sulphur 0·078 Soda Ash						10·9	· ·	· ·	215
K	Silicon 2·13 Calcium Silicide						14·2	25·5	0·09	225

Approximate Casting Temperatures:—A, 1,380 deg. C.; B, 1,330 deg. C.; J, 1,340 deg. C.; Remainder, 1,375 deg. C.

FIG. 1.—INFLUENCE OF COMPOSITION AND PROCESSES ON THE PHYSICAL PROPERTIES OF VARIOUS TYPES OF CAST IRON.

point as previously stated. In many pots examined it was quite obvious that sullage porosity and not fluid shrinkage porosity was the direct cause of early failure due to penetration by the corrosive solution.

Influence of Elements on Structure

Fig. 1 is interesting in connection with the effects of adding special metals and metalloids to cast iron. This investigation was carried out by the author some three years ago. It is extremely difficult to compare the effects of various alloying elements. Usually investigation proceeds in stages whereby the effects of perhaps one or two elements on a base cast iron are tested at any one time. The many variables which might affect the true comparative results may be present on the occasion of next and successive tests.

The investigation had for its object the testing of the influence of various added metals and metalloids on the structure of cast iron. A step casting designed as shown in Fig. 1 proves a very suitable example to work on, disclosing as it does so clearly the effects of the added elements on the structure and soundness. Tensile and transverse test-bars were poured at the same time as the step casting. All the test castings were poured from the same melt of cast iron, the analysis of which is stated in the table included in Fig. 1.

Reduction of Variables

In order further to eliminate as many variables as possible, the step castings were moulded in the centre of a square core box, using black sand and dried so as to avoid any longitudinal joint flash and its influence on freezing rate. The whole of the test moulds were made from the same batch of sand and rammed as near as possible to the same density. After ramming the step pattern was withdrawn endways in the direction of the heavy end, and through the side of the box. The mould just accommodated the full length of the pattern, so that the ends were exposed. The large end was closed by a flat core carrying a standard-sized in-gate of ¼ in. square section, as shown at G, Fig. 1, to which was linked a down-gate and pouring basin. The small end was closed by a core, except for a very fine outlet gate or vent to allow air to evacuate from the mould, thereby ensuring that the metal was not impeded in filling the small ends of the mould by gas pressure. The moulds were just warm when poured.

With a view to holding and controlling the temperature of the molten base cast iron, crucible melting was resorted to. Two sets of tests were poured without any additions. The desire was to introduce 1 per cent. of the metals, nickel, copper, copper-nickel and manganese, and sufficient aluminium (1 oz. per 10 lbs.) to influence graphitisation. It was hoped to raise silicon in one test by the addition of ferro-silicon to about 1.50 per cent. and again further raise silicon in another test to about 2 per cent. by the addition of calcium silicide. The remaining two tests consisted of sulphur reduction by the use of soda ash, and sulphur increase by the introduction of flowers of sulphur.

All the intended additions were weighed and heated in readiness for when the molten cast iron was taken from the furnace. A number of refractory-lined and heated hand-ladles were prepared and marked on the lining to indicate the amount of base metal to be poured therein.

With everything ready, the metal was taken from the furnace, tested for temperature, and measured quantities of molten cast iron were poured into the several hand shanks, into which had been placed the heated alloying elements. One ladle contained no added material. The moulds were then poured together, with the exception of the soda-ash treated metal, which required most time for reactions to complete, and one of the two sets of tests without alloying elements. This last test was deliberately poured at a much lower temperature than the rest. The soda-ash treated metal would also be poured at some 20 deg. lower than the other tests poured at the same time.

The chart (Fig. 1) indicates, in the test A and B, the structure and properties obtained from the metal without any additions of modifiers. B was poured at 50 deg. lower temperature from the remains of the metal after the various test moulds had been cast. The analysis of the test-bar B varies a little from that of A. The following is a summary of the results of the experiments:—

A shows that graphitisation had penetrated about 30 per cent. down the ¼-in. section.

B indicates a slightly lower carbon precipitation penetrating about 20 per cent. of the ¼-in. section.

C with the silicon addition turned out completely grey throughout all sections.

D carrying the nickel addition created graphitisation down to approximately 70 per cent. of the ¼-in. section.

E with the copper content is remarkably similar to *D*. It will be noted that the copper content is a little higher at 1.12 per cent. as against 1.07 per cent. in the case of the nickel test.

F test reveals a new phase. With nickel and copper a hardening of the metal has taken place. Graphitisation is less than in the tests without additions, showing that somehow nickel and copper together in the same alloy have acted as a mild carbon stabiliser and not as graphitisers when employed separately.

O, which includes aluminium, shows that a core of graphite penetrates nearly the full length of the ¼-in. section.

H, with manganese at 1.04 per cent., indicates that graphite precipitation is reduced. White iron had penetrated the ½-in. section by about 10 per cent.

I test clearly shows the hardening effect of the increased sulphur content. White iron had penetrated the ¾-in. section.

J is soda-ash treated, producing a lowered sulphur content, and shows that white iron had slightly penetrated the ½-in. section, indicating that softening effect of the lowered sulphur had been more than offset by the lowering of the silicon to 1.08 per cent., 0.06 per cent. being eliminated during desulphurisation.

K test with the calcium silicide addition produced a silicon content of 2.13 per cent., resulting in graphitisation throughout the step section. Furthermore, a $\frac{1}{16}$-in. section gas-relief riser gate leading from the ⅛-in. section end was also grey.

The table of Fig. 1, showing the physical and mechanical test results, confirms the state of the structure of the various examples, with the exception of the soda-ash treated metal J. It is difficult to understand why the hardness value and tensile test results are so low in J. The Brinell hardness test was taken on a ⅛-in. depth machined surface located on the centre side of the 2-in. section.

Paper No. 715

Some Notes on Liquid Shrinkage and Contraction*

By E. LONGDEN, A.M.I.Mech.E. (Member)

What is really inferred by soundness in castings? Soundness can only be defined to mean that a casting is perfectly acceptable for the duty it must perform and contains no defect which can be described as unsoundness in its particular category. There appears no other "yardstick," since soundness covers so many phases in a casting. The degrees of soundness necessary for a particular type of casting may mean unconditional rejection in another class or type of casting.

A street gully or a balance weight which is poured with the most common of metals at indifferent temperatures, and under the most elementary of moulding conditions, is considered sound if the exterior shape be correct. The vast majority of such castings would be considered unsound if the surfaces were machined, which would reveal defects otherwise hidden from view. On the other hand, an open-grained structure in the slideways of a machine-tool bedplate, or the bore of a steam or internal-combustion cylinder, may be considered porous and thereby unsound for the particular casting.

Again, the general open-grain structure of an ingot mould is considered very necessary, and in such a casting a mark of soundness, because the cast iron must be capable of responding to thermal shocks of repeated heating and then comparatively sharp cooling.

The prevailing and commercial view of soundness embraces superficial or deep-seated defects revealed, or shown up, by some form of test as blowholes, porosity or sponginess, cavities and cracks. If a casting cracks in service, whether due to design or foundry practice, then it is considered that the stresses have not been so far controlled and taken care of during manufacture, and that the casting has, therefore, been unsound.

Test-Bar and Casting

It is a well-accepted opinion that soundness cannot be measured by the performance of test-bars. Is there a responsible and mature foundryman who has not at some time obtained a splendid yield on a test-bar, then to find his casting fail on test after machining? At another time a test-bar has failed to meet the specification, but the casting represented by the bar has turned out to be an obviously, and, by other tests, a very high-class casting in every respect and quite sound.

Generally speaking, it is thought necessary that it is of far greater importance for a casting to be sound than to possess a defect in some part and a high degree of strength in the good sections.

Constitution of Metals

The constitution of a particular metal or alloy must be understood to obtain satisfactory results. The quality and soundness of a casting are profoundly influenced by the manufacturing methods employed. The sensitivity of the metal to the gating and feeder heads and the character of the mould materials is very considerable. Liquid shrinkage and contraction and distortion are influenced in varying degrees by design.

With rare exceptions, metals employed for castings are not pure but are mixtures of metals and elements of a semi-metallic nature, and dissolved and semi-dissolved gases. The constituents of the metal will possess different characteristics and different solidification points during the cooling of the metal. Whilst there are general similarities in the changes which take place during the cooling down of all metals from fluid to solid and to normal temperature, changes vary in degree and intensity according to the type of alloy. Therefore, an understanding of the process of solidification and solid cooling rate is of primary importance. The changes which take place are both chemical and physical, the changes taking place at a critical temperature, according to the alloy contents—metals and impurities. The behaviour of crystallisation in an alloy or impure mixture of metals will be considerably modified by the varying solidification points, crystal growth, gas content, and shrinkage of the differing constituents forming the alloy.

Other changes, also, take place in metals after

---

* Presented to a joint meeting of the Lancashire Branch and the Manchester Association of Engineers. See footnote to Paper 713.

solidification by segregation and diffusion of the constituents in the structure of the solid metal. Slow cooling favours the maximum segregation, or diffusion, and quick cooling the minimum change. Heat-treatment of metals is based on these alterations in the structure in the solid state. The malleablising and softening of hard or white cast iron, and the tempering and hardening of steels and non-ferrous alloys, such as aluminium and gunmetal, may be referred to in this connection.

On solidification, metals will change in volume. With one or two exceptions, such as with bismuth and cast iron under certain conditions, which expand on solidification, metal shrinks.

After solidification, the general body of the casting reduces in volume until room temperature is reached. This solid reduction in volume or contraction, as with freezing rate, may be accelerated or retarded by mould influences and pouring temperatures. Since the density of the metal can be much influenced by freezing rate, these influences are of primary importance. The more rapidly the metal solidifies and cools to below its particular critical temperature ranges, the greater the density of the metal or alloy.

Steel and most non-ferrous alloys have a high liquid shrinkage, which may vary from about 8 per cent. in an aluminium bronze or steel to about 5 per cent. in a common brass; bismuth stands out as a clear exception, with a slight expansion on freezing. One can well imagine that in a high phosphor bronze (0.25 per cent. P) poured under average sand-mould conditions, voids will be present up to perhaps 4 or 5 per cent. of the mass of the casting.

Balancing Action of Cast Iron

Cast iron which solidifies to produce a grey fracture will have its liquid shrinkage reduced by the precipitation and growth of graphite, the amount of shrinkage varying with the amount and size of the graphite particles. The amount of fluid shrinkage in normal sand-moulding practice amounts to from about 1.0 per cent. in a very soft hematite iron to 2.5 per cent. in a close-grained cylinder class of iron.

If a steel or aluminium-bronze freezes with a shrinkage of the order of 8 per cent., this means that each solid crystal occupies only 92 per cent. of the volume of the liquid from which it was formed. Therefore, density and soundness of metal are markedly influenced by the freezing range as determined by the composition, pouring temperature, temperature and condition of the mould material, sections and mass of the casting. Consequently, close study is made as to correct pouring temperature. With bronzes and aluminium the temperature is usually controlled by pyrometer readings, correlating the known cooling range of the particular alloy with the mass section of the casting to be produced.

The shrinkage propensities of a metal or alloy will command consideration of the sensible disposition of runner and riser, gates and feeder heads. With quick-freezing metals the most successful combination of temperature control and feeding headers will be shown by a rapid sinking of the metal in the heads a few seconds after pouring.

It may not always be possible to locate feed headers so that liquid metal will reach a heavy section cut off by an intervening thinner section, or a section which by virtue of its location will remain fluid longer than similar sections having quicker cooling outside areas. In such cases a metal or a material of high heat-conductivity may be inserted in the mould or core opposite the areas which are late to freeze normally. This artifice is termed "densening." The use of densening on non-ferrous alloys or steel does not function so effectively as with grey cast iron, which holds large quantities of graphite carbon. The judicious application of denseners to heavy sections or hot locations of any class of metal, however, will facilitate a rapid passage of such sections from liquid to solid, the quota of shrinkage metal being drawn from the areas which solidify later and which have more immediate contact with suitably disposed feeder heads. The general effect of densening a casting is to speed up the freezing of the entire casting, thereby creating the desired shortest freezing range with its great influence on soundness and grain size.

Gases

Gases are absorbed during the smelting, melting and refining of metals, the absorption increasing with a rise in temperature, and there is a tendency for such gases to be occluded on cooling. The extent to which gases are occluded or retained by the metal provides serious study if the maximum success and sound castings are to be obtained.

Molten steel dissolves large quantities of gas, which at the higher temperatures may exceed in value several times that of the cold steel. The steelmaking process being one of oxidation, deoxidation and refinement, will tend to retain hydrogen, carbon monoxide and nitrogen, the amount retained by the metal being dependent upon the degree of refinement reached or desired in a particular class of steel.

Cast iron may hold a similar range of gases as steel, but the volume held by the metal at any stage will be considerably less than steel, due to the presence in the metal of efficient deoxidisers and degasifiers, such as silicon, manganese and phosphorus.

The amount of gases absorbed by non-ferrous alloys is considerable, certain metals and alloys being very sensitive to oxide and gas absorption. The gases absorbed are hydrogen, oxygen, carbon monoxide, sulphur dioxide and nitrogen, and perhaps other combinations of gases.

The amount of gas absorbed and occluded will be modified by the melting practice, pouring temperature and nature of the alloy. A very slow cooling rate will favour the liberation of the maximum amount of gas, but will create generally large crystals in the metal. An intermediate cooling rate will be conducive to the metal occluding gas which cannot liberate itself from the solidifying metal, and may result in general porosity, cavity and blowholes. In aluminium, this stage is characterised by the appearance of numerous pinholes throughout the metal section. A rapid freezing rate allows little time for gases to become liberated. With gases held firmly in solution, very sound castings are produced.

Gates and Feeder Heads

It is usual, when considering gating and feeding castings, particularly in connection with non-ferrous castings, to combine the two functions at one point, so that hot feeding is ensured. This is quite good practice with certain types of castings. It is, however, not always advisable and is less practicable in most types of large castings. If the feeding point happens to coincide with the best delivery gate point, then there is the best combination so far as feeding is concerned. Yet there is to consider, side by side with such a decision, the effect of local over-heating of the mould and the slow cooling encouraged and supported by the additional metal at the delivery entrance gate and feeder-head areas.

It has been thought necessary to avoid introducing metal into a mould in more than one stream. With this point of view the author cannot agree as always being the best way to introduce metal into a mould. There are undoubtedly certain types of castings which lend themselves to being poured at one single point of entry.

Gates to provide the admittance of metal to moulds must be arranged of suitable dimensions and located with a view to the freezing range of the metal and its influence on fluidity and the elimination of very hot zones where the metal enters the mould.

Liquid or fluid shrinkage of certain non-ferrous alloys and steel will range between 5 and 8 per cent., depending upon the nature of the alloy. Consequently, to provide for this shrinkage from 20 to 50 per cent. of additional fluid metal is needed in the form of chubby and large reservoirs or headers. So much metal above the amount needed to supply shrinkage is required, because the headers must be maintained in a fluid state until the casting is fed solid. Several methods of reducing the amount of head metal have been tried. Various compounds which produce exothermic reactions, thereby prolonging the fluidity of the headers, have been tried with limited success. For steel, heat generated by electricity (by electric arc struck between electrode and the metal) in the header has had reasonable success. Phosphor copper introduced into feed headers will prolong fluid feeding periods.

Fluid shrinkage feed gates are arranged on the upper parts of the mould disposed over heavy sections, or where the metal will remain fluid until the casting is set generally. It is not always practicable adequately to feed a complicated casting with fluid metal. Heavy sections may be cut off from all possibility of being supplied with fluid shrinkage feed. In such cases, if the design cannot be altered by lightening, then metal inserts may be employed.

Relief riser gates are located at various points of a mould to reduce the pressure of gas generated and present in the mould, so that the metal will not be impeded in filling the most remote, complicated, or thinnest sections. The riser gate is also useful in relieving fluid-metal and gas pressures, on the upward lift of the mould at the moment of complete filling, thereby reducing the danger from metal escaping from the mould, and, perhaps, spoiling the casting.

Metallostatic Pressure

Pressure of the fluid head of metal has a very profound effect on soundness in all metals. The greater the height of the head of the runner or riser gates, the greater the possibility of soundness in castings. Whilst the pressure of the head of metal has little or no direct effect on closing and refining the crystal structure of metal, the influence on soundness is due to the elimination of gases and gas pressure inside the mould and cores. The head pressure forces gases to evacuate from the mould cavity through riser gates, or pass through the natural and artificial vents provided in the mould and cores. This evacuation takes place before the metal has solidified in the runner, riser or feeder gate connections and heads, so that metal feeds forward to take the place of the spaces occupied by gases. The late evacuation of gases from moulds and cores is a greater cause of unsoundness than has yet been recognised by the average foundry authorities. If gases are slow to evacuate from a mould, the natural feed from the gates may be impossible, due to prior freezing of the metal. Finally, when the gas has evacuated, certain areas of metal will exhibit either distinct depressions on the face of the casting, or will show porosity after machining or tests by air and water pressure. If founders will pay attention to this phase of moulding practice, they will be agreeably surprised at the improvement wrought by the combined effect of ample head pressure in conjunction with generous gas outlets in moulds and cores.

Densening and Chilling of Metal

The rate of solidification and subsequent cooling rate of metals have considerable influence on the general properties of an alloy. The solidification and cooling rates are determined by the following factors:—(1) Composition of the metal; (2) melting temperature, latent heat and super-heating; (3) pouring temperature; and (4) influence of mould materials.

The mould influences depend upon the heat-conductivity, strength, rigidity, and gas-forming properties of the material composing the mould. Generally, the greater the density of the mould material, the greater the heat-conductivity, rigidity and freedom from gas-forming elements.

Sand composing a mould is a poor conductor of heat. The voids around sand grains are probably 15 and 25 per cent. of the bulk of the sand. The voids are filled with air or other gas. The thermal conductivity of gas is much lower than the silica and other materials composing the sand. Sand facing the metal and for some distance back from the face of the mould may lose as much as 15 per cent. of weight when subjected to molten metal temperature due to gasification of organic matter and dehydration of the iron oxide and clay bond, etc. This means that the rigidity of the walls of the mould is being steadily reduced, and its density being lowered as the metal is freezing. A restricted evacuation of gas from the mould cavity, especially when the mould contains intricate cores, will retard the settling of the metal in a mould.

The various influences, namely, composition of the sand, its rigidity, density, heat-conductivity and the rate at which gas is evacuated from the mould, affect all metals to a degree depending upon the inherent properties of the metal.

Directional Control of Graphite Growth

Grey cast iron is the metal which is most affected by mould influences. This metal holds appreciable quantities of graphite which is formed during the solidification and cooling of the metal. The precipitation of carbon from carbide to form graphite means an expansion. On the solidification of the first layer of metal, cast iron, therefore, will tend to distend its shell if the mould material will allow it to do so, in addition to an expansion towards the still molten interior of the metal section. Pressure will progressively continue to be exerted on the unsolidified interior of the metal by the progressive growth of graphite and the pressure of the contracting solidified exteriors of the casting. These forces reduce the apparent liquid shrinkage experienced in grey cast iron compared with other metals.

The amount of resistance to outward expansion of the first solidified layers of cast iron depends upon the rigidity and the force set up by the contracting shell of the casting, the speed of which is determined by thermal conductivity of the metal. It is proved by the experiments to be outlined that the degree of soundness in a grey iron casting increases with an increase in the thermal conductivity and rigidity of the mould, and also with the freedom from or the rate of evacuation of gases formed in a mould.

DENSENERS AND CHILLS

Chills are often employed with most metals to help to equalise the rate of cooling between heavy and light sections, hot locations induced by junctures of metal, or enclosed portions of a mould, or core, and denseners are used generally to close the grain of all classes of alloys used for castings, in addition to eliminating local porosity and cavity.

Steel

Steel chills are used when making steel castings to aid in balancing the rate of cooling between thick and thin sections and to allow progressive liquid shrinkage from feed headers to eliminate porosity, cavity, and also local fractures and hot-tears from irregular contraction. The application of chills to steel must be exercised with caution since such a device may, whilst removing a cause of a certain type of defect, introduce another one. To prevent hot-tears it is necessary carefully to study the sections of the casting and the chill to be used, so that the chilling action be not too severe; otherwise the sudden contraction of a comparatively thin section of steel, especially if attached to a thick section, may cause a crack. Chills should vary in cooling effect to suit the circumstances. Very light chills, or silicon-carbide blocks, well covered with refractory and soundly located in the face of the mould, so that the edges of the chill cannot be gripped by the contrasting steel casting, can be recommended.

Non-Ferrous Alloys

Chilling is practised in certain classes of non-ferrous alloys, such as aluminium and manganese-bronze alloy castings. Chills are located on heavy sections of metal which do not immediately communicate with a feeder head, the rate of cooling being such that the necessary liquid shrinkage is met by the thinner section which cools more slowly than the heavy chilled section. The thin section is fed in turn by the metal in the feeder gates. Chills are applied in a much lesser degree to other grades of non-ferrous metals. The wearing surfaces of heavy high-tin phosphor-bronze castings, such as bearings, are often densened by the application of cast-iron or copper chills. Large quantities of round and variously sectioned bars and strips are regularly made in metal (chill) moulds in many alloys, especially the phosphor-bronze series.

Cast Iron

The application of chills to white-iron castings for malleablising may be practised as for steel. Chills used for grey iron castings could be more correctly termed "denseners," because the device is not only applied to eliminate local shrinkage defects, but also to increase the density of wearing and sliding surfaces.

CONTRACTION AND DISTORTION

The amount of contraction and degree of distortion in the various classes of ferrous and non-ferrous alloys will have relationship particularly to the physical properties of the alloys, but also to other conditions, including:—(1) The class of alloy; (2) melting and pouring temperature and super-heat of the metal; (3) design, section and volume in comparison with its section; (4) size, shape, location and distribution of runner and riser gates; (5) character of the mould and core materials and their conditions when the metal is poured into the mould; and (6) the method of moulding and core-making.

Wherever a casting encloses cores or portions of a mould, or carries varying sections, or mass, and is a composite unit, the standard contractions will not be quite in line with established standards. In such cases the amount of contraction will be less than the standard laid down for any particular class of alloy. Under the conditions, stress and distortion occurs. If distortion is not obvious, it can be readily understood that stresses are present in the casting. This strained condition of the metal structure is taken care of in most steel castings by suitable heat-treatment, either during the cooling down of the casting or subsequent to the primary cooling-down phase. Many classes of aluminium and malleable-iron castings receive heat-treatment during or after the cooling down of the casting from the pouring temperature. There is also a number of types of grey iron castings which may be subjected to heat-treatment to relieve stresses. Additionally, consideration is given to the method of moulding, so that enclosed portions of the mould or cores will offer the least resistance to the contraction of the metal.

When all conditions have been understood, it will be necessary to modify standards, and to make allowances in the construction of a pattern or in the mould, so that distortion may be counteracted. Such allowances may be in the form of dimensional accommodations, or by suitable bonds or contours—camber—which, being a reverse to the natural contraction tendency of the metal, will produce castings which are of correct shape.

At the conclusion of his lecture the author exhibited a considerable number of lantern slides showing many old and new photographs and drawings to illustrate the views put forward in the Paper.

DISCUSSION

A vote of thanks was heartily accorded to the author, on the proposition of Mr. L. Massey, of the Manchester Association of Engineers, seconded by Mr. A. Phillips.

Denseners and Porosity Movement

Mr. F. Dunleavy reiterated the query, What was soundness? He understood that soundness depended upon the opinion of the customer; it must be perfectly sound from his point of view. If this were so, why apply denseners? From the point of view of the machine shop, inspectors, foundries, and even the customers, it could not be a perfect casting because denseners were applied to drive away porosity, or drive it further into the castings where the customers or anyone else could not see it.

It was generally agreed that the gas in aluminium was present when the metal was in the molten state, and it was the period of solidification which determined whether it would go out of or remain in solution. A definite pouring temperature was nebulous unless associated with a standardised method of ingates and risers.

He agreed with Mr. Longden's views on risers. Many foundrymen had the impression that if they added a 1-in. riser on to the top of a casting, disregarding the shape and the point it was intended to feed, the casting would either pull on the risers or the risers at the casting. Moreover, they assumed that such a riser would take away dirt. He asked for the lecturer's views, his own being that such an action was no better than by casting in open sand.

Gunmetal Test-Bars

Mr. A. Hopwood said he had known of trouble arising through the use of test-bars for the inspection of ordinary gunmetal. There was not merely trouble in meeting tests, but also in having to remelt the castings. An endeavour was made to place the position upon what might be termed a basis under which 100 per cent. good test-bars could be obtained. The first consideration was why test-bars varied in regard to strength and elongation, those being the two particular criteria by which they were judged. In one particular case they were cast in green sand, and so poured that there could be no doubt as to inadequate feeding. There was a question in the case of gunmetal, however, of an oxidised surface skin which was liable to be formed in the casting of an upright test-bar. An attempt was made to establish a method of running which would ensure sullage and skin being washed off the bar, through modification of the introduction of the metal to the mould. An improvement was shown, but still it was not quite satisfactory, as occasional faulty bars still occurred.

The next procedure was to try to eliminate any occurrence of hot spots and sullage. A heavy riser was carried up the full length of the bar, which led to a distinct improvement; but there was a hot spot along the length of the bar due to slow cooling from the still hot risers. Finally, a chill was used to form the test-bar. There was then a quick cooling of the actual bar itself, and the sullage was carried away into the head, and there was a slight annealing back due to the large head of the heavy casting. It was thus possible to obtain 24 tons tensile with a reasonably controlled casting temperature, associated with an elongation of 50 per cent., whereas 35 per cent. was formerly obtained.

Use of Contraction Rule

Mr. E. White said it was his experience that in various special alloys a dry-sand core did naturally retard contraction; but was Mr. Longden familiar with any particular case, because in making a pattern it was naturally necessary for very important points, such as centres, to be taken into account? If one was making a particular job with a special alloy, and had to depart from the ordinary standard contraction rule, it would upset the job considerably, because there were so many points where thicknesses and the design of the pattern would be materially affected. Had Mr. Longden experience of any particular alloy in regard to which he had noticed an appreciable difference in contraction?

Mr. R. S. Turner asked for further information concerning the coatings for chills and their life.

Views on Soundness

Mr. A. Phillips, touching upon Mr. Dunleavy's remarks, said that what were thought to be sound castings in 1929 might not be so regarded in 1939, if they now had to be X-rayed. Porosity was being overcome by the use of chills. He asked for greater consideration be given to the subject of taper by all concerned.

With regard to solidity and soundness in castings, Mr. Longden had not fully enlarged upon the difference in regard to alloys. For instance, it was stated that chills were used on cast iron in order to give a close grain structure of the graphite. Chills were put on aluminium alloys and manganese-bronze alloys in order to prevent cavities and not to give a close-grained structure. A material where there was carbon in solution would give a different structure if a densener was used. In that particular case, there would be a solid casting with an absence of porosity; but in the case of other alloys a chill had to be put on in order to prevent the formation of a cavity. What was the chief difference between a chill in cast iron and a chill in non-ferrous metals?

Mr. Dunleavy said that the point with regard to general cast irons was that porosity was being driven away from the face. Mr. Longden had shown illustrations of instances which to all intents and purposes were sound and passed the special test, but still it was not a perfectly sound casting.

Mr. Turner again referred to the subject of denseners on test-bars. Some buyers insisted on having test-bars actually cast on the casting. There was no option but to cool such test-bars quickly so as to counteract the annealing effect of the heavy casting.

Head Pressure and Porosity

Mr. A. Jackson referred to the phenomenon of head pressure on castings reducing the porosity. Foundrymen had considered this to be the case for a number of years, but if he was not mistaken, Mr. Longden had put the matter in another way in considering the question of air getting away from the mould. The air in a mould must, of course, be evacuated during the time occupied in casting. With the greater head pressure, Mr. Longden said that the air would get away quickly from the mould; consequently there would be less air in the casting and there would be sounder casting. This seemed to be rather unusual. With regard to the question of freeing the mould from air more rapidly, he asked if Mr. Longden had heard of any provision for drawing the air out of a mould by means of a vacuum process.

Wearing Surfaces and Chilling

Mr. R. A. Jones said he would like to know whether the lecturer had actual records of better wearing surfaces on machine-tool castings by chilling? Personally, he did not think that there would be a better wearing surface. He had seen a planing machine which had worked for 20 years day and night, and there was hardly any wear showing.

Green-Sand Moulding Practice

Mr. Turner, referring to the chilling effect of green-sand moulds, and the benefit obtainable therefrom, said it was natural to assume that a damp sand did actually conduct heat away quicker than dry sand. Nevertheless, it must be realised that castings varied in weight from an ounce to tons. The effect of this, coupled, of course, with the type of castings, the surface area and the ferro-static pressure which could be imposed on the mould surface, had a very great bearing on the soundness of the casting. It was a matter for speculation sometimes as to which was the cheaper process—the green sand to obtain production and less handling of plant, or to produce a mould which would withstand the pressure of the molten metal and obtain a casting of predetermined dimensions. It must be remembered that any easing of the mould in any individual application, particularly in non-ferrous work, was dangerous. Whenever there was any question of thickness of skin, coupled with low casting temperatures, his view was that it was essential to have a good sound mould, whether it be obtained by means of green sand or dry sand in one's own particular foundry practice. Personally, he did not think it possible to get a perfectly sound mould in green sand.

Pitted Inspection Covers

Mr. F. A. Harper illustrated an inspection cover of the ordinary type, but which had to be galvanised and well finished. It was stiffened with a cross-section on the back. The fault which developed in the top section was a pitting. He invited Mr. Longden's opinion upon the point.

Mr. Vickers (Manchester Association of Engineers) thought that with the boring-bar casting which had been shown on the screen, and which was stated to be 47 ft. in length and 18 tons in weight, the best method was to mould it horizontally.

Mr. H. Haynes said that in describing the runners on a 22-ton casting which had been illustrated, the lecturer said he had tried to run it as quickly as possible. He (the speaker) did not understand what was implied by the term "as quickly as possible." He would also like to be informed as to what method the lecturer adopted with regard to the cooling of a casting weighing about 10 tons. How long did he leave it in the mould before stripping? A third query concerned heads of liners or cylinders. Did Mr. Longden believe that the success with liners or cylinders would be better achieved with the head pointing inwards?

AUTHOR'S REPLY

Mr. Longden very much appreciated the discussion. Actually the lecture finished rather abruptly, he said, because he had not time to deal with the points on contraction and distortion, and would therefore take advantage of Mr. White's questions to say just a little more on those subjects. There was definitely a considerable difference in the contraction of large castings, as, say, a heavy hammer block or a headstock carrying a great mass of cores, compared with a large, thin open plate. An open plate would definitely conform to standard allowances; but in regard to the massive castings, such as a hammer block, there was a swelling action on the mould and massive graphite growth in regard to which the patternmaker ought to work in conjunction with the foundry staff, and understand that the casting would gain due to such influences. Again, a headstock had a complicated mass of cores, which would retard the contraction of the various members of the casting; consequently, there would be less contraction than was allowed for according to standard.

Mr. Longden illustrated this point by displaying screen illustrations of new experiments.

Gas in Light Alloy Castings

In reply to Mr. Dunleavy, Mr. Longden said that the gas control in aluminium alloys depended on many factors. In any case gas would still be present in the solidified metal, but its amount and distribution would depend upon the composition of the alloy, the mass of the casting, and the rate of pouring, etc., all influencing the freezing rate. In the case of aluminium there had been practised what is termed the pre-solidification process, whereby the metal, after melting down in the crucible of the furnace, was allowed to cool down slowly to solid again with a view to eliminating gas from the metal. After this the metal was quickly melted again, and promptly poured at a correct temperature. There was thus a time factor, under suitable temperature conditions, which allowed much gas loosely held in solution to escape. The most modern practice endeavoured to avoid gassing as much as possible. The newer aluminium-silicon alloys did not cause so much gas trouble.

So far as Mr. Hopwood's comments on gunmetal test-bars were concerned, if a test-bar was chilled in a restricted metal mould and sufficient head metal added above the mould, there would be returned sufficient heat to anneal the test-bar which had the effect of lifting the test yield.

Denseners and Sound Castings

Returning to the comments by Mr. Dunleavy, Mr. Longden expressed surprise at such remarks after the information given with respect to soundness, especially with densening cast iron. As stated in the lecture, there was no yardstick by which soundness could be measured, since the qualities required in one class of casting might be a mark of unsoundness in another class. The type of soundness demanded would depend upon requirements. Mr. Dunleavy laboured under a good deal of misunderstanding when he stated that castings were not sound when denseners were used. Actually the test castings were sound from every point of view. With a progressive application of denseners it was seen that porosity and cavity disappeared; it was not pushed to some point where it could not be seen, because the castings were sectioned and exposed throughout the middle sections. The green-sand test casting (with feed headers as in the other comparative tests) was not sound. Finally, the castings made in densened moulds were produced sound.

An ordinary sand mould, especially a green-sand mould, was weak, and the expansion which occurred with the precipitation of graphite, in the case of grey iron, at the point of solidification, tended to press back the mould face. A densened mould resisted the expansion somewhat—and this would be in reply to Mr. Jackson also.

Factors in Expansion

There were three factors to be considered: *The strength of the mould* which would resist shell expansion and allow such expansion to be directed more as a compressive force on the unsolidified interior of the metal. Again, *the high rate of heat conductivity* of the mould material would give a quickly solidified shell which would also contribute to a resistance to shell expansion. The effect of gases, particularly in the case of moulds holding complicated cores, was that there occurred a rapid evolution of gases. Whilst sand was porous it did not allow gases to evacuate as quickly as was desirable. If the metal was of sufficiently high temperature, gas had time to escape, and it was aided by fluid head pressure. It had often been noticed when the riser basin had been actually displaced, and the head pressure released, that the metal was seen to flutter and even blow quite clearly, due to gas passing through the metal, which might for the time being be the easiest path for the gas. If a metal was dull and sluggish, gases, which might be late in passing through the vents, were prevented from passing out through the riser gates; consequently much gas might be trapped in the metal section. If riser gates froze early there would be no fluid metal to feed back into the mould cavity to replace gases vacated too late.

Wearing Surfaces

In reply to Mr. Jones, the lecturer stated that a harder surface could be obtained on undensened grey iron by employing a suitably strong close-grained iron. Such an iron did not obviate porous places opposite junctures of section, and there were contraction fracture dangers with very hard irons in long, bed-types of castings. The great feature of densening was that the treated surface was uniformly hard and free from porous and cavity patches, and the Brinell hardness figure was very satisfactory on the class of castings on which denseners were usually widely used. The metal for the densened metal was necessarily softer than a straight iron, otherwise hard white iron would result. On the other hand, the heat given up to the chills was again available to soften the casting face by annealing.

Chills might be used hundreds of times. A blow might occur on the first occasion of use, just as a blow could occur with a chill after being used a hundred times. It was a question of protecting a densener by a refractory covering, or its location in the mould in respect to its section, and the ingate metal passing into the mould.

For heavy and medium castings, in order to protect the surface of the densener it was necessary to impart a refractory face to the densener. The refractory should not be gassy, otherwise it would flake off the metal of the densener. A good-quality blacking with a ganister water-bond could be recommended.

Stripping Times

Mr. Haynes had referred to the speed of pouring the 22-ton blowing engine casting and the time the casting was retained in the floor after casting. The time in the floor depended upon the section as well as on the size of the casting. The blowing-engine bed was retained in the floor for 10 days—a week to 10 days being a safe period. The rate of pouring depended upon the class of casting. If the casting covered a large open area of mould it was necessary to pour quickly to cover the surfaces early, otherwise scabbing of the mould surface would result.

Another type of mould, holding a large number of cores, might be poured comparatively slowly in order to allow gases to escape to the vents and outlet gates, but in this case the metal must be of a high temperature or fluid enough to fill the mould with a reserve of heat left in the metal. Heads on such castings as liners were accommodated better if extra metal was allowed on the core side, instead of on the outside, as was usual, and as shown in an illustration of a heavy 22-cwt. pump valve. Of course, the core might be too small to allow a thickening as suggested.

The example cited by Mr. Harper called for an alteration in the gating and running system, so that the seams, which were due to the meeting of two or more streams of oxidised and sullage-loaded metal, might be avoided. Spray-gates extended along one side of the casting and controlled pouring with very high-temperature metal would be helpful in removing the trouble.

Removal of Porosity and Cavity by Densening and Chilling

MR. LONGDEN, in further written comments, added the following statement:—

It is astonishing how fallacious statements can be repeated over a long period of years, because some prominent technician or text-book made or recorded the assertion.

During the lecture a series of illustrations were exhibited showing personal experiments on cast-iron test blocks carried out 20 years ago. These tests were shown to explain why the unusual course of having an exceptionally difficult casting made in a strong metal-faced mould was taken. Actually three cast-iron boring-bar castings of the following description were made :—One solid bar, 16 in. dia. by 43 ft., weight 11 tons; one solid bar, 18 in. dia. by 45 ft., weight 16 tons, and one cored bar, 22 in. dia. by 47 ft., weight 19 tons.

Denseners and Porosity Movement

After such evidence it was suggested that "The application of a densener or chill to eliminate cavity and porosity only pushed the defect to somewhere else in the casting." This statement is suspiciously like one made in 1920 after the findings of these experiments had been given. The lecturer never thought that it could persist and crop up again, after such a long period, during which cast iron has made metallurgical history, especially in connection with the control of graphite and total-carbon contents. Such assertions cannot be made if even the elementary principles of the constitution of cast metals is understood. All metals are influenced by cooling conditions in a similar manner, but in varying degrees, as follows:—

Solidification of cast metals is progressive. Freezing of the molten metal starts from the areas of the mould from which the heat conductivity is most rapid—the outside of the mould, or where, by virtue of its lighter section, a portion of the casting may solidify early. If a casting holds varying sections, with perhaps isolated lumps of metal so placed that normal fluid feed cannot reach such a section through an intervening thin section, what must be done? Resort is made, in all metals, to accelerating the rate of cooling of the section which would normally cool very slowly, and be unable to draw on fluid metal to take the place of shrinking metal, by the application of material of high conductivity to the heavy sections. Usually metal chillers are applied.

Progressive Solidification

In effect, it is necessary to arrange for (as nearly as possible) a progressive order of solidification. Therefore, thousands of perfectly sound castings are made daily, in all metals, which without resort to some method of accelerating local cooling of the metal could not possibly be made.

An acceleration of the speed of solidification of all cast metal will confer, on the metal, closer compactness of the crystal structure and reduced danger from porosity and cavity.

Grey cast iron is the most responsive of all metals to mould influences, because it holds a large quantity of carbon, much of which is precipitated from carbides, at the point of solidification, to form graphite, which involves expansion since graphite occupies a bigger volume than carbon in solution with the molten metal. The specific gravity of carbide is about 8.0, and graphite approximately 2.2.

The successful production of the large boring-bar castings is based on the previously ascertained results on the influence of mould materials in preventing, as far as possible, the expansive effect of graphite growth being lost to some extent, by a weak mould of low conductivity, which cannot effectively resist the first expansion of cast iron on solidifying.

Much fuller information of the above views was given in the course of the lecture. One can welcome helpful criticism when supported by similar demonstrable facts, as the lecturer has repeatedly put forward. If the experiments, and castings made, are repeated independently by critics, it is certain that the statements referred to will never be made again.

Principles of Foundry Management*

By A. J. SHORE (Member)

When establishing any commercial undertaking, the aim is to make a profit. The foundry is no exception. The percentage profit is the index of success of the venture.

One often hears the expression that "you can't run a works on paper." However true that may be, it is certain that the indicator which determines finally whether a business can run at all is a piece of paper—the balance sheet.

The rather obvious fact that the *raison-d'être* of a commercial undertaking is profit has been purposely stressed, because there is a chance that foundrymen, whether metallurgists, scientists or practical men, may get so involved in the problem on hand that they fail to appreciate its financial significance.

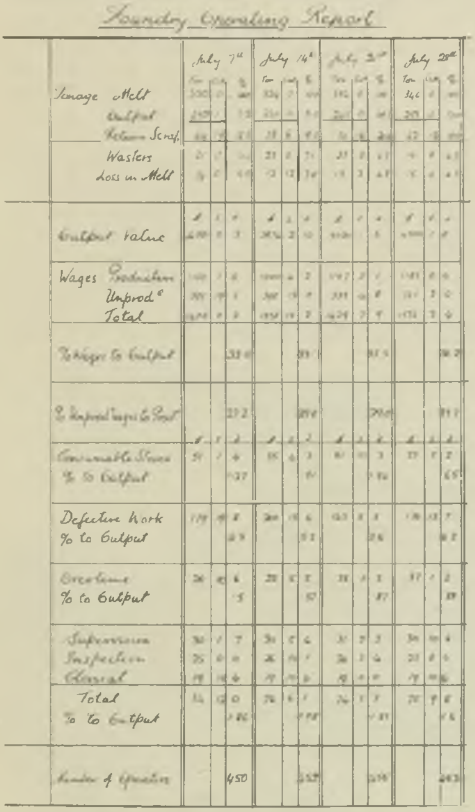


FIG. 1.—SUGGESTED TYPE OF OPERATING COST REPORT

Further, the author has suggested that the percentage profit is roughly the index of the success or efficiency of the venture because he wished to introduce the idea of indicators at an early stage. In fact, a better title perhaps would have been "Indicators as an aid to control," for indicators are a real aid to control and control is the essence of management.

Indicators

Consider this analogy: A well-equipped motorcar has a dashboard on which are mounted a number of meters or indicators. These meters indicate the car's performance and aid in its control. The test of a good car is the ease with which it can be controlled to meet the demands put upon it, and it is suggested this is also the test of an efficient foundry. There is no obvious dashboard in a foundry; nevertheless the elements of one should be in every foundry manager's office, if he intends to maintain effective control.

On a dashboard the more important meters indicate "rate," *i.e.*, a dimension compared with time, as the speedometer—miles travelled *per hour*; revolution-counter—revolutions of the engine *per minute*, and ammeter—quantity of electric flow *per second*, etc.

Other meters do not indicate rate, but still embody the idea of a ratio, for example, the oil pressure gauge which shows lbs. *per sq. in.* There is a third class which does not indicate a ratio at all, but rather a quantity or state, as the petrol gauge showing the available stock of petrol and the thermometer showing the temperature of the circulating water.

These indicators have their parallels in foundry practice and it is with some of them that it is proposed to deal.

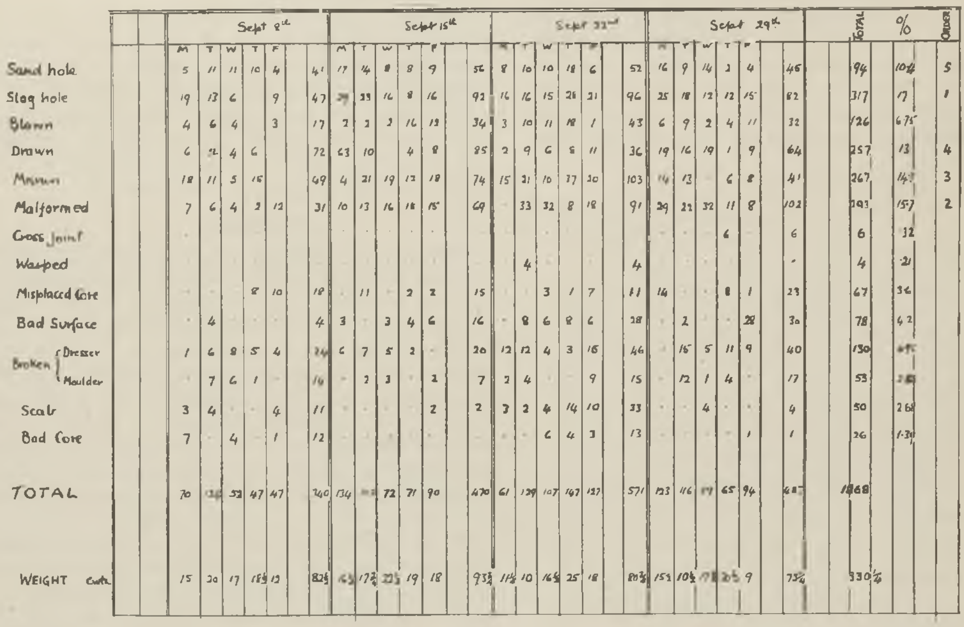
One important factor must be borne in mind when considering indicators; to be effective there must be a minimum of time lag between an occurrence and its indication. For instance, a speedometer which showed only what speed

---

* The author was awarded a Diploma for this paper.

a car was doing five minutes ago would be useless, and a petrol gauge still indicating a tank half-full, when it was in reality empty, would not be looked on with much favour. Likewise, considered from the point of view of control, the original example of an indicator, namely, percentage profit on a year's trading, is useless.

A Profit and Loss Account and a Balance Sheet taken together are capable of giving a true picture of the state of a business. They are usually got out at intervals of as long as a year, so the time lag between an occurrence and its inclusion in the balance sheet may be considerable. Valuable as these summaries are for determining general policy, they are practically useless as working indicators because of this time lag.



	Sept 8th						Sept 15th						Sept 22nd						Sept 29th						TOTAL	%	ORDER
	M	T	W	T	F		M	T	W	T	F		M	T	W	T	F		M	T	W	T	F				
Sand hole	5	11	11	10	4	41	17	14	8	8	9	56	8	10	10	18	6	52	16	9	14	2	4	46	194	10.4	5
Slag hole	19	13	6		9	47	29	23	16	8	16	92	16	16	15	26	21	96	25	18	12	12	15	82	317	17	1
Blown	4	6	4		3	17	2	2	2	16	12	34	3	10	11	18	1	43	6	9	2	4	11	32	126	6.75	
Drawn	6	[illegible]	4	6		72	63	10		4	8	85	2	9	6	8	11	36	19	16	19	1	9	64	257	13	4
Misrun	18	11	5	15		49	4	21	19	12	18	74	15	21	10	37	20	103	14	13		6	8	41	267	14.[illegible]	3
Malformed	7	6	4	2	12	31	10	13	16	18	15	69		33	32	8	18	91	29	22	32	11	8	102	293	15.7	2
Cross Joint																						6		6	6	.32	
Warped														4				4						-	4	.21	
Misplaced Core				8	10	18		11		2	2	15			3	1	7	11	14			8	1	23	67	3.6	
Bad Surface		4				4	3		3	4	6	16		8	6	8	6	28		2			28	30	78	4.2	
Broken Dresser	1	6	8	5	4	24	6	7	5	2		20	12	12	4	3	15	46		15	5	11	9	40	130	[illegible]	
Broken Moulder		7	6	1		14		2	3		2	7	2	4			9	15		12	1	4		17	53	[illegible]	
Scab	3	4			4	11					2	2	3	2	4	14	10	33			4			4	50	2.68	
Bad Core	7		4		1	12									6	4	3	13					1	1	26	1.39	
TOTAL	70	[illegible]	52	47	47	240	134	[illegible]	72	71	90	470	61	129	107	147	127	571	123	116	[illegible]	65	94	[illegible]	1868		
WEIGHT cwts.	15	20	17	18½	12	82½	[illegible]	17¾	20½	19	18	93¾	11½	10	16½	25	18	80¾	15½	10½	[illegible]	20½	9	73¼	330¼		

FIG. 2.—SUGGESTED WEEKLY WASTERS REPORT.

Most foundries have a record of their melt and output expressed in terms of weight. It will be recognised immediately that the mere statement of output without reference to time is valueless. Output is expressed invariably as so many tons per day, per week, or per month, as the case may be—it is, in fact, a rate.

At the outset, therefore, it is necessary to fix a period of reference; wages usually are paid by the week and a week is suggested as a convenient period for comparison for such items as output, melt, wages and materials consumed.

Weekly Cost Sheet

The first indicator then to set up is a "Weekly Cost Sheet" or "Operating Cost Report" (Fig. 1.) This is an example of its general layout, though in actual practice it would show much more detail and would be modified to suit any particular foundry's requirements. (The author's personal report has 50 items.) It will be noted that ratios are given prominence because it is on them that reliance is placed for detecting variations in the functioning of the foundry. Merely reporting figures on individual pieces of paper is insufficient.

It is essential that all relevant figures are assembled on one sheet of paper and that they are neatly arranged in columns. More important figures can be made to stand out either by the use of coloured ink or variation in spacing.

Just as one learns to tell the time by a glance at a clock, or maintain 30 m.p.h. in a built-up area, by noting almost unconsciously the position of the speedometer finger, so will one gain a comprehensive view of the foundry activities by a swift perusal of a well-laid-out report sheet.

Wasters Report

Another useful indicator is a "Wasters Report" (Fig. 2). The percentage wasters, back scrap and overmetal can be incorporated in the Weekly Report sheet, but percentage scrap is not much use in itself. If scrap is to be held at a minimum, causes must be known. The report illustrated is an actual one. It is considered to be sufficiently detailed to show, say, if the sand is giving trouble; if the men are getting careless; whether box pins are wearing, or if the metal is melted badly.

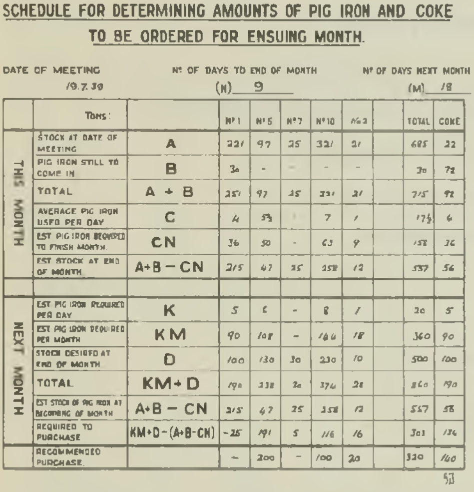
If recorded figures are to have any real significance, everyone who reports scrap must use the same terms to describe the same phenomenon. "Malformed," for instance, frequently heads the list because it is the sum of a number of things, *viz.*: parts missing, swell, holes cast solid, popped bar, hole and lump and joint flash. At first it also included "cross-joint," but later it was decided to make a separate class of "cross-joint." Cross-joint indicates plant inefficiency, whereas "Malformed" is mostly concerned with the moulder.

In the author's foundry every item of scrap over 2 cwt. is recorded separately under the following headings: Description, Weight, Moulders' Name, Order No., Date, Scrap Result, Cause, Remedy, Remarks.

The report is ordinarily kept in a drawer, but as soon as a casting is scrap the inspector notifies the foundry clerk, who takes the report out of the drawer and enters all particulars up to and including "Scrap Result," *i.e.*, what the job is, who made it, when, and why the inspector has rejected it. He then puts the report in the author's basket. Now as it is not ornamental, and associated with a dislike of "waiting attention" papers, this immediately induces action. The charge-hand is sent for and the cause discussed, often visiting the scene of the "crime" and determining on a remedy. This operation has purposely been detailed because of a desire to bring out a number of ideas:

(1) Indicators are useless if unused, so they must be readily available, or, better still, attention should be drawn to them when they have anything fresh to show.

(2) Reliance must not be placed on having to go and look for information—let it be brought to the executive automatically.



SCHEDULE FOR DETERMINING AMOUNTS OF PIG IRON AND COKE
TO BE ORDERED FOR ENSUING MONTH.

DATE OF MEETING 19.7.30
Nº OF DAYS TO END OF MONTH (N) 9
Nº OF DAYS NEXT MONTH (M) 18

	TONS:		Nº 1	Nº 5	Nº 7	Nº 10	Nº 2		TOTAL	COKE
THIS MONTH	STOCK AT DATE OF MEETING	A	221	97	25	321	21		685	22
	PIG IRON STILL TO COME IN	B	30	-	-	-	-		30	72
	TOTAL	A + B	251	97	25	321	21		715	92
	AVERAGE PIG IRON USED PER DAY	C	4	5½		7	1		17½	4
	EST PIG IRON REQUIRED TO FINISH MONTH.	CN	36	50	-	63	9		158	36
	EST STOCK AT END OF MONTH	A+B − CN	215	47	25	258	12		557	56
NEXT MONTH	EST PIG IRON REQUIRED PER DAY	K	5	6	-	8	1		20	5
	EST PIG IRON REQUIRED PER MONTH	KM	90	108	-	144	18		360	90
	STOCK DESIRED AT END OF MONTH	D	100	130	30	230	10		500	100
	TOTAL	KM + D	190	238	30	374	28		860	190
	EST STOCK OF PIG IRON AT BEGINNING OF MONTH	A+B − CN	215	47	25	258	12		557	58
	REQUIRED TO PURCHASE	KM+D−(A+B−CN)	−25	191	5	116	16		301	134
	RECOMMENDED PURCHASE.		−	200	−	100	20		320	140

53

FIG. 3.—SCHEDULE FOR CONTROLLING MONTHLY PURCHASES OF IRON AND COKE.

Stock Control

Nowadays, considerable interest is attached to the petrol gauge of a car. As mentioned before, this indicates *quantity* and not rate. The stock card takes its place in the foundry, and it is just as important to see that there is raw material in stock as there is petrol in the tank—"another truism," certainly—but how is one to know what quantity to put into stock?

Take the case of pig-iron. The buyer, the chief chemist, and the author used to meet once a month to decide on what iron was to be bought for the next month. Roughly, the chief chemist said what sort of iron was wanted. The author said how much was likely to be used, and the buyer considered how he could meet these requests with the smallest possible outlay of cash. Pencils would be pulled out, calculations made on odd bits of paper, figures compared, and only disagreement resulted. Now these meetings frequently lasted an hour, and it became apparent that though the present stock, how much iron was on order, and the daily consumption were known, there was still plenty to be done before a true estimate of how much to purchase could be determined. The "Schedule" shown in Fig. 3 was accordingly devised. It freed the mind from the mechanical relationships of figures, and saved considerable time, reducing the meeting time to $\frac{1}{4}$ hr., and sometimes doing away with the necessity of a meeting altogether. It will be noticed that the two last lines are similar, but not the same.

"Required to purchase" is the result of the mathematical process and as such is unalterable. "Recommended purchase," on the other hand, has the human touch, it allows the buying of more of one class of iron and less of another, keeping the total the same.

There are normally five classes of iron in use—common, siliceous, hematite, engineering, refined—though these are, of course, sub-divided and stacked in the yard according to their analyses. Suppose the formula for a mixture was 1 common, 1 siliceous and 2 engineering, yet a mixture of 2 common, 1 hematite and 1 engineering might give similar physical results. A fall in price in hematite might make this second formula the cheaper mixture. The line "recommended purchase" will provide the elasticity necessary to accommodate changes of this sort.

The Exercise of Control

Indicators will show when to exercise control and how the control is functioning, but they have nothing to do with the means of control. For instance, suppose a car is descending a steep hill at 60 m.p.h. The transmission is broken and the brakes are burnt out. The speedometer correctly registers the speed, but provides no means of controlling it.

In a foundry, control is effected by means of orders written and verbal. For smooth working, it is essential that these orders should be unambiguous and rapidly and accurately transmitted. Some sort of system must therefore, be devised and an efficient office routine maintained.

Many foundrymen profess a mistrust in system, describing it as so much red tape. It is certain, however, that system of some sort is necessary. These gentlemen, who scoff, would be distinctly disconcerted if the car they were driving suddenly went into reverse when they moved the gear lever into a position usually associated with top; yet, unless a definite system be established and adhered to, it is by no means certain that an order issued will be carried out. In fact, promptness of response may be taken as a measure of management control.

Discipline is the keystone of the Army, and a modified discipline is essential in the foundry. A loyal staff is of primary importance—but which men are the most useful—those who do exactly as they are told, or those who carry out the spirit of the instruction and report any varia-

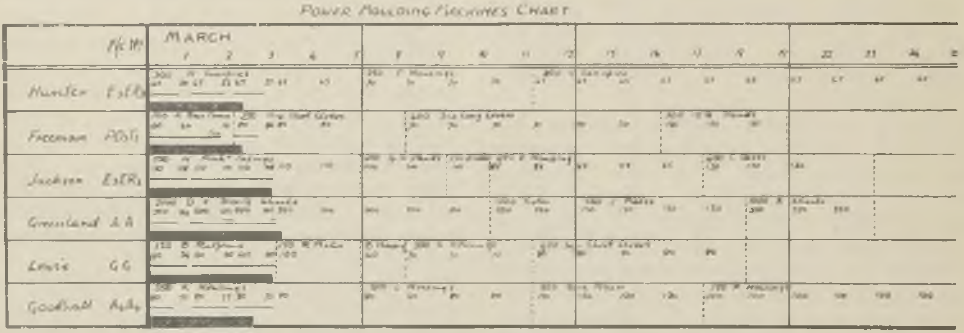


Fig. 4.—Gantt Chart for Moulding Machine Section.

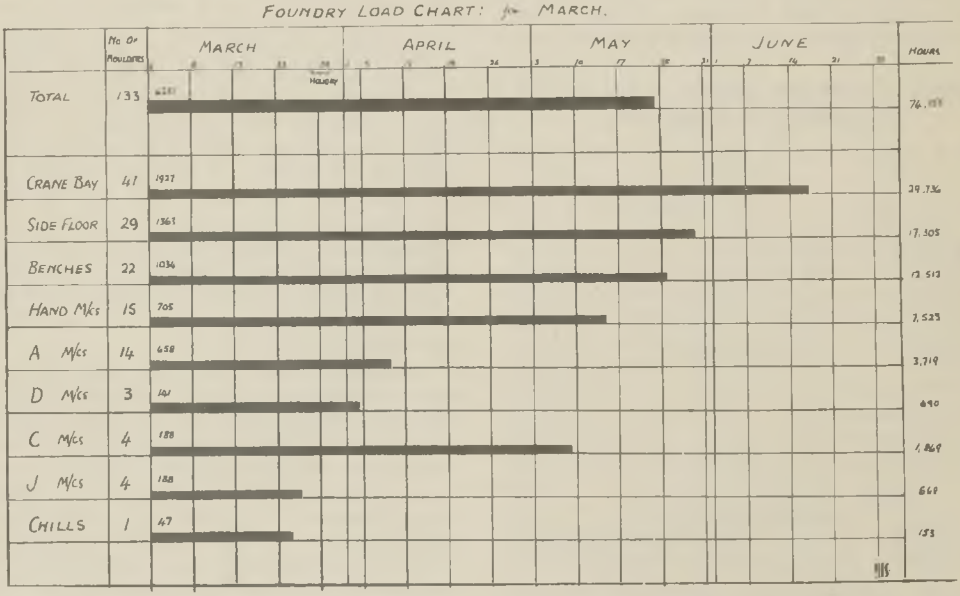
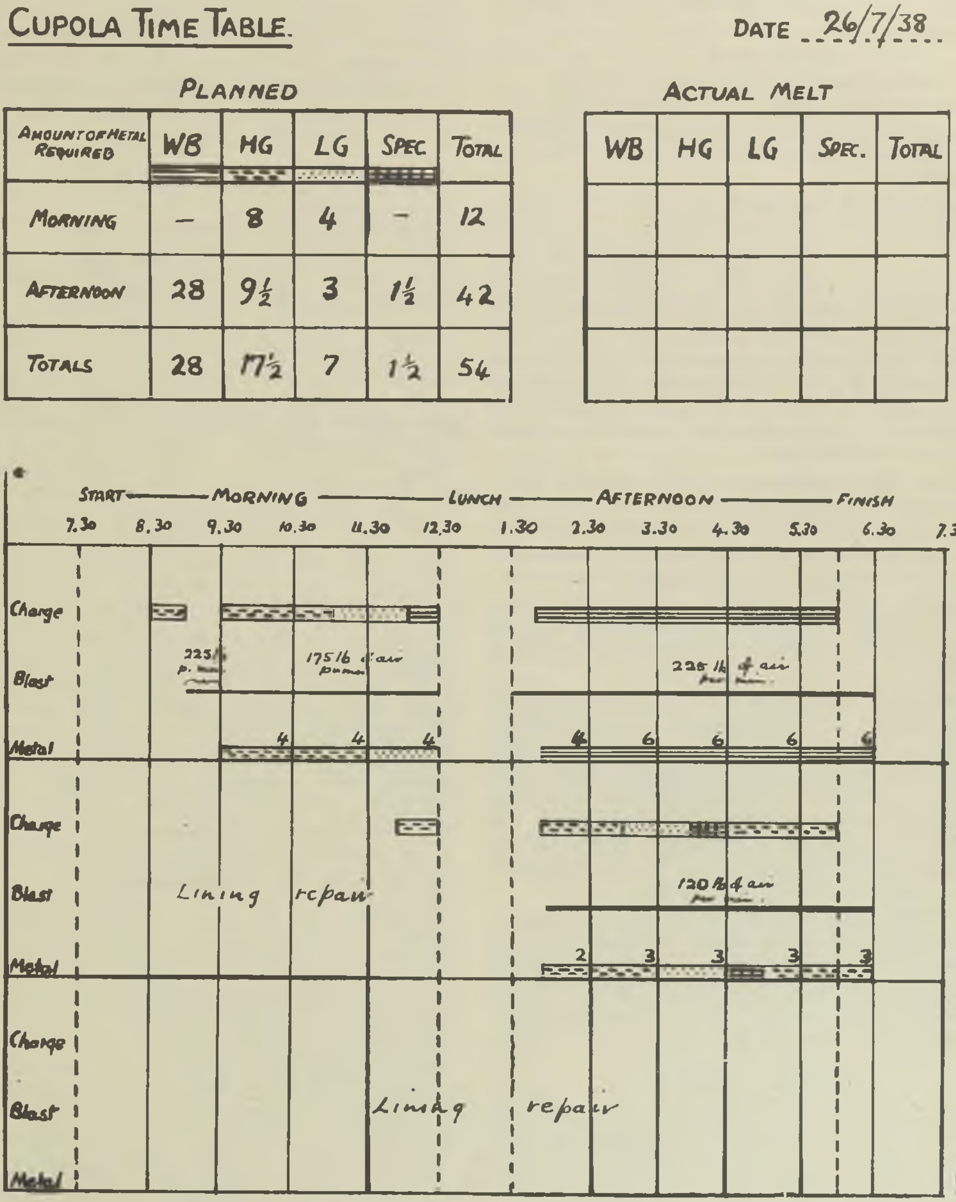


Fig. 5.—Monthly Foundry Load Chart.

tions? With some possible exceptions in the case of specialised or quantity production foundries, a certain amount of personal latitude is desirable; by this means the benefits arising from the exercise of initiative are not lost. The most difficult problem is to determine how much shall be dictated and how much left to personal initiative.

A Digression on Planning

Personal experience has been largely derived from a foundry producing a wide variety of castings which have to satisfy diverse conditions. Orders are frequently for one or two castings at a time. This sort of foundry is often described as a jobbing foundry. On the other hand, there are a number of running lines which



CUPOLA TIME TABLE.

DATE 26/7/38

PLANNED

AMOUNT OF METAL REQUIRED	WB	HG	LG	SPEC	TOTAL
MORNING	–	8	4	–	12
AFTERNOON	28	9½	3	1½	42
TOTALS	28	17½	7	1½	54

ACTUAL MELT

WB	HG	LG	SPEC.	TOTAL

FIG. 6.—CUPOLA TIME TABLE.

recur at intervals of perhaps two months, when 100 or even 1,000 castings are ordered.

This, it is thought, is typical of many foundries, but it makes for a great deal of complication, if not positive muddle. Now to avoid a muddle a plan is needed, and planning is so closely associated with management that it can usefully be included as one of its functions. In order to be perfectly planned, a job must be done satisfactorily—

in the simplest way;
in the shortest time; and
with the least expenditure of energy.

The words "simplest," "shortest" and "least" have no determinate meaning unless the questions—

simplest of how many ways?
shortest of how many times?
least energy of how many expenditures?

are answered. These words "simplest," etc., increase in significance the greater the number of different ways that are tried.

This is equivalent to saying that "trial and error" will produce the perfectly planned job in the end. It also shows that "experience" is more likely to produce the perfectly planned job than inexperience.

From these conditions it appears that (1) it takes time to plan, and (2) it is impossible to plan a one-off job which is entirely dissimilar from previous experience. Actually in a foundry no job is dissimilar in all respects from every other job. However, jobs may range from being almost entirely dissimilar to identical—that is, general jobbing foundry to specialised repetition foundry.

When one component has been produced, to make a second it is necessary to perform the same operations with the same, or similar, tools in the same order. These operations have to be repeated every time a component is made. Obviously, the total time will be reduced if the number of operations is reduced. How can this be done? By making some *thing* which incorporates some of these operations.

For instance, instead of cutting the runner every time a mould is made, incorporate it as part of the plant by forming a suitable piece of metal and attaching it to the pattern, remembering, however, it takes time to make "plant" just as it takes time to plan.

What is Plant?

Notice here the significance of the word "plant." It is a concrete noun formed from the past tense of the verb "to plan." "Plant": "that which has been planned." It is useful to look on plant as so many frozen operations. The relationship of these ideas may be expressed in symbols thus:—

Let the time taken to perform operations incorporated in the plant .. .. $= t_o$
Let the time taken to make the plant .. $= t_p$
Let the number of repetitions .. .. $= r$
If S is the saving in time effected (if any),

$$\text{then } S = t_o r - t_p,$$

from which it will be seen that the saving in time will be greatest (*i.e.*, planning most perfect) when:—

(1) The number of operations incorporated in the plant is at a maximum.

(2) The number of repetitions is at a maximum.

(3) The time taken to prepare the plant is at a minimum.

Planning either as making "plant" or collecting information and forming a "plan" takes time. The simpler the plant (providing, of course, that it incorporates the same number of operations), the quicker it can be made, and so the more worth while it is to plan. In general, the fewer repetitions there are, the less worth while it is to plan. Further, the quicker information can be collected, the more worth while it is to plan. Records are in a way "plant"; they are a sort of "frozen experience," just as mechanical plant is, as has been shown, "frozen operations." Reference to records may reduce the number of operations in a job, and "few off" jobs will benefit from this kind of planning. The great advantage of plant is the fixing of operations—it is likewise its great disadvantage, because as soon as these operations require altering, the plant becomes useless.

The clear-minded man with manual dexterity is the exact opposite to plant. The more skilful the man, the less plant he requires, and therefore the more useful he is for the production of few-off jobs. However, the operations exist in his mind, and if he changes his mind or forgets, the job alters. Further, if the castings prove to be unsatisfactory, one cannot apply a correction until the job goes out again, and then one must remember to tell the moulder. A written plan in the form of an instruction card will help the moulder, but at best this can only be sketchy, and he may not read it anyway.

He is rather like a violinist; if he is skilful he can play a great variety of tunes. A sheet of music will aid his memory or guide him in playing a new tune. On the other hand, if there be plant available in the form of a gramophone an unskilled operator can produce any given piece of music and repeat it *ad lib.*, provided he has the right record. The record here is "frozen" music, just as a pattern plate is "frozen" foundry operations.

This simile brings out the essential difference between a general jobbing and a mechanised repetition foundry. In the one, the manager is a sort of conductor of a band of musicians—in the other, management is chiefly concerned with devising means for producing gramophone records, keeping the gramophone in order, planning the correct sequence of tunes, and seeing that the operators put the right records on and change the needles at the right time.

The fundamental idea of control is the same in both cases, but the means employed are entirely different and this returns the subject back to the point from which the author digressed.

Extent of Control

" How much shall be controlled ? " Obviously from what has been said it is evident that " How much to control " is largely a question of finance. Money and time are roughly interchangeable terms. The introduction of plant automatically stiffens control, but at the same time costs money and the formula $S = t_o r - t_p$ may show that plant is not justified. Pre-planning also may be too costly, yet there is still a powerful means of control.

A good policy is to make it easy to do a job correctly and hard to do it wrongly. That may sound so obvious that it is hardly worth mentioning; still, how often has it been found that a man has done a job the wrong way when he knew perfectly well what was the correct way? Circumstances were too much for him. For instance, he moulded a bearing bracket with the important machined face upwards, because so-and-so was using that deep top, and the manager said he wanted the casting that afternoon certain, and the moulders had already had to wait for some special facing for the lettering on the rib, and he was afraid of missing the metal if he waited any longer; moreover, he had a box at his side that would just take it, so he thought perhaps it would not matter. The management is lucky if it finds that the job has been made the wrong way at this stage. Generally, the casting is almost completely machined before the holes are exposed, and much painful investigation follows. By now, of course, the casting in question is super urgent—it becomes the butt of everyone in the vicinity—all the jokes about sponges and pikelets are recalled; young designers suggest that it ought to be fabricated! The moulder was wrong, certainly, but he would not have gone wrong if the management had made it easier for him to go right.

No orders should be given which cannot possibly be carried out. The management ought to decide what it wants to do, determine what is possible, make its plans, issue its orders, and have a suitable indicator which will show how far these orders have been carried out.

An example of a simple system which embodies these principles is the Gantt chart. The author has been using one for a group of moulding machines for over ten years, and has found it invaluable.

Moulding Machine Chart

The chart shown in Fig. 4 is divided into vertical columns, each representing one working day and headed with the date. Horizontally it is divided into six sections, each representing a moulding machine group.

(*a*) Orders are allocated to different machines, bearing in mind the date required; the size and form of moulding box; whether it is necessary to strip or roll over or use an undersand frame; the nature of the cores, etc. The quantity of castings it is expected to make per day is written on the left-hand side of the vertical column. The expected completion of the order is marked by a vertical dotted line.

(*b*) Every morning the actual quantity made on the previous day is entered on the right-hand side of the column, and a horizontal pencil line is drawn indicating the proportion of actual work done to work estimated. A thick line is made representing the total of the pencil lines. The end of the thick line shows how far a group is in advance or arrears.

(*c*) When a machine is out of action, a gap is left in the thick line corresponding to the time the group is idle. The cause of breakdown is written in this gap.

Foundry Load Chart

Another Gantt chart is the " Foundry Load Chart " (Fig. 5). This is prepared once a month, primarily as an indicator to the works management. It entails a detailed survey of every order and a review of the activities of each man. The lines are measured in proportion to the ratio of " allowed " hours of work in any given section to the available man hours in that section. In other words, they are indicators showing when each section is likely to clear the amount of work it has on hand, which section is busiest, and how the labour is distributed.

Cupola Time Table

Another application of this type of chart is the Cupola Time Table (Fig. 6), which has proved useful in planning a melt. In passing it might be mentioned that with a combination of constant-air-weight blower and balanced-blast cupola, the same furnace is able to melt at 4 tons per hr. in the morning and 6 tons per hr. in the afternoon. This is effected by changing the blower setting and slightly altering the tuyere valves. Within the last two years the management has replaced the whole of its melting plant, and this chart was used in the early stages to establish the new routine. It has now served its purpose, and is no longer used. Mixtures are changed at approximately the same time each day, but the precise time is determined by information supplied by the charge-hand of labourers. He goes round in the afternoon to the moulders about an hour and a half before the final change of mixture and compiles an estimate of the metal still required. This total is given to the cupola charge-hand, and the number of ladles required by each section is entered on a blackboard to aid distribution.

In practice this method is superior to the chart because when laying out the chart one has to estimate *all* the metal required, whereas with the second method one only needs to estimate the *difference* from standard. The chart, however, had its use in determining the standard in the first place. A simple mechanical recorder (Fig. 7) has been rigged up by the Plant Department on the wall of the foundry office. It has been invaluable in keeping the cupola staff efficient. Before the new melting plant was installed the author could never be sure who was determining the foundry output—the moulders or the cupola men.

The moulders said they could make more castings if they got the metal when they wanted it. The cupolamen said it was no good melting any more because the moulders did not use the metal fast enough as it was.

Now, each cupola has its own constant-air-weight blower. A certain weight of air pro-

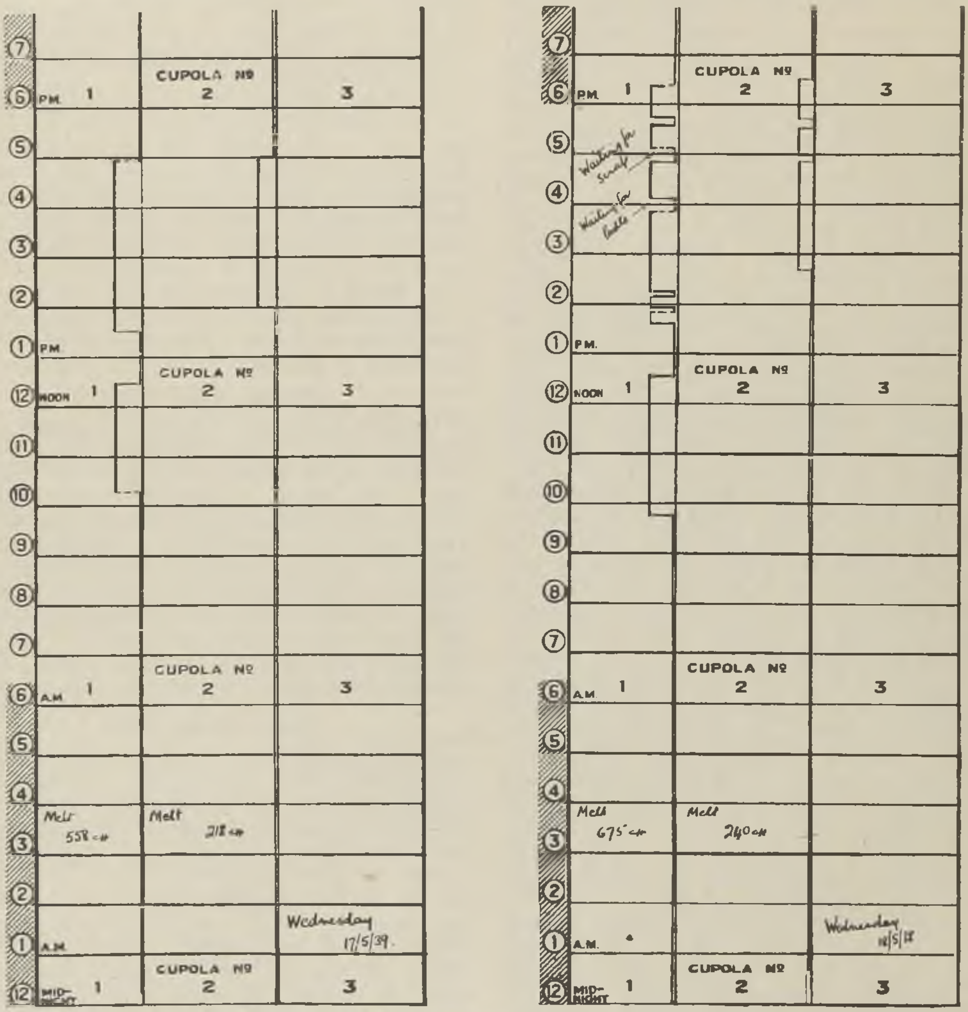


FIG. 7.—MECHANICAL RECORDER FOR CUPOLA PRODUCTION.

duces a definite melting rate—in other words, the weight of air is the factor which controls the pace of the chargers. A chemist sets the blower; no one else is allowed to touch it. The cupola man can only start and stop the blower; he has no control over the air once the blower has started. When the blast is off the cupola is not melting. When the blast is on the cupola is melting at a definite rate. Mercury switches are fixed to the automatic control valve of each cupola, and are connected electrically with the recorder.

As soon as the air is being delivered at the correct rate, the valve moves, the switch opens and the pen is deflected. The recorder is worked by a.c. and gives out a slight hum, which ceases, of course, as soon as the air is cut off and the pen returns to normal. In the early days as soon as the hum stopped, the author used to hurry to the cupola and ask why it was not working. He usually found they were waiting for scrap, or so and so was just putting on the top part of a mould so they had not got the big ladle back yet. If the cupola man had been allowed to alter the air to his liking, the management would never have found out these delays; perhaps the cupola would have been blamed for melting only five tons per hour when it was rated at six.

The obvious aim of the constant-air-weight

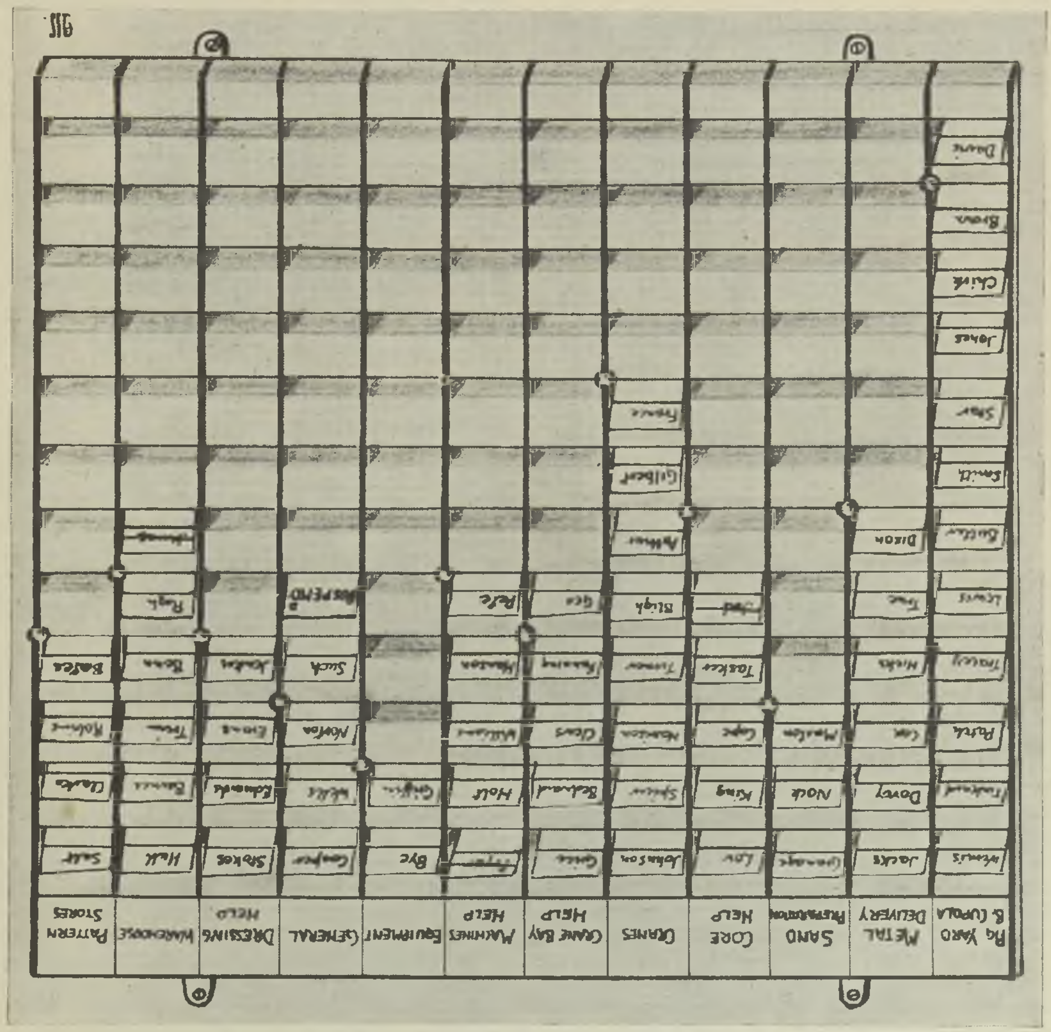


Fig. 8.—Day Workers' Job Board.

installation, including recorder, is to economise melting of iron, but its real value lies in its contribution to the shortening of the working day by showing up avoidable delays—thereby keeping overheads and expensive overtime to a minimum.

It is surprising how many cupolamen, crane-drivers, labourers and the like, are kept hanging about if one moulder is late putting a top on to his mould.

Day Workers' Board

The proportioning of unproductive to productive labour is one of the major problems of foundry management. To aid in its solution, a "Day Workers' Board" (Fig. 8) has been devised.

This board is divided into a number of vertical columns formed of slots into which cards can be put. Every day-worker is represented on the board and allocated to a specific section; his absence is indicated by turning the card upside down when his name then appears with a red line through it; enforced absence is shown by reversing the card, the word "suspended" showing. The time clerk is responsible for keeping the board up to date and in practice it can be said that it is correct 5 min. after starting time. The charge-hand of "unproductive" labour adjusts the board when he makes any major alteration of the disposition of personnel.

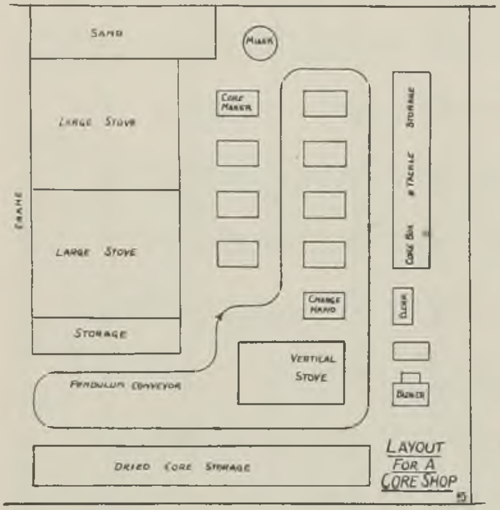


FIG. 9.—PHYSICAL LAYOUT OF A SMALL CORE SHOP.

The number of men required in each section to meet the foundry "load" is roughly calculated and large tacks with red leather covered heads are stuck into the board to mark these numbers. A glance at the board is sufficient to determine whether or not a preconceived plan is being adhered to.

Core Shop Control

As a concluding example an application of management to a small shop is given. It is a core shop employing about 15 men dealing with cores $\frac{1}{2}$ in. dia. by $\frac{1}{2}$ in. long, wanted 1,000 at a time, to cores say 6 ft. by 4 ft. by 2 ft., wanted one at a time.

The physical layout is roughly as is sketched in Fig. 9. One pendulum conveyor takes sand to the core-makers, green cores to the stove, dried cores to storage, and returns core plates and dryer shells. There are two large batch-type stoves and one vertical continuous stove. Other plant comprises a sand mixer, a horizontal core blower and a "sausage" type machine for extruding cores. A second diagram (Fig. 10), which, for lack of a better title, has been called "Design for Core-making," refers to the same shop.

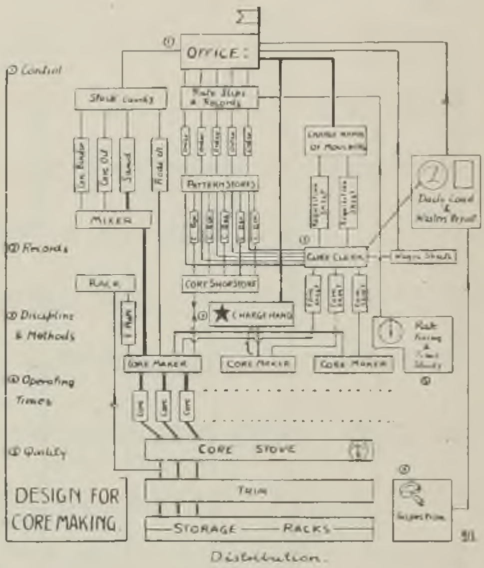


FIG. 10.—CONTROL IMPOSED ON THE CORE SHOP SHOWN IN FIG. 9.

It will be seen at a glance that it is considerably more complicated than the first. It is an attempt to portray the various functional relationships, the position of control points, and the arrangement of suitable indicators.

Notice, the charge-hand is the most skilful core-maker in the shop; is a piece-worker, and earns his living like the rest.

A common error when putting a skilled operator in charge of a shop is to invest him with a certain amount of authority and then turn him into a second-rate clerk. In this case a competent clerk deals with the clerical side; he works the indicator by producing a "daily load," but has only an indirect share in control.

It is unlikely that in a shop of this size there will be enough new jobs to keep a time-study man fully occupied, but there is generally someone in the organisation who can act in this capacity when occasion requires.

In the actual shop on which this "design for core-making" is based, the function of rate-fixing and time study is exercised by a member of the Planning Department. It is largely due to his efforts and influence that the present arrangements have proved so successful.

The function of inspection is well known and needs no comment, save perhaps that *tact* is a useful adjunct. Tact is valuable in almost any occupation; it is rather like oil on a rusty lock giving freedom of movement in regions which would otherwise be barred.

Lack of space forbids a consideration of the psychological aspects of foundry management. Suffice it to say that the author is a great believer in free discussion, and holds a meeting of charge-hands each morning at 8.30.

Because some prominence has been given to charts, it should not be thought that charts can take the place of personal contact; both are valuable if used with discretion.

CONCLUSIONS

Foundry management is a subject which has long been neglected, and there have been times when the author wondered whether there was such a thing after all. Personally he believes there is, and feels that there is as great a need for research in the realm of management or that of metallurgy or mechanical engineering Popularly "science in the foundry" is synonymous with physics and chemistry; it is supposed to radiate in some mysterious fashion from the laboratory. May not science be applied to the foundry organisation itself, rather than merely to its products? May not mathematics with the ability to disentangle relationships of constants and variables prove to be the true science for the solution of foundry problems?

Prof. Bragg, when speaking of atoms at the International Conference last year, said that complete uniformity of pattern caused weakness, and spoke of the strength of "organised muddle."

It is thought a parallel principle is apparent in foundry management, which means that the organisation of personal initiative is superior to the perfect uniformity of dictatorship—or, to borrow a thought from politics, a democratic system is best.

The question of "how much to control" cannot be answered generally. It must be determined for each foundry individually.

Further Note

The relationship of overheads to mechanisation is dealt with fully and a mathematical theory worked out by Erik Aug, of Sweden, in his Paper on "The Economic Limits of Mechanisation," presented to the Scientific Management Congress in 1935.

The investigation is based on the formula

$$x = at + bt.$$

Where x = the cost of converting material into finished product.

t = the working time,

a = the wages per hour,

b = the burden per hour, *i.e.*, such overheads as interest and amortisation, repairs, tools, power, light, rent, etc

The fundamental idea of mechanisation is to attain by increased mechanisation a saving in working time. The time t is thus conditioned by b, or, mathematically, a function of b—

$$t = f(b)$$

$$x = a.f(b) + b.f(b).$$

The author goes on to discuss the question "at what degree of mechanisation (and wages corresponding to this) will manufacturing costs be the lowest?" and concludes with, "For the present the old law 'Thou shalt eat thy bread in the sweat of thy face' still applies." The author cannot quote that law in the original Hebrew, but in the language of the mathematics it is $\phi(b) > 2$.

DISCUSSION

In calling upon Mr. E. C. Dickinson and Mr. T. H. Gameson to propose and second a vote of thanks to Mr. Shore, the CHAIRMAN (Mr. A. Tipper, M.Sc.) remarked that he was convinced that foundry management was a definite science of which Mr. Shore had given an extraordinarily lucid account.

The proposition having been heartily received, MR. G. R. SHOTTON opened the discussion by questioning the validity of the equation $S = t_D r - t_D$, on the ground that it did not take into account overhead charges. Regarding his analysis of wasters, the table did not give the distribution of wasters amongst moulders, etc. Detailed reports on each of the men against the distinct types of scrap were necessary.

MR. N. C. BLYTHE also commented on the lack of overhead charges in connection with Mr. Shore's equation.

MR. SHORE said that Mr. Blythe and Mr.

Shotton had questioned the validity of the equation $S = t_o r - t_p$ on the ground that it did not take into account overhead charges. It was admitted that it did not. The equation was not intended to be used as a general formula for determining the cost of a job. It was introduced merely as a summary of personal ideas—it was none the less true. No greater claim was made for it than that it clarified one aspect of the " nature " of plant.

The CHAIRMAN remarked that, as far as the science of foundry management was concerned, he was learning a great deal. He began to realise that foundries were not places where, as he once gained the impression, a man strolled in at a certain hour in the morning, set to work to make a casting, and got it through during the day or the week, but that the whole thing was planned. Success in a foundry could not be achieved without the use of science and thought.

In reply to Mr. J. Gardom, MR. SHORE emphasised that the problem in a foundry oftentimes was to find some constants in a sea of variables. When their relationships had been sorted out, they were helpful in making decisions.

Malleable Cast Iron*

By H. G. HALL (Member)

What is malleable cast iron? Ten years ago it would have been said that malleable cast iron could be divided into two grades, whiteheart and blackheart. To-day, although these two types predominate, special malleable cast irons are being produced which can no longer be classified under either of these headings, and therefore a definition of malleable cast iron must be framed with care.

There is a definition suggested by the Malleable Committee of the B.C.I.R.A. which can hardly be improved:—" Malleable cast iron can be defined as any hard iron composition, cast into moulds, free from graphite in the unannealed or hard state, and in which, after heat-treatment, part or all of the carbide is transformed into temper carbon. If heat-treatment takes place in an oxidising atmosphere, the carbon is completely or partially removed by oxidation. The mechanical properties required of the finished product are governed by the method of heat-treatment."

Fundamentally, however, although there are several types of malleable cast iron, softening of the brittle cast iron is still controlled by (1) decarburisation—the basis of the production of whiteheart, or (2) graphitisation—the basis of the production of blackheart.

These two phenomena can best be understood by considering the changes taking place during the annealing of white cast iron.

Graphitisation

White cast iron consists at ordinary temperatures of pearlite and cementite and the changes taking place during graphitisation are as follow:—When white cast iron is heated above the A_1 critical point the pearlite changes to austenite which is capable of dissolving and retaining in solid solution certain definite amounts of cementite for definite temperatures. That is to say, austenite is capable of dissolving increasing amounts of cementite at increasing temperatures until for a definite temperature and time a saturation limit is reached and the structure will consist of saturated austenite and free cementite.

Therefore, assuming that a temperature of 900 deg. C. has been chosen as a maximum annealing temperature and that the temperature has been reached in the shortest practical time, the structure will consist of austenite and cementite, and as the temperature is maintained cementite will be dissolving in austenite. While this is going on, however, and before equilibrium (that is, the saturation limit of cementite in austenite at 900 deg. C.) is reached, the less soluble carbon or free graphite is being precipitated from the austenite. As annealing continues, more carbon is precipitated from the austenite as free graphite, the nodules of which rapidly increase in size. During the precipitation the austenite absorbs free cementite to maintain its saturation which is continually tending to be lowered by the precipitation of carbon.

This continued precipitation of graphite and corresponding absorption of cementite continues until there is no free cementite left. Equilibrium for the temperature chosen, in this case 900 deg. C., has been attained and the material consists entirely of saturated austenite and free graphite carbon. In theory, there is no point in holding at this temperature after equilibrium has been reached, and since austenite cannot hold so much carbon in solution at lower temperatures it will be necessary to work below 900 deg. C. in order to precipitate more free graphite. From 900 deg. C. the metal is allowed to cool slowly to the A_1 critical point, that is about 720 deg. C., graphitic carbon being progressively precipitated and the austenite becoming lower and lower in carbon content.

In fact, at and just below 720 deg. C., roughly 0.5 per cent. carbon remains in solution in the austenite, the rest of the carbon being present as graphite. If the temperature is dropped too rapidly at this stage, the 0.5 per cent. C is retained in the metal at ordinary temperatures as pearlite. In practice, therefore, cooling over the critical range should be slow so as to ensure complete graphitisation.

Summing up, graphitisation can be divided into two main stages: (1) Heating to and holding at a predetermined maximum temperature until all the free cementite has been dissolved and the structure consists of saturated austenite and free graphite, and (2) cooling to just below

---

* The Author was awarded a Diploma for this Paper.

the critical temperature (roughly 720 deg. C.) and holding there if necessary, until the comparatively weak solution of austenite has been decomposed into nodules of graphite and free ferrite.

By quenching the metal before the total disappearance of the cementite and examining under the microscope, it is possible to show up the slow change of the dissolved carbon of the cementite to nodulus of graphite.

A typical photomicrograph has previously been published[1] which showed the microstructure after annealing at 880 deg. C. for 2 hrs. and drastically quenching in water. The quenching was not drastic enough to prevent the austenite decomposing to martensite, but the structure is in other respects identical to that in which the material existed prior to quenching. It will there be seen that the austenite has absorbed much free cementite, although the original dendritic structure has not been completely broken down. A little graphite has already been precipitated from the austenite, and can be detected as small dark nodules in the decomposed austenitic background. A second micrograph[2] showed a further sample of the same iron water quenched after 7 hrs. at 880 deg. There is a conspicuous increase in the amount of temper carbon, the nodules of which have grown considerably. The ground mass of decomposed austenite was shown to have absorbed nearly all of the free cementite, residual traces of which were visible as a fine network around the crystal grains of decomposed austenite.

A third micrograph[3] showed the same iron which had been air cooled immediately when the temperature had dropped to 720 deg. C., and showed the pearlite resulting from insufficient time to have allowed complete dissolution of austenite at that temperature.

Normal Annealing Cycle

To emphasise the practical side of the previous data it may be advisable to consider them in the form of a graph of an ordinary annealing cycle, as is shown in Fig. 1, where *point* 1 indicates the austenite trying to dissolve sufficient cementite to reach its saturation limit for that temperature, and not succeeding because free graphite is being precipitated, thus weakening its solution; *point* 2 is the position where austenite has almost succeeded in dissolving all free cementite, and considerable graphite has

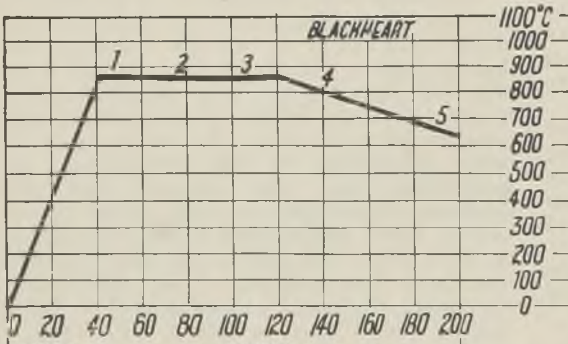


FIG. 1

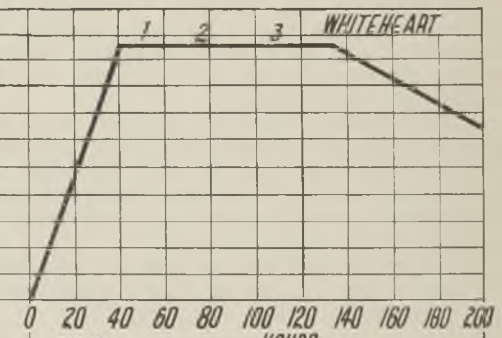


FIG. 8.

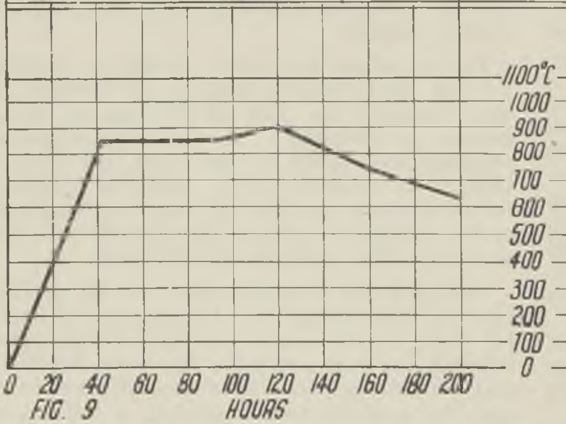


FIG. 9

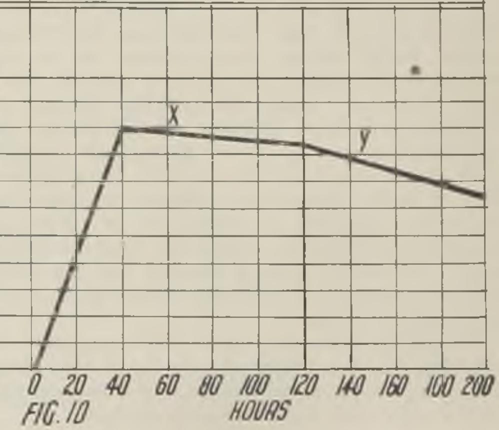


FIG. 10

been precipitated; *point* 3 is the place where no free cementite is left. The structure now consists of saturated austenite and nodules of temper carbon. In theory, there is no point in retaining at this temperature of any length of time, as no further graphite will be precipitated, but in practice it is rare to be able to say that it is certain that the whole oven has been at the required temperature for the whole period, and it is therefore advisable to extend this period as a safety factor; *point* 4 shows that the temperature is being allowed to drop, so that the dissolving power of austenite for carbon is lower and so to enable more graphite to precipitate, and finally *point* 5 serves to indicate that the second stage of graphitisation is usually obtained in practice by the use of well-insulated ovens, which prevent the temperature dropping rapidly and the time taken to drop over the critical range is slow enough to allow of the complete dissolution of the carbides just below the critical point. From this point cooling can be as rapid as is desired, but in practice it is not usual to open up the oven until the temperature has decreased to about 620 deg. C.

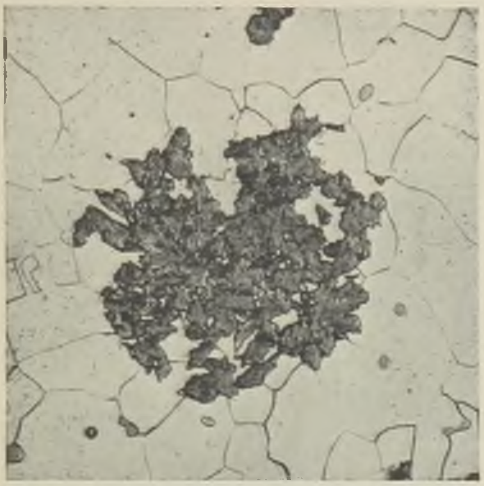


Fig. 2.—Normal Ferrite Graphite Structure of Low Carbon Malleable × 300. Etched 5 per cent. HNO_3 in Alcohol.

As a matter of interest, the evolution of heat at the critical point will make itself seen on a continuous temperature record in the shape of a slight flattening of the curve or even in the form of a slight rise.

Quick Anneal Cycle

The annealing technique of those producing the so-called quick anneal could be considered at this stage. It must be obvious that the higher the initial maximum annealing temperature then the faster equilibrium will be attained, that is the time required to dissolve all free cementite completely. In fact, to illustrate this by the use of rough figures it is suggested that for a given iron, equilibrium or first stage graphitisation could be attained in

about 15 minutes at 1,050 deg. C.
or 6 hrs. at 1,000 deg. C.
or 24 hrs. at 900 deg. C.
or 50 hrs. at 860 deg. C.

The advocates of short-cycle annealing therefore use as high a temperature as they consider practicable and then insist that when they have attained equilibrium they may as well get on with second-stage graphitisation as quickly as possible. They suggest that the time used in cooling from the initial maximum temperature to the critical stage does very little useful work (the author is to some extent in agreement with this) and therefore in effect it is practicable to quench from the maximum temperature to the critical stage and only hold there for sufficient time to complete graphitisation—a period in some cases less than 12 hrs. or a complete cycle of approximately 24 hrs.

There are, of course, other factors involved such as the use of border-line compositions, small ovens, etc., and it is suggested that although in theory the above suppositions are reasonable, there is no apparent safety factor. For a comparison of annealing times it is worthy of note that Schwartz[4] has succeeded in com-

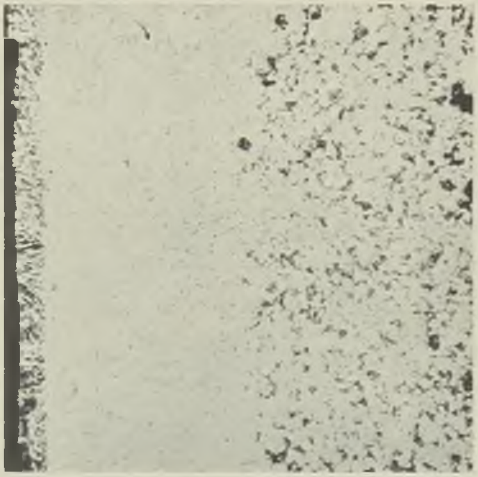


Fig. 3.—Edge of Well Annealed White-heart × 150. Etched 4 per cent. Picric Acid.

pletely graphitising a normal white cast iron at 725 to 710 deg. C. in 73 days.

Fig. 2 shows the normal ferrite graphite structure of a fairly low carbon blackheart iron. This structure is uniform from centre to edge in true blackheart, although there may be a slight rim of ferrite on some due to slight decarburisation.

Decarburisation

Decarburisation is the basis of the production of whiteheart malleable cast iron. It has sometimes been described as a mechanical process, compared with the physical changes taking place in blackheart production. This is hardly correct, as decarburisation is one of the most complex of metallurgical operations. Decarburisation takes place through the oxidation of carbon by oxygen and carbon dioxide gases surrounding the castings. An oxidising agent such as hematite ore—iron oxide—is generally used for this purpose. As space precludes a detailed examination of the various reaction of the gases present during decarburisation, it is suggested that those interested study the classic diagram of Dr. Schenk[5] showing the iron-carbon-oxygen equilibria in relation to temperature. Various chemical equations are given, some of which are reversible at different temperatures and pressures.

The gases surrounding the castings, rich in carbon monoxide produced by the combustion of the carbon, are regenerated by the oxidising media—usually hematite ore—which gives up part of its oxygen according to the main equilibrium reaction:—$Fe_3O_4 + CO \rightleftharpoons 3\,FeO + CO_2$.

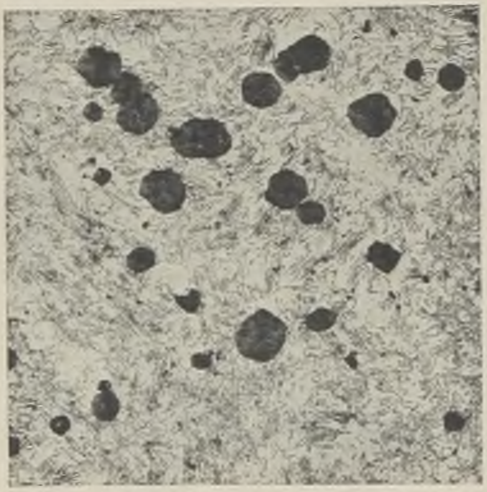


Fig. 4.—Centre of Well Annealed Whiteheart × 150. Etched 4 per cent. Picric Acid.

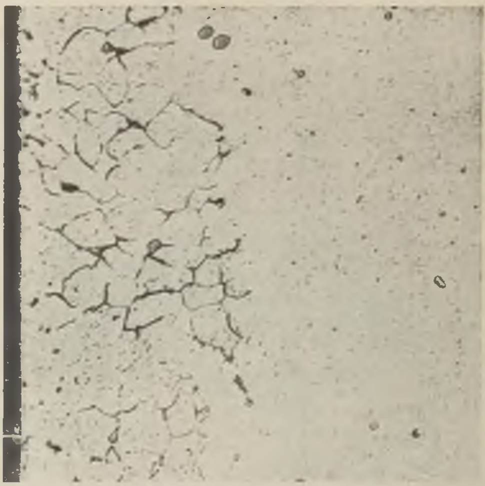


Fig. 5.—Illustrates a Case of Oxide Penetration × 300. Etched 4 per cent. Picri cAcid.

Briefly then, the castings, packed in hematite ore, are raised to a predetermined temperature, say 960 deg. C., as rapidly as is practicable, and here again as in the case of iron suitable for graphitisation, the structure consists of austenite attempting to reach its saturation limit by dissolving free cementite and at the same time precipitating carbon as free graphite. The oxidising action of the gases takes place continuously from the surface to the centre of the castings so long as the carbon content of the metal tends to equalise itself by the migration of the dissolved carbon of the portions rich in that element towards the impoverished surface layers, *i.e.*, by the migration of the rich solid solution of austenite in the centre towards the poor solid solution of austenite at the edge.

Simply stated, the carbides from the solid solution of austenite at the centre are continuously being removed by oxidation. This reaction proceeds quickly so long as there is any free cementite left.

The austenite is continuously trying to reach its saturation limit for 960 deg. C., so that as the solution weakens at the edge the austenite at the centre dissolves more cementite and migrates towards the edge in an attempt to replace its saturation limit. The decarburisation from edge to centre proceeds much more slowly when there is no free cementite left and the austenite has to start dissolving the already precipitated graphite in order to maintain its saturation. Apart from castings of thin section, however, decarburisation is practically never complete.

After cooling down, the centre of a section usually contains a small quantity of temper carbon, plus the decomposition product of the remaining austenite solution—namely, pearlite. It will be evident therefore that the predominating factor controlling successful decarburisation is mainly the speed at which carbides migrate from the centre towards the edge. It is obvious that this speed will be increased by the use of higher maximum annealing temperatures. Moreover, according to Schenk's equilibria diagrams, the speed of the regeneration of the carbon monoxide and the reaction of the packing medium are accentuated at higher temperatures.

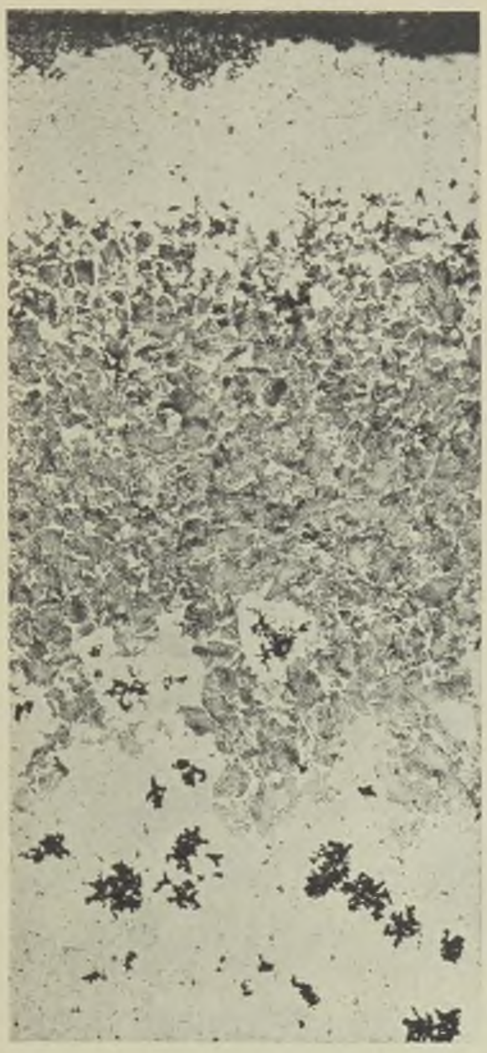


Fig. 7.—An Example of the "Picture-Frame" Phenomenon × 100. Etched 4 per cent. Picric Acid in Alcohol.

Unfortunately, the facts do not help each other sufficiently; in other words, the danger is that the speed of decarburisation is so great that migration of carbon from centre to edge cannot keep pace with it and surface oxidation of the castings occurs, resulting in iron oxide penetration. Leroyer[6] states and practical experience confirms that the speed of migration can be helped by lowering the silicon content and generally of all the elements which enter into solution with the gamma iron. The migration of the solid solution after all the cementite has been used up is far more difficult and it is therefore necessary to reduce any tendency of the iron to graphitise to a minimum. In addition to the lowering of the silicon content, the presence of an excess of sulphur over that required to form manganese sulphide, however small the excess may be, undoubtedly favours the retention of carbon as carbide and not as graphite. The use of sulphur in this respect therefore constitutes the main compositional difference between blackheart and whiteheart hard cast irons.

Thin castings will decarburise more quickly than thick castings, as owing to the comparative chilling action during casting the cementite goes into solution more quickly at the maximum annealing temperature.

A word of warning must be given on the use of too low a silicon content, because during cooling there is a risk that the pro-eutectoid cementite will separate out in the centre of the castings, rendering them extremely brittle. It is, of course, the excess of sulphur which prevents the decomposition of the weak solution of austenite remaining at the critical stage into graphite and ferrite, the solid solution changing almost completely into pearlite.

Fig. 3 shows the edge of a well-annealed whiteheart casting; the extreme edge consists of completely decarburised iron, there being a progressive increase in carbon towards the centre. Fig. 4 shows the centre of the same section and it will be seen that the main background consists of pearlite with a little ferrite, and the temper carbon is in the well-rounded form usually associated with irons having a slight excess of sulphur. Fig. 5 illustrates the oxide penetration at the edge indicating excessive decarburisation.

Referring to the decarburisation data given in Fig. 6 showing the forms of a normal time-temperature curve:—

Point 1 indicates the location where austenite is trying to dissolve sufficient cementite to reach its saturation limit and again graphite being precipitated although not nearly so fast as in the case of the more easily graphitised iron suitable for blackheart work. On the surface the austenite is being impoverished due to oxidation.

Point 2 shows the place where not much free cementite is left in the centre, as a concentration gradient has been set up between the surface and centre of the castings. The austenite at the centre is absorbing the remains of the cementite and attempting to diffuse or migrate towards the edge in order to enrich the poor solution of austenite remaining there.

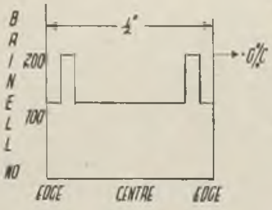


FIG. 8.—BRINELL HARDNESS OF "PICTURE-FRAME" IRON.

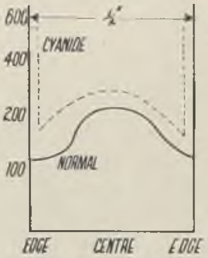


FIG. 11.—BRINELL HARDNESS OF WHITEHEART.

Point 3 is the position where decarburisation is still proceeding but as there is no free cementite left, the austenite is compelled slowly to dissolve the already precipitated graphite in order to replace its concentration in the now very weak solution at the surface.

This stage is critical because of the comparative slowness of migration of solution from centre to edge and it is easy to set up zoning, that is decarburisation overbalances migration and the result is at worst the oxidation of surface iron resulting in oxide penetration and eventually in peeling, when an oxidised layer of metal is formed which breaks away from the surface of the casting. At best the result is, from edge to centre, a deep layer of ferrite, a sharply defined layer of pearlite and then the normal ferrite-pearlite-graphite core.

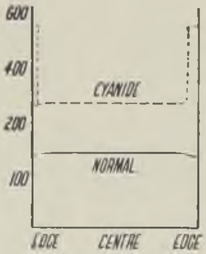


FIG. 12.—BRINELL HARDNESS OF BLACKHEART.

Potentialities of CO-CO_2 for Decarburisation

From the above it must be obvious that the mechanical side of the operation of decarburisation is somewhat clumsy and must if progress is to be registered be superseded. Referring again to *point* 3 of Fig. 6, if at this juncture, or perhaps even earlier, the oxidising atmosphere could be changed to a neutral one for a sufficient length of time, the carbon-rich area at the

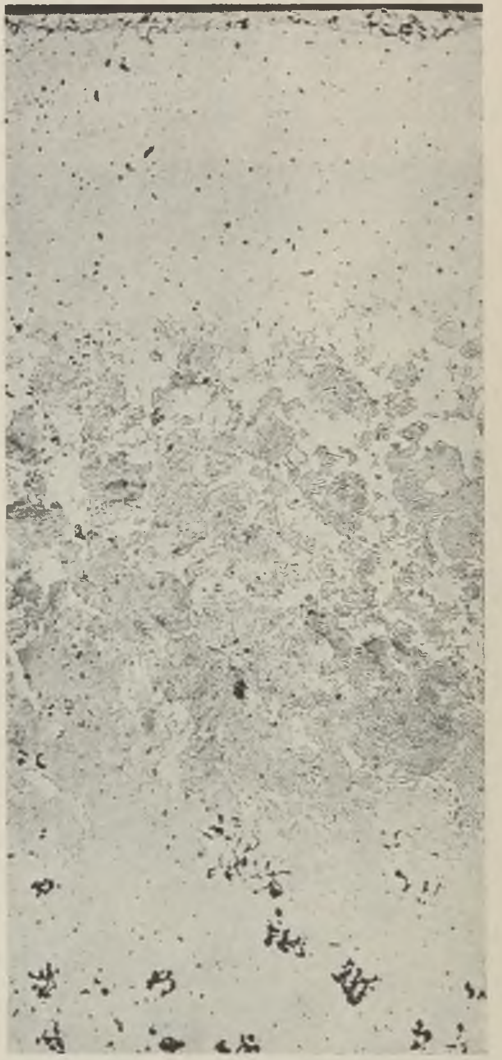


FIG. 13.—EDGE OF HIGH CARBON IRON, ANNEALED UNDER DECARBURISING AND GRAPHITISING CONDITIONS. × 150.

centre would have time to diffuse towards the edge until the whole area was of uniform carbon concentration. This would permit rapid decarburisation again to take place. This process could be repeated, and there are grounds for stating that the sectional limitation which now applies in the production of whiteheart castings could partially be overcome.

It is suggested with some diffidence that a gas mixture of carbon monoxide and carbon dioxide could be used as an oxidising agent, the gases being applied in such proportions that the carbon is oxidised but not the iron, and in support of this it is germane to recall that in a recent Paper[7] by Kalling and Rennerfelt it is stated that these gases are being used to decarburise granulated pig-iron, the product being used for the manufacture of high-quality steel. These authors point out, however, that increased silicon contents slow up the rate of decarburisation, and they suggest as a reason that an oxide film is formed which becomes progressively less permeable to the oxidising gases.

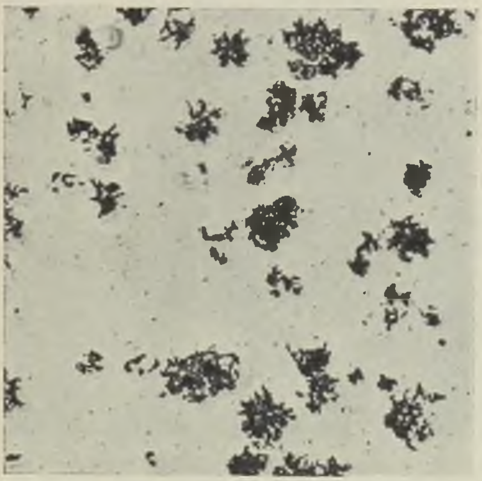


FIG. 14.—CENTRE OF THE SAMPLE SHOWN IN FIG. 13. × 150.

Further support in favour of de-carburising by the use of CO-CO_2 mixtures is given by Lissner and O'Kahl in their Paper "Recent Studies on the Graphitisation of a pure White Iron."[8] Research on the above lines might well mark a decided step forward in the production of malleable cast iron.

"Picture Framing"

Decarburisation and graphitisation have been dealt with at some length, and these two phenomena have been associated with whiteheart and blackheart respectively. In practice, however, there is nearly always some degree of decarburisation in the production of blackheart. It may take place as a result of the packing (if any be used) being insufficiently inert, or as a result of an oxidising atmosphere in the oven itself. The result of this partial oxidation may be what is unhappily designated "picture-frame malleable." A personal view is that the term "picture-frame malleable" is misleading, as it implies malleable which is difficult to machine, with high tensile and low elongation values. These factors apply only if the product is accidental and has taken place during the attempted production of true blackheart. Malleable cast irons are often deliberately produced having a so-called "picture-frame" fracture. Such irons must never be regarded with contempt.

Consider briefly the type of "picture-frame" malleable which does give trouble in machining, from the annealing side only. A typical example is shown in Fig. 7.

The main difference from true blackheart consists of a heavy pearlitic rim, the core being usually quite normal. The hardness of such an iron is shown diagrammatically in Fig. 8. It is a personal opinion that such irons are produced by poor annealing technique, as the same hard iron properly treated usually results in true blackheart. For instance, a time-temperature curve of the type shown in Fig. 9 would be liable to produce a "picture-frame" malleable. The rise of temperature occurs at a point where there is no free cementite to even out any concentration gradient which might be set up by surface oxidation. A further illustration may be drawn from a realisation that the same trouble would occur if the oven atmosphere at point 3 in Fig. 1 became heavily oxidising. On the other hand, an oxidising atmosphere at point 1 (Fig. 6) would rarely be detrimental as diffusion would cancel out oxidation.

The last few hours at maximum temperature are usually a safety factor to cover temperature and compositional variations. From decarburisation and graphitisation data, therefore, it would appear that a curve of the type shown in Fig. 10 is a practical way of utilising those facts and producing true blackheart. Safety is ensured through a number of hours at gradually decreasing temperatures—temperatures, however, at which the austenite is still giving up part of its carbon as graphite.

Summarising this type of "picture-frame" malleable, it is suggested that it is almost impossible to graphitise decarburised sections where the carbon content has been reduced to below 0.9 per cent. Pearlite is the stable form of carbon in these conditions, and although the reactions necessary for decarburisation are reversible and can result in recarburising, it is not thought that this is the reason for these heavy pearlitic rims. Incidentally, Howe succeeded in completely graphitising a 0.3 per cent. carbon steel—but only in the presence of over 3 per cent. silicon.

Indentation Hardness of Malleable

Brinell hardnesses of whiteheart and blackheart cast irons are shown graphically in Figs. 11 and 12, which indicate that it is possible to visualise the comparative machining speeds. Therefore, from a machining point of view, there is some justification for demanding blackheart in preference to whiteheart unless the latter is limited to thin-section castings only. There are, however, many intricate castings of thick and thin sections, and if whiteheart is chosen the machining of the thick sections must inevitably be somewhat slower than that of blackheart. If blackheart be chosen then certain foundry difficulties may present themselves. Usually the carbon content of whiteheart hard iron is higher than that of blackheart hard iron. The resulting extra fluidity is of considerable value in running intricate thin and thick sectioned castings. The use of a hard iron of suitable high carbon but of suitable composition for graphitising and therefore for making blackheart might suggest itself. This is of course possible, but under existing B.S. Specifications the minimum tensile strength demanded for whiteheart or blackheart is 20 tons per sq. in. The use of a truly high carbon content giving iron of sufficient fluidity to produce good sound castings of intricate thin and thick sections, usually involves that however well controlled the annealing technique, the tensile strength is often below 20 tons per sq. in. on a 0.564-in. bar although elongations of up to 12 and 14 per cent. can still be obtained. The bend value, too, is comparatively low—in the region of 70 deg. on the standard bar. It is possible, however, to utilise the advantages of a high-carbon content without materially affecting the normal physical properties of blackheart castings by combining the graphitisation and decarburisation processes.

Fig. 13 shows the edge of a high-carbon hard iron, annealed under decarburising and graphitising conditions. The decarburised edge of ferrite reveals a very slight band of scattered pearlite, and towards the centre, the normal ferrite-temper carbon structure.

In Fig. 14 the centre of the same section is shown; it consists of normal temper carbon and ferrite, the temper carbon being rather larger than normal low-carbon blackheart. The tensile strength of the material was 24 tons per sq. in. associated with 14 per cent. elongation and the 180-deg. bend on the normal bar, whilst hammering and deforming tests seemed quite normal. In this way a product can be obtained giving 22 to 26 tons per sq. in., 10 to 14 per cent. elongation, and 180-deg. bend. There appears to be a great future for malleable iron of this type.

The advantages of a high initial carbon content are self evident. In America, pipe fittings are invariably made of cupola blackheart because soundness is of paramount importance. Smaller feeders can be used resulting in a saving in iron and fuel, and nowadays this fact is of some importance. One eminent engineer, when discussing whiteheart and blackheart, stated: "The future malleable cast iron for engineering purposes will be a semi or intermediate product possessing the best combination of mechanical properties of well-made material of both types."

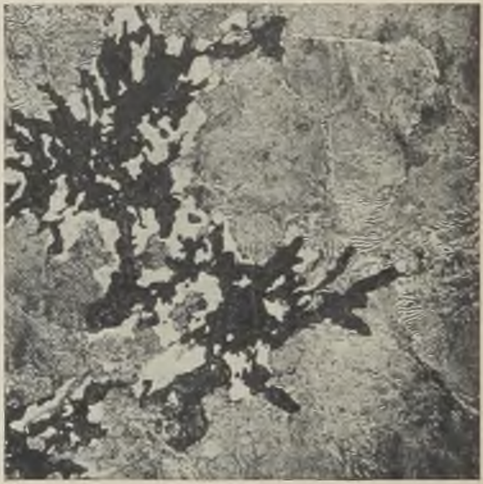


FIG. 15.—TEMPER CARBON IN FERRITE IN PEARLITE MATRIX. ETCHED PICRIC ACID. × 250.

Pearlitic Malleable

Additional types of malleable have recently been developed, called "pearlitic malleable," "heat-treated malleable," and malleable under various trade names, such as "Promal," "Z metal," etc. The American Foundrymen's Association has put forward the following tentative definition:—

> "Any material which starts out as white cast iron, and is subsequently heat-treated to produce graphitisation, is to be called 'pearlitic malleable,' if the graphitisation be

purposely terminated when sufficient combined carbon remains, significantly to affect the properties of the product. The combined carbon is often present as pearlite, sorbite, or might be martensite or some other form of decomposition product of austenite."

Pearlitic malleable can be divided into two main groups, produced by (1) stopping the annealing process before graphitisation is complete, or (2) reheating completely graphitised metal.

Consider the first group from Fig. 10. At the highest temperature (900 deg. C.) reached during annealing the structure consists of austenite, graphite, and still some free cementite. If first-stage graphitisation was stopped here (at X) and the normal cooling was allowed (thus permitting complete second-stage graphitisation), the final product would have a structure consisting of some primary cementite, in the normal ferrite-temper carbon background.

Such a material could be used for resistance to wear in the same way as Babbitt metal, containing as it does a hard constituent (cementite) embedded in a soft material (ferrite), with the temper carbon acting as a definite aid to lubrication. By cooling at a fast rate from Y second-stage graphitisation would be prohibited, the solid solution of austenite at this point containing 0.4 to 0.6 per cent. carbon changing almost completely into pearlite.

The structure finally obtained would be temper-carbon nodules in lakes of ferrite—what is commonly known as a "bull's eye" structure. This structure is shown in Fig. 15. The tensile strength of such material would be in the region of 28 to 32 tons per sq. in., with 6 to 10 per cent. elongation; in other words, reasonably high strength plus a fair amount of ductility. The Brinell hardness of the "bull's eye" structure is shown graphically in Fig. 16.

There are certain difficulties in either of the methods just mentioned, for it is difficult, even with most accurate control, to stop graphitisation at a certain definite predetermined point. This annealing technique would naturally involve the use of special ovens. The second group is by far the most feasible—by reheating completely graphitised metal, thus not interfering with normal production. Actually the same fundamentals are involved as in the first group, because a completely graphitised iron reheated for sufficiently long periods above the A_1 critical point is, metallurgically speaking, identical with a white cast iron held to equilibrium at the same temperature. For instance, if heated to 840 deg. C., a temperature the same as the point previously indicated, and allowed sufficient time at that temperature, the structure would be austenite of about 0.9 per cent. carbon content and temper-carbon nodules. Air-cooling would allow the austenite to decompose into pearlite. The final product would be "bull's eye" structures similar to those just shown.

On the other hand, oil-quenching from 840 deg. would result in the austenite decomposing into sorbite, and from water-quenching the austenite would probably decompose into martensite or troostite, depending on the sectional thickness and how drastic the quenching was. With a sorbitic structure, strengths as high as 35 tons per sq. in. with elongations of 4 to 5 per cent. can be attained. With martensite-troostite structures 40 to 45 tons per sq. in. and elongations of 1 to 3 per cent. are usual.

Tempering Malleable

These quenched materials could with advantage be subjected to a tempering treatment such as is given to medium and high-carbon steels and with comparatively the same beneficial results. It will be seen, therefore, that almost any form of combined carbon can be produced at will by experienced operators with tensile strengths ranging from 20 to 45 tons per sq. in. and inversely elongations of 18 per cent. down to 1 or 2 per cent.

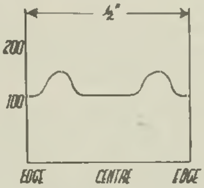


FIG. 16.—BRINELL HARDNESS OF IRON SHOWN IN FIG. 13.

Influence of Alloying

So far the Paper has dealt with metals of normal composition suitable for complete graphitisation, but it will be readily seen that alterations of composition and the addition of alloys enlarge an already wide field. The influence of various elements on the stability of iron carbide during casting and upon graphitisation during annealing is as follows in order of importance:—*Those promoting graphitisation* are: Si, Al, Ni, Cu, Co and P, and *those rendering the carbides more stable* are: Mo, W, Mn, V, S and Cr. Manganese is probably the most commonly used element in the production of the so-called pearlitic malleables, 0.5 to 1 per cent. above that used in normal production being fairly common. This element particularly affects second-stage graphitisation. Ladle additions of ferro-manganese to normal iron followed by normal annealing result in the retention of combined carbon from the second-stage graphitisation in quantities almost proportional to the amounts of manganese used.

There are certain dangers in ladle additions of any alloy which should be mentioned at this point, for if the original composition is a borderline one, the possibility of primary graphite separating out during casting is quite feasible. Obviously, also, the choice of an alloy to be used to stabilise the carbide must be one which, when diluted in the ordinary scrap, cannot affect the normal material in any way. Chromium, although useful for stabilising carbides in small amounts, is particularly dangerous unless production is entirely of the pearlitic malleable type.

The field of pearlitic malleable is also extending in the same direction as that of various alloy steels. For instance, Chubb stresses the advantages to be gained from a combination of very high silicon contents and the use of molybdenum, claiming that there is very little fear of primary graphite being precipitated during casting even in very thick sections, and claiming also that the high silicon will then allow of a reduction in annealing time. Incidentally he gives figures as high as 47 tons tensile with 5 per cent. elongation, or 27 tons tensile with 17 per cent. elongation. Pearlitic malleable irons are usually of higher strength and lower elongation than normal blackheart, the permeability is lower and the net shrinkage from pattern size is rather less than that of normal blackheart probably due to incomplete graphitisation. The machining is obviously slower.

Fig. 17.—Example of a Good Case Produced by Cyanide Case-Hardening of Malleable. × 94.

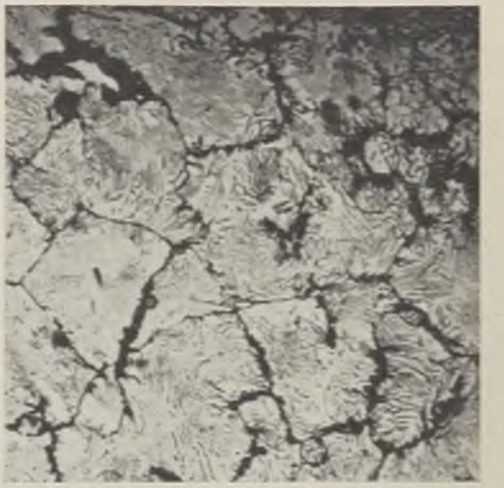


Fig. 18.—Centre of Blackheart Section After 30 mins. Heating at 950 deg. C., then Oil-Quenched. Etched Sodium Picrate. × 400.

Cyanide Case-Hardening

Another specialised treatment of malleable which is particularly important at the moment is that of cyanide case-hardening. As the name implies, the process aims at producing an intensely hard surface suitable for resisting wear. The process consists of heating the malleable castings to and holding at 950 deg. C. or 900 deg. C. for 30 minutes in a cyanide salt bath. They are then either (1) quenched direct in oil, or (2) cooled in air, reheated in cyanide to 800 deg. and quenched in oil. This latter treatment gives somewhat better ductility, probably due to the partial tempering in heating up to 800 deg. C. again before final oil quenching. An intensely hard case of 550 to 600 V.P.N. (450 to 530 Brinell) is produced. The core hardness will vary according to the type of malleable used: obviously, true blackheart, particularly the high-silicon, low-carbon type, will be rendered extremely hard and in most cases brittle by the drastic reheating and soaking.

The resolution of graphite and consequent precipitation of cementite are almost inevitable, and although V.P.N. figures of 200 to 250 in the core together with tensile strengths of over

40 tons can be obtained, the form and shape of the cementite usually render the material liable to failure by shock.

On the other hand, if whiteheart malleable is used, particularly if great care has been taken to achieve a very high degree of decarburisation, the case-hardening treatment will have little material effect on the core. The result is then an extremely hard case plus a moderately ductile core, capable of withstanding abrasion and shock. Failures to achieve this ideal are due to the core of the original castings, prior to treatment, being too hard, resulting in failure by shock, or when trying to avoid the above, such intensive decarburisation has been attempted that peeling has resulted. The effect of cyanide hardening a peeled skin of iron oxide need not be described.

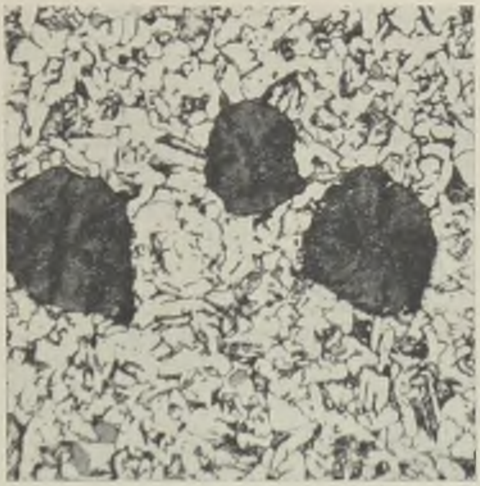


Fig. 19.—Centre of Whiteheart Section After Same Treatment as for Fig. 18.

Fig. 17 shows a good case; the magnification is 94 and the depth of the case is 15/1,000. Fig. 18 shows the centre of a blackheart section after 30 mins. at 950 deg. C., followed by a direct oil-quench. The resolution of the graphite and the consequent appearance of the cementite render this core rather brittle. Fig. 19 shows the centre of a similar whiteheart section after treating, the difference in ductility being very apparent.

Fig. 20 shows another example of blackheart, which was air-cooled, reheated to 800 deg. C., and oil-quenched. The core would be considered fairly satisfactory.

A rough idea of the way the hardness jumps for whiteheart and blackheart after cyanide case-hardening is given in Figs. 11 and 12, where these hardnesses are shown as dotted lines.

Effect of Various Elements

Though it is usual to deal with the elements separately, it is felt that the effect of carbon must be considered together with that of silicon, for a high carbon necessarily means a low silicon in order to avoid the precipitation of primary graphite in the original hard casting. *Vice versa*, low total carbons are naturally associated with high silicon contents.

The choice of a suitable carbon content for normal production depends essentially on the type of casting to be produced. Obviously better physical results can be expected in either blackheart or whiteheart, the lower the total carbon. For instance 2.3 per cent. carbon would give approximately 24 tons and 18 per cent. elongation, whilst 3.3 per cent. carbon would give 19 tons and 12 per cent. elongation on 0.564 in. dia. bars—both being annealed to give a true blackheart of ferrite and temper carbon. This is mainly due to the difference in size and amounts of temper carbon, although it can be definitely stated that the ferrite strength is increased with increased silicon percentages.

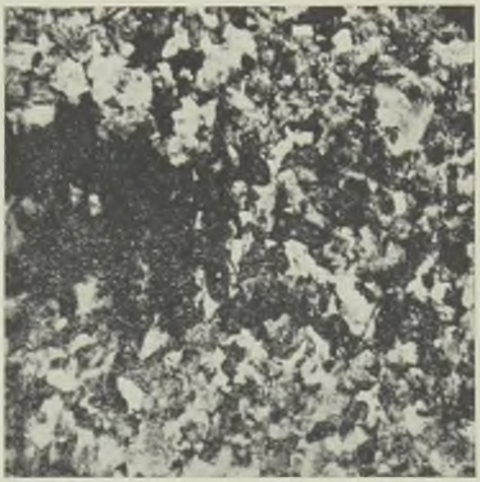


Fig. 20.—Blackheart After Air-Cooling, Reheating to 800 deg. C., and Oil-Quenching. × 400.

From a practical and commercial point of view, successful production of thin and intricate small-section castings necessitates rather high total carbons, and naturally the heavier the general run of castings, the lower the total carbon can be. Here again there is a practical low limit for normal production, this being about 2.3 to 2.5 per cent. C. Below this point, casting difficulties offset the possible physical-test and annealing advantages.

Various elaborate formulæ have been given correlating carbon and silicon percentages, and although these form a good guide, they may not always apply to the type of furnace and melting conditions, and a certain amount of trial and error is necessary before standardising on definite percentages.

So far reference has been made to normal production because the use of very low total carbons and high silicons is the very basis of short-cycle malleable irons, carbons of 1.5 to 1.7 per cent. and silicons of 2.0 to 2.5 per cent. being fairly common. These border-line compositions are very susceptible to melting and pouring-temperature variations, and are thus prone to the production of primary graphite. Control therefore must be extremely accurate or otherwise worthless material may escape the inspectors. Fig. 21 illustrates the fracture of a 3-in. section of a "white" cast iron showing mottle, and Fig. 22 shows the type of graphite resulting after annealing iron containing primary graphite. Such iron is inferior to ordinary grey cast iron.

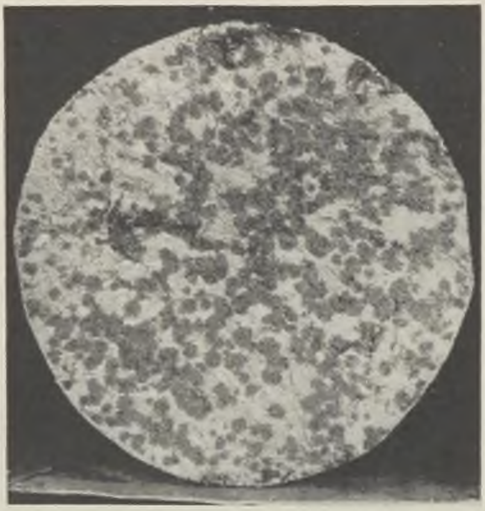


Fig. 21.—Fracture of 3-in. Section of "White" Cast Iron Showing Mottle.

Unfortunately border-line compositions are apt to precipitate primary graphite in unexpected places, such as thin sections, with the thicker sections perfectly normal. This often happens at local hot spots in the mould and can easily escape detection until the casting fails in service.

Manganese and Sulphur

Manganese must be considered in connection with sulphur. For successful graphitisation manganese must be present in such proportions as to balance the sulphur, *i.e.*, manganese should be present in the atomic ratio of 1.72 times the percentage of sulphur. Sulphur is then present as manganese sulphide. As a safety factor in the production of blackheart, a slight excess in the region of 0.1 to 0.2 per cent. is usually maintained. For the production of whiteheart, the sulphur and manganese should be present in equal percentages to ensure the presence of ferrous sulphide, so restraining graphitisation and speeding up decarburisation. Even so high a sulphur content as about 0.4 per cent. should be avoided, particularly in heavy-section castings, as this would necessitate such prolonged high temperature annealing, to eliminate primary cementite, as to be commercially impracticable.

Influence of Phosphorus

Phosphorus is rarely found above 0.1 per cent. in this country but can be as high as 0.2 per cent. without material effect. Above 0.2 per cent. it is not soluble in the ferrite and forms iron phosphide, which, on account of its low melting point, must be avoided. In America, however, white-fracture malleable, sometimes called temper embrittlement or white ferrite, is often found when phosphorus contents of 0.2 per cent. are associated with high silicons. Forbes describes this malleable as "moderately ductile with practically no combined carbon, easily machinable, breaking with a white crystalline fracture and appearing normal under the microscope." He suggests that the white fracture is caused by the fracture following the crystal boundaries, thus exposing the surfaces of crystals and giving a steely appearance, whereas, in normal blackheart, when broken the crystals elongate to points and have no smooth reflecting surface. He also suggests as reasons: (1) Weakness of intercrystalline cement and/or (2) the extra strength of ferrite. In any case, the phenomenon is unknown in England because of the low phosphorus content of the irons used.

Alloy Additions

Much data have been published on the use of alloys in malleable iron, and these make interesting reading, but it is necessary to decide carefully if the advantages to be obtained from the use of alloys for the production of normal structure malleable will offset the increased cost. No reference is made to pearlitic malleables, for here the use of alloys, plus a trade name, plus careful propaganda, render the proposition a commercial possibility. A personal opinion is that the use of alloys to diminish the time of annealing, although this is a distinct possibility, rarely justifies the increased cost. Provided that the malleable produced conforms to a required specification, it is maintained that the engineer demands primarily maximum machining speed plus dimensional accuracy, plus reasonable finish, and it is doubtful if any alloyed malleable will give more satisfaction in these respects than correctly produced normal material.

The use of copper has been advocated as a means of reducing annealing time and graphite size. These claims are undoubtedly correct, but to take full advantage of this element the annealing technique must be one involving the use of either small batch-type ovens capable of very accurate control or a continuous annealing furnace. Here again—given the above furnaces—it might be necessary to consider whether the extra cost of copper was justified.

Having mentioned reduction of graphite size, a digression seems desirable to discuss some recent experiments carried out by Schwartz, Schendler, and Elliot.[4] Four samples of the same white cast iron were taken, and treated as follow: A was heated to 950 deg. C. for 1 hr., oil-quenched and tempered at 500 deg. C.; B was heated to 825 deg. C. for 1 hr., oil-quenched and tempered at 500 deg. C., and C was untreated. These three were then given a commercial anneal. The 4th sample, D, was heated for 73 days at 725 to 710 deg. C. All four samples were completely graphitised.

In the case of A there were 40,000 nodules of temper carbon to each cubic mm.; for B there were 28,000; for C 135, and for D 30.

It seems therefore relatively simple to cause a given white iron to deposit a variety of sizes of temper carbon, and it would be interesting to carry the experiment a stage farther, in order to ascertain whether the preliminary oil-quench and temper might possibly accelerate graphitisation.

Schwartz had already proved by a special etching treatment that the physical test results were in direct relation to the as-cast structure, and these recent experiments add again to existing knowledge of malleable cast iron and confirm its immense possibilities.

Raw Materials and Their Melting

Metallurgists, or perhaps one should say "chemists," have in the past contended that almost any mixture of pig and scrap which would give a definite required analysis could be relied upon to produce consistent results for a given annealing treatment, and have in consequence derided the old-fashioned foundryman who insisted that pig-iron had inherent properties and that while one brand would give good results, the addition of another brand, even though the same analysis was obtained, would lead to the production of inferior material. The foundryman, for once, was right, and no one has done more to prove this point than Hurst.

These facts are probably the main reason why manufacturers in this country, with few exceptions, have fought shy of the so-called "quick-anneal" method. During the normal, rather lengthy, annealing cycle, these inherent differences tend to be ironed out, and do justify the safety factor obtained by such anneals. In fact, one of the biggest producers of short-cycle malleable in the States keeps a metallurgist permanently stationed at the blast furnace from which they draw their iron, stating that the operation of the blast furnace and composition of the burden play an important part in the production of sound castings which will readily anneal.

It has been suggested, and to some extent proved, that superheating of the metal would eradicate these inherent properties. Some investigators claim that nuclei are present to a greater or less degree in different brands of iron when molten. These nuclei are sometimes called graphite nuclei and it is suggested that they affect the precipitation of graphite during annealing. They further claim that superheating tends to refine or dissolve these nuclei. On the other hand, Norbury and Morgan[10] suggest the nuclei are not undissolved graphite, but non-metallic inclusions such as silicates, oxides,

Fig. 22.—Type of Graphite Resulting After Annealing Iron Containing Primary Graphite.

sulphides and so on, which have such high melting points that they are solid before the metal solidifies and thus act as centres for the precipitation of graphite.

Whichever theory be correct, practical experience will confirm that superheating the metal to temperatures higher than those necessary for casting will tend to iron out differences due to the use of different brands of iron, thus rendering control of graphitisation more positive and introducing yet another safety factor.

From a practical point of view superheating must be carried out with caution; it is expensive and this must be balanced against possible advantages, and secondly care must be taken to avoid burning the molten metal. This burning or oxidation is not always characterised by excessive carbon, silicon and manganese losses, and can result in metal of very short life, poor fluidity and so on, which is extremely difficult to correct.

This phenomenon is also sometimes met with in attempting to use large percentages of steel scrap in any furnace other than a cupola. It is suggested that many conservative manufacturers, jealous of their reputations, avoid the use of high steel-scrap percentages. For practical reasons the superheated metal should not be poured from the temperature which it has attained.

In theory various advantages can be tabulated for the use of very high pouring temperatures, such as fine grain size due to chilling, cleaner metal, less risk of primary graphite, but in practice the use of too hot metal means greater fluid contraction—and hence larger feeders. The high contraction, moreover, may lead to the cracking or tearing of castings with thin and thick sections adjoining. So once again theory must be tempered with practice and economy.

In conclusion it seems desirable to stress the fact that malleable iron founders are required to produce castings possessing certain qualities and physical properties, to deliver these at an agreed time, and for a price which is less than that of a similar article made in a competitive material. Moreover, though the fundamentals governing the production of malleable castings have been known for many years, the author hopes that he has succeeded in showing, by demonstrating the application of these fundamentals, that malleable cast iron has immense possibilities and should play no little part in the present war effort. Finally, he wishes to thank the directors of Castings, Limited, Walsall, for their encouragement and permission to give the Paper, and also the B.C.I.R.A., and in particular Mr. Timmins and Mr. Morogh, for their help in connection with the photographs.

REFERENCES

[1] " Malleable Cast Iron " by G. R. Shotton and H. G. Hall, " Foundry Trade Journal." May 29. 1930. p. 403, Fig. 14.

[2] *Loc. cit.* (Fig. 15).

[3] *Loc. cit.* (Fig. 16).

[4] " Relation of Carbon Nodule Size and Tensile Properties," Trans. A.S.T.M., 1939. Reprinted " Foundry Trade Journal," Oct. 5, 1939, p. 234.

[5] " Physical Chemistry of the Metals," Chapman & Hall, Ltd., London, 1919.

[6] " Some Notes on the Malleablisation of White Iron," ' La Fonte," 1938. Reprinted " Foundry Trade Journal." Jan. 5. 1939, p. 6.

[7] " Decarburisation of Granulated Pig-Iron : The R.K. Process," Jour. I. & S.I., Vol. CXL, 1939, p. 137P.

[8] Paper presented to the International Foundry Congress, Paris, June, 1937. Summarised in " Foundry Trade Journal," Sept. 2, 1937, p. 179.

[9] " Alloying of Malleable Iron," " Foundry Trade Journal," Dec. 9 and 16. 1937. p. 457 and p. 465.

[10] " Effect of Non-Metallic Inclusions on the Graphite Size of Grey Cast Iron," Jour. I. & S.I., Vol. CXXXIV, 1936, p. 327P.

[11] " Banded Structures in Cast Materials," " Die Giesserei," No. 2, 1938. Reprinted " Foundry Trade Journal." April 14, 1938. p. 306.

DISCUSSION

The Branch-President (Mr. A. Tipper, M.Sc.), in thanking Mr. Hall for his excellent Paper, said that the preparation of such a Paper obviously meant considerable sacrifice, and for that reason the members were extremely grateful to him. Mr. Tipper said he had been particularly interested in the way Mr. Hall had described the sort of balance between the taking up of cementite by the austenite, and the breaking down of the austenite into ferrite and graphite. The author had also given a graphic picture of what went on under graphitisation and the decarburisation process.

Better Definition Needed

Mr. G. R. Shotton thanked the lecturer for his comprehensive survey of the recent developments in malleable cast iron, but said he must take exception to one phrase in the definition of malleable iron. It was to the effect that malleable cast iron was a white iron free from primary graphite as cast in which part or all graphite was broken down by annealing. He thought the phrase " part or all " was too loose. By heating up for a few minutes and producing one speck of graphite, it became a malleable casting. He agreed with Mr. Hall's remarks concerning short-cycle malleable, but he did not think its development in this country was likely to succeed rapidly. When producing castings of various sections they could not force concentration close to the danger line, as the danger of getting primary graphite became great.

Mr. Hall's remarks concerning cyanide hardening were interesting. The same thing applied to whiteheart unless it was particularly good whiteheart initially. Although the process was very successful, it was only so when applied to particular types of work and under strict control. He had seen whiteheart castings that would break when dropped on the floor in the same way as blackheart castings would. In regard to pearlitic malleable, the author had said that the net shrinkage was less than normal blackheart, but although he did not know definitely he would have expected that the net shrinkage from the pattern size would have been greater.

Short-Cycle Malleable

Mr. Hall, replying to Mr. Shotton, said that the definition of malleable iron he gave was actually the best he had seen. Mr. Shotton was correct in saying that the particular phrase "part or all graphite" was a little loose. He himself had a little difficulty in putting it clearly, but fundamentally he thought the definition was a sound one. In regard to short-cycle annealing, they semed to be much of the same opinion. If iron was decarburised to a depth of $\frac{1}{4}$ in. and then re-annealed,. the austenite from the centre travelled towards the edge, and at the end of annealing the structure was fairly uniform from centre to edge. It reduced the carbon content to such an extent that complete graphitisation was rather difficult, but it did tend to point to the fact that reheating tended to even things out. He would suggest that pearlitic malleable could be successfully produced from inferior original malleable. That reaffirmed his idea that annealing could be carried on in a gas atmosphere, if that gas atmosphere could be controlled to produce decarburisation at will. Mr. Shotton was correct concerning the expansion of pearlitic malleable. What it was meant to convey was that in the final stage the casting would be slightly smaller than if made in blackheart iron.

Pearlitic Malleable

Mr. A. J. Shore wondered if Mr. Hall could indicate the scope of the application of pearlitic malleable. Would it be possible to use it in connection with hydraulic cylinders and rams, where high pressures were required, and how did it compare with steel castings both from the question of performance and price? Was it easier or more difficult to produce than steel castings? The surface finish of small steel castings was often criticised, and he wondered if a better finish could be obtained on such malleable.

Mr. Hall said he had already suggested one way in which it could be used as a bearing metal. Its application originally was for brake-drums and gears, and also for castings in cement mills in place of steel castings. The finish generally was of a much higher order than that of steel castings. One particular advantage of pearlitic malleable made by reheating was that it allowed of freer machining and a final heat-treatment. After that final heat-treatment the metal would probably be too hard to machine. The obtaining of a certain degree of hardness was far more difficult than obtaining the same degree of hardness in steel, because there was a potential background over 2 per cent. of carbon to be dealt with. It was rather difficult to control thin and thick sections from that point of view. Thin sections produced a harder matrix than thick sections, and in the following quenching the thin section would be hardened far more than the thick section. It was not so easy, as it seemed to produce pearlitic malleable with a definite range of Brinell numbers, which was the only way of checking up hardness. There was so much surface decarburisation present that one might get a figure of 150 or 160 on the surface, while the body of the casting would be well over 200. Although its field of possibilities was enormous, the control necessary was very difficult, particularly in regard to castings weighing about a cwt. Then the quenching of heavy-section castings would, he was afraid, set up so many strains that it would be inadvisable.

Influence of Sulphur

Mr. A. A. Timmins added his quota of praise of Mr. Hall for his clear definition of an interesting subject. It was difficult to offer criticism, but he did not think he sufficiently stressed the influence of sulphur on white malleable iron. That was one of the bugbears of the majority of whiteheart irons produced in this country. It probably dated back to the old days when malleable founders mostly used white pig-iron or a grey pig-iron which was cupola-melted material. High sulphur content was detrimental from an annealing point of view, but at the same time sulphur was a definite advantage to whiteheart malleable in that it prevented graphitisation while decarburisation proceeded.

That was an important point from the malleable point of view which did not arise in the case of blackheart iron, because there was better control in the melting furnace. In regard to short-cycle and pearlitic malleables, he had heard it said that there was no difference in the chemical properties of the short-cycle malleable and blackheart material, the only change being that the annealing cycle was shortened. He was somewhat surprised that Mr. Hall did not say more about the type of pearlitic iron known as Z-metal. In his opinion that was the type which was likely to be more rapidly developed than any other variety because of its good combination of strength, ductility and machinability.

Mr. Hall said he was under the impression that he had stressed the influence of sulphur in the way that Mr. Timmins had indicated. He wondered why this country had not gone in more for the high-manganese type of whiteheart than for the sulphur type. A certain diffusion of sulphur took place under decarburising conditions, and Dr. F. Roll[11] had indicated that that migration of sulphur actually formed big points of sulphur just under the surface which coincided with a layer of fine pearlite. From that he argued that there was a certain recarburisation taking place which gave a fine layer of pearlite. He agreed with Mr. Timmins that Z-metal was probably the most likely type of malleable to be developed. Short-cycle blackheart was as good as normal blackheart, providing there were no pearlite areas on the edge In regard to short-cycle annealing, the chief difficulty was the use of high temperatures initially. One of the reasons why it was not popular in this country was that small quantity production with small batch-type ovens must be adopted, and the temperature kept up and held for a definite time.

Limit of Phosphorus Content

Mr. J. Bell declared it was refreshing to hear a lecture on malleable iron without the author being biased in favour of whiteheart or blackheart iron. He was not quite clear whether 0.2 per cent. limit of phosphorus was permissible in whiteheart or in blackheart iron.

Mr. Hall stated that 0.2 per cent. of phosphorus could be regarded as the limit, but, as he had indicated, there were certain dangers. In regard to cyanide hardening, he really did not see why it should not be applied to blackheart, providing it was sufficiently decarburised.

On the proposition of Mr. Bell, seconded by Mr. L. W. Bolton, the lecturer was heartily thanked for his Paper.

Birmingham Branch **Paper No. 718**

Electric Motor Castings in Green Sand

By JOHN HIRD (Associate Member)

This Paper is a description of the making in green sand of a 4 ft. 6 in. dia. electric motor casing or shell weighing 22 cwts. and the end covers for the same motor. When instructions were received to make this particular casting, the largest casting so far made in the foundry was 2 ft. 4 in. dia.

Deciding Upon the Moulding Method

The usual method of making these castings is in dry sand or by striking them up in loam, thus avoiding the need of making a complete pattern. Four factors had to be considered when deciding upon the method to be adopted: (1) The crane is only of 3 tons capacity; (2) there is no suitable mould-drying stove; (3) the foundry floor is concreted all over; and (4) the quantities off these castings, while not initially large, were likely to increase in the future.

FIG. 1.—COMPLETED CASTING READY FOR MACHINE SHOP.

It was decided that if the moulding boxes were kept as light as possible and a minimum amount of sand used, the crane would be adequate. This was possible if the green-sand method was used, and it eliminated the second and third factors. The making of a permanent pattern suitable for green-sand moulding satisfied the fourth factor. A further consideration was that, should it prove impracticable to make these castings in green sand, the cost of a waster would be small compared with that of a core stove sufficiently large to dry these moulds.

There is, of course, the alternative and "half-way house," skin drying, which is often unsatisfactory owing to uneven drying, and the risk of burning in one part while other parts remain green or strike back. On these considerations it was decided to make the first casting in green sand.

Fig. 1 shows the completed shell casting ready to go to the machine shop. It is 4 ft. 6 in. dia. and 2 ft. 4 in. wide, with a wall thickness of $\frac{3}{4}$ in. There are ten ribs, $2\frac{1}{2}$ in. thick by 6 in. wide in the centre, and stepped down at each end to 3 in. wide for a distance which varies at each end. The flange round each end is 1 in. thick and $2\frac{1}{2}$ in. wide.

The triangular holes in the feet are at both sides of the shell and were asked for by the

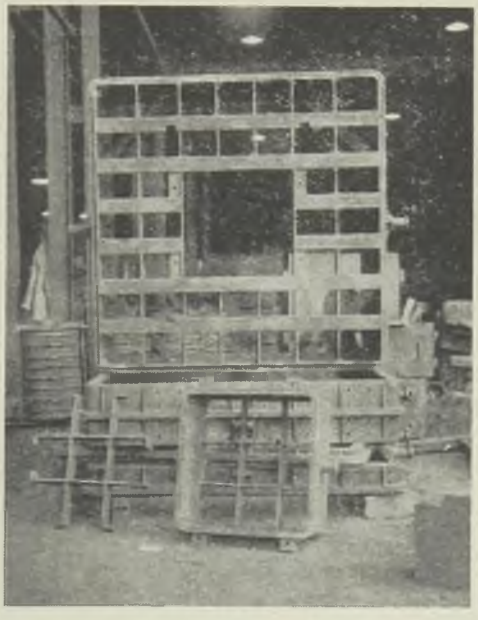


FIG. 2.—WELDED BOX PARTS USED.

foundry to help to support the feet cores and enable the feet core prints to be kept small, and so allow the size of the moulding box to be at a minimum. Actually the feet core prints are only $1\frac{1}{4}$ in. wide. This is a good example of the excellent co-operation which exists between the foundry and the drawing office. As every foundryman knows, such co-operation is a great asset in making satisfactory castings economically.

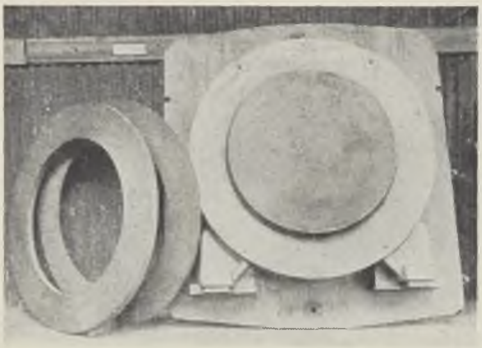


Fig. 3.—Half Pattern for Motor Casing.

The hole in the side of the shell is for leading the cables to a terminal board. This feature is not permanent, but will be altered to suit the wiring needs of each order.

Moulding Boxes

The welded steel moulding boxes, shown in Fig. 2, were designed and purchased, the main reason for using such boxes being to keep the weight within the capacity of the crane. The total weight of these boxes, which are 5 ft. square, is 27 cwts. The top box alone weighed 10 cwts. The dimensions left only 3 in. of sand between the edge of the pattern and the box.

One top part was made 17 in. deep, and the three other parts to be used as middle or bottom parts as required were 4 in., 6 in. and 12 in. deep. The various depths are arranged so that the boxes can be built up to suitable depths for making the end-cover castings, of which there are two depths. The bars in the top box are arranged so that there is a 2-ft. square opening in the middle, fitted with detachable bars to be taken out when making the shell casting. This is to allow a 2 ft. square by 1 ft. deep extension box to be added when making sleeve-bearing end-covers.

Lugs are arranged on all parts, so that any assembly can be bolted together from top to bottom by four 1 in. dia. bolts, and $1\frac{1}{4}$ in. dia. pins are used for locating the pattern and moulding boxes. A $\frac{3}{8}$-in. thick bottom plate was purchased with a 2-ft. dia. hole in the centre and strongly ribbed on the back, the front being machined all over, as were all joint faces on the moulding boxes.

Shell Pattern Employed

A half-pattern (Fig. 3) was made and mounted centrally on the pattern board. The pin-holes are placed between the feet. Both top and bottom halves of the mould are rammed off this half-pattern. The print to take a core to form the hole in the side can be changed over from one side of the pattern to the other, for top and bottom moulds.

As several widths of shell will be required, the pattern is made to the *narrowest* width that will be wanted, and the print for the body core is made $3\frac{1}{2}$ in. long. This leaves a $1\frac{1}{2}$-in. long print when the widest shell is being made. Rings fit over this print to make the pattern width up to that required for any particular shell casting. This can vary from 28 to 32 in. The depth of the moulding box is arranged so that the print comes to the top of the box in both top and bottom moulds. There being no sand over the print, this is possible, as the height of the print does not vary, whichever width of shell is being made. This makes a hole right through the mould.

In the bottom half the 2-ft. dia. hole in the bottom plate is a few inches smaller than the diameter of the print. In the top half-mould the 2-ft. square section fitted with the loose bars has the bars removed, and the print comes up to the bottom edge of the bars. No sand is rammed in the square opening. Round rods, $1\frac{1}{2}$ in. dia., are placed on the feet in the centre of the place where the triangular pad on the feet cores cuts through. These rods are wedged under the bars in the top part, and rest on the

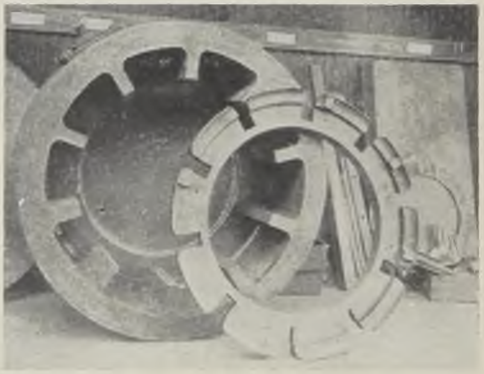


Fig. 4.—Half Core Boxes Used.

bottom plate in the bottom part. They connect directly on to other rods running right through each half of the foot cores, and ensure that the foot cores will not lift when casting. The 1¼ in. wide prints on the feet only act as location prints, and are not intended to take much of the weight or lift of the cores.

Core Boxes

A half core box (Fig. 4) was made, as the two halves of the core are identical, with the exception of the print for the round cored hole in the side, which is changed over for the top and bottom half-cores. The body of the core is made to suit the *widest* shell required. The bottom of the print is made to the same depth from the joint as the top of the print on the pattern to the joint.

Rings are placed in the bottom of the body of the core box when not making the widest shell, to bring the body of the core down to the width required. Conversely, the rings are taken off the pattern when not making the widest shell, to bring the height of the pattern down to the width required. The 2½-in. by 6-in. ribs previously mentioned as being stepped down at each end are the full width right through the core box, the step being made by inserting green-sand cores of the required length into the recess formed by the ribs on the body core, before coring-up. The steps are of a different length at each end of the shell, and vary in different shells from 2 to 6 in. at each end.

These cores eliminated the necessity for interchangeable loose ribs in the core box. As there are at least six varying lengths of these ribs, this obviated a considerable amount of patternmaking.

Original Design of Core Grid

The grid shown in Fig. 5 is a ring, open at both ends, made of ¾-in. plate with ½ in. dia.

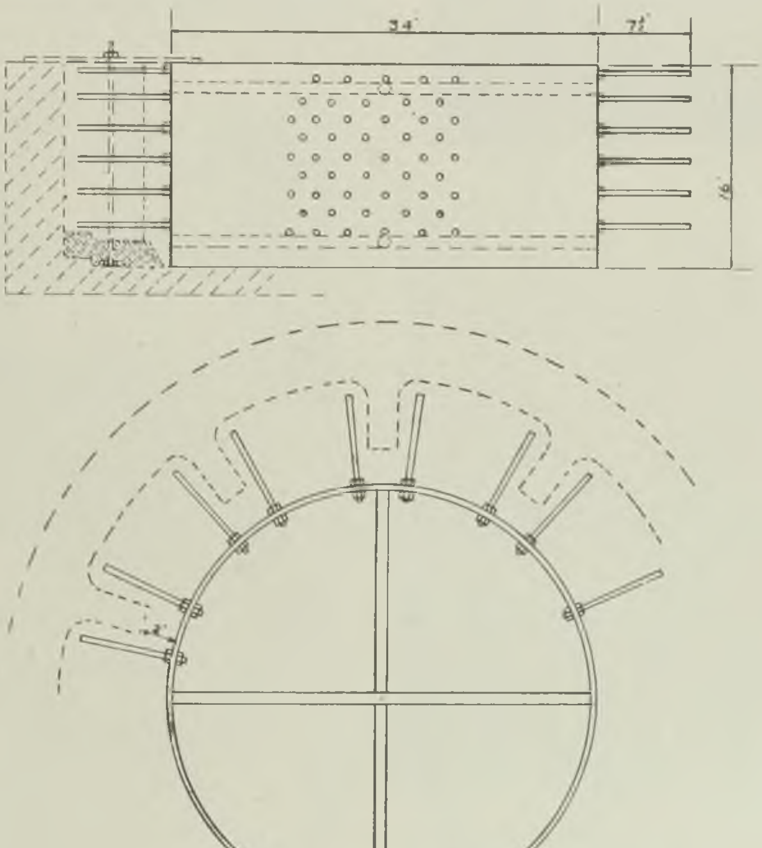


Fig. 5.—First Type of Core Grid.

holes at 3-in. centres, stiffened by two 1-in. dia. rods across each end. Gaggers, made by threading ½-in. dia. rods 1½ in. at one end and locking through the holes in the grid with a nut each side, were used. These were placed so as to be each side of the ribs in the core box, and were extended to within 1 in. of the outside of the core box. About 120 of these were used in each half of the core. It was thought that, being a green-sand core, the sand would give when the contraction came into play, and that provision need not be made for contraction in designing the grid.

Fig. 6.—Top Half of the Core.

The core, whilst being 4 ft. 2 in. across, has only 2 in. of sand from the root of the ribs to the grid, which was made to fit in the print at the bottom of the core box, and was exactly level with the joint. The object of the grid, besides carrying the sand, is to vent the core quickly and freely, and to minimise the weight of the core. The bottom half-core is lifted out of the core box with an adjustable four-hook sling. This is assisted by using the ring in the bottom of the core box as a lifting or stripping plate. Four ½-in. rods, threaded at each end, are arranged with a nut, countersunk under the ring. Bars threaded over the top of the rods are bolted to the grid. The core when lifted out, and the bottom ring removed by taking off the nuts under the ring, will stand on a board, as the weight is taken on the rim of the grid.

The grid in the bottom core rests over the 2-ft. dia. hole in the bottom plate, and the bottom rim of the grid makes a metal to metal contact with the bottom plate. When the core is put in the mould, it is bolted to the bottom plate by means of a piece of channel iron across the hole in the bottom plate, and straps on to the 1-in. dia. stiffening bars in the grid.

The top half of the core, shown rammed up in Fig. 6, is turned over on the trunnions after a round board has been bolted on to the top of the core box, right through the grid, and the bottom of the core box. The bolts are then released and the core box lifted off with the slings through four 1-in. eye-bolts screwed into nuts, let into the bottom of the core box. The core is then picked up with the eye-bolts in the grid and placed on top of the bottom core. The rims of the grids make a metal to metal contact, and the top core is bolted down to the bottom core with straps across the 1-in. dia. bars in the grids.

The bottom-half foot cores are put in the mould, and the top half placed on them, with oil and blacking on the joint. All the air is brought off from the bottom core. These cores and the round one for the hole in the side are dried. They are made from ordinary backing sand, bonded with 2 per cent. bentonite.

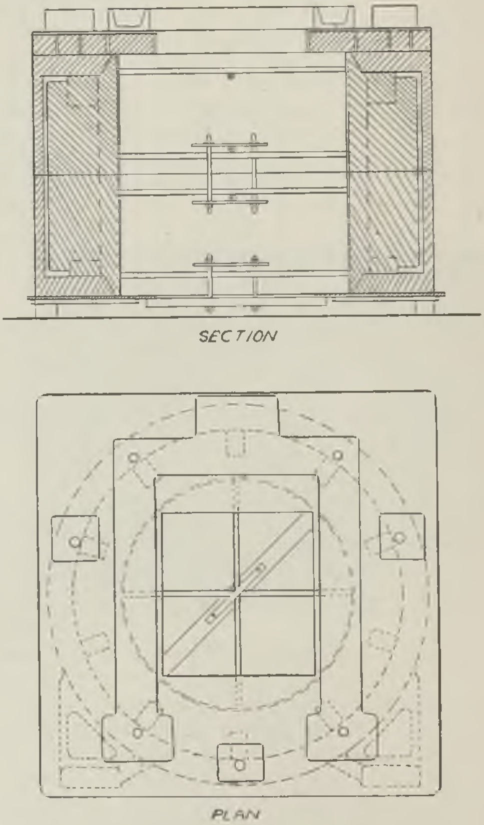


Fig. 7.—Runner Arrangement.

Running Arrangements

These castings have to be run at several points on the diameter, as it has been found, with much smaller shells, that if they are run at one point the castings are not symmetrical, owing to all the hot metal being at one side of the mould; the cooling is then uneven. This shell is run as is shown in Fig. 7 straight off the top with four ¾-in. dia. down-runners direct on to the ribs. Three 1¼-in. dia. risers are brought off the ribs between the runners. Stoppers are used until the bush is full, when all four are lifted simultaneously.

The first mould was made, closed and cast. Everything went according to plan, and it was thought that all was well. However, next morning during stripping a ⅞ in. wide crack was found across the width of the shell, through the round hole in the side. It was realised that, as the thickness of sand in the core is comparatively small compared with the weight of iron, particularly in the ribs, the sand had baked hard, like a dry-sand core. This was also assisted by the good venting, and baking had taken place before the contraction set in. It was afterwards learnt that about 4 a.m. the following morning the men on duty at the A.F.S. station had heard two loud reports which they could not account for. It would seem that the otherwise good casting broke through one side of the hole first, followed very shortly afterwards by the other side.

Another casting was started as soon as the core grids had been modified to allow for con-

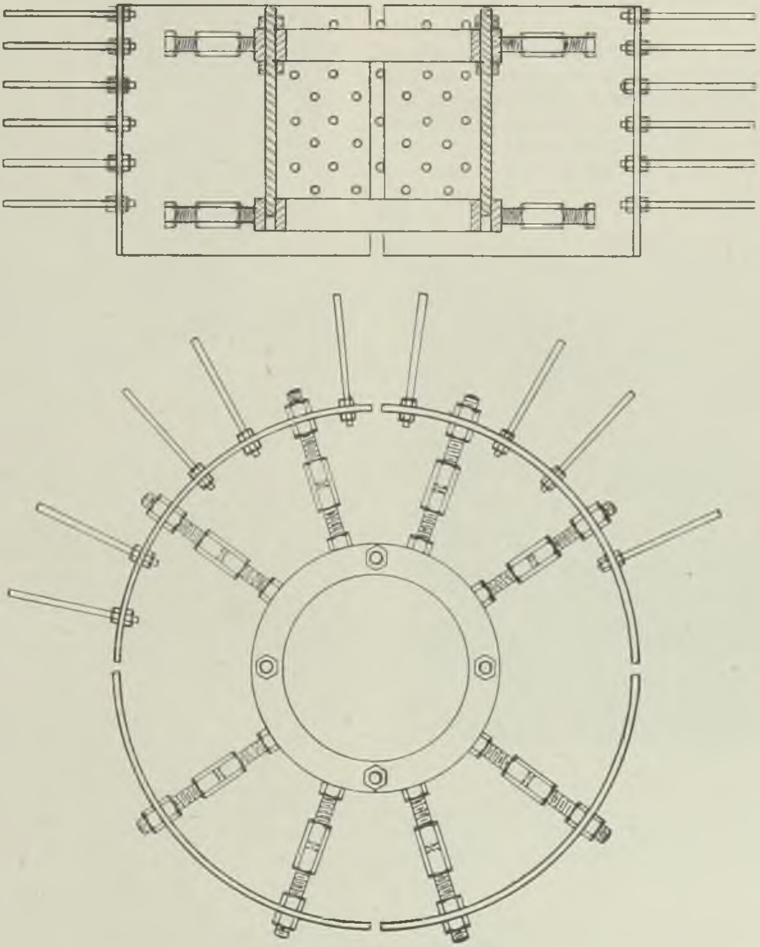


Fig. 8.—Second Type of Core Grid.

traction. There was also another fault in the grids which became apparent when the core was removed. The sand was difficult to get at, as the grid extended the full width of the casting. It took three men a day to remove the core.

Core Grid Modified

In modifying the grid, as shown in Fig. 8, this was kept in mind. Instead of splitting the ring and taking about 2 in. out at one point and strapping it, the grid was cut into four pieces by drilling $\frac{1}{2}$-in. dia. holes across its width and grinding off the jagged edges. This left a $\frac{1}{2}$ in. gap at each joint, 2 in. in all, to allow for initial contraction. The segments are held together by two cast-iron rings in each half-grid, and $\frac{1}{4}$-in. threaded rods are screwed into rings, two to each segment. Others are fastened in the segment with nuts each side, exactly opposite the rods in the rings. These rods are fastened together by screwed sleeves, thus holding the whole grid together. The top and bottom rings in each half-grid are held in position by four vertical rods $\frac{3}{4}$-in. dia. The same $\frac{1}{2}$-in. dia. threaded rods were used for gaggers.

In this second shell, the sleeves were screwed back after casting and the nuts taken off the vertical rods. Then the centre rings were lifted out. The inside nuts were taken off the gagger rods and this allowed the segments to be drawn inward and lifted out. The casting was now free to contract and it was easy to knock out the core.

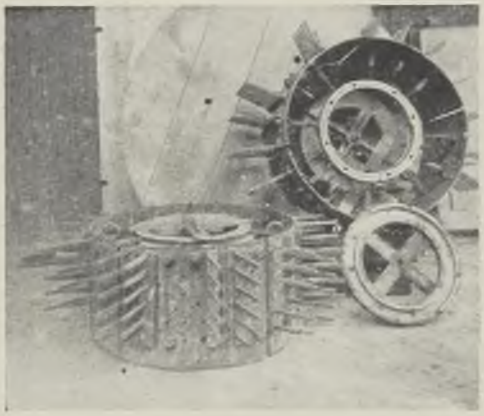


Fig. 9.—Final Modification of Core Grid.

It was decided to remove two opposite segments in each grid immediately after casting. In theory this may seem easy, but in practice it was an exceedingly unpleasant job, working in the centre of the mould. It required four men from 4.30 (the casting was poured at 4.0) until 9.0 to do the job working in relays. This casting was sound, and as the second one of the order had still to be made, a further modification to the grid was made, in order to ease the work of releasing it after casting.

Final Arrangement of Core Grid

The rings were now turned to carry a taper and were cut into four pieces, and a component was chuck-turned to the same taper to receive them. The whole assembly was held together with two clamps in the form of a cross with a 1-in. bolt through the centre as shown in Fig. 9. The threaded rods and sleeves were used to hold the grid segments to the ring segments, as they were already in existence, but the sleeves were not screwed out after casting, as the grid now came into sections when the centre bolts were released.

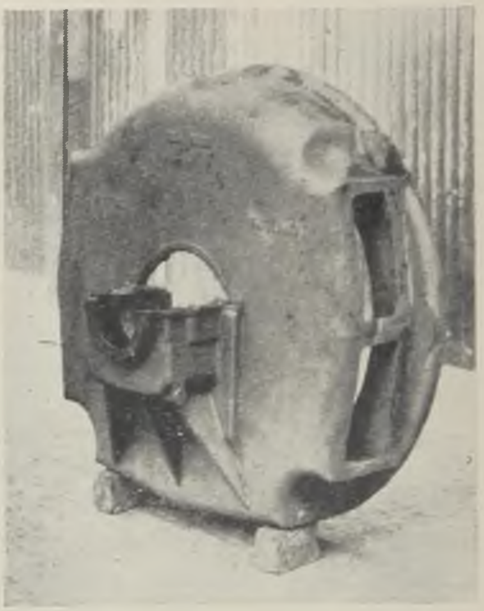


Fig. 10.—End Cover Casting.

In place of the $\frac{1}{2}$-in. dia. gagger rods, cast-iron gaggers were made. These consisted of a single casting carrying six gaggers, the back of which was drilled and tapped and held in position on the grid with a $\frac{3}{8}$-in. bolt at each end. The front had six gaggers $\frac{1}{2}$ in. by $\frac{1}{2}$ in. projecting out $7\frac{1}{2}$ in. Two of these were arranged between each rib, making a total of 20 on each grid. The unpleasant job of releasing the core was much easier and was reduced from $4\frac{1}{2}$ to 2 hrs. This casting was, in the words of the standard specification for iron castings, sound, clean, out of twist, and free from blowholes, distortion and all surface defects. The casting was made from start to finish by two men in three days.

The End-Covers

There are two end-cover patterns for these machines, one deep and the other shallow. The variable speed a.c. commutator motor uses one shallow and one deep cover. Other types take two shallow covers. Each type of machine is made with either sleeve bearings or ball bearings, which involves a change-over of bearing bosses for each end-cover to avoid making four patterns.

Fig. 11.—Pattern and Grid for the End Cover.

Fig. 10 shows the shallow end-cover casting carrying a sleeve bearing. The general thickness of this casting is $\frac{5}{8}$ in. There are six windows for ventilating, two on each of the three sides. The baffle round the inside is 1 in. thick and projects inwards a mean distance of $4\frac{1}{2}$ in. The diameter of the casting is 4 ft. 6 in., the same as the shell. The depth is 13 in. and the weight 8 cwts.

Fig. 11 shows the pattern and grid for the shallow cover. A solid block pattern was built up for the outside of the pattern, and mounted on a pattern board. The inside was built up, and fastened into a frame, which formed the pattern board. The windows and baffle are formed by four loose pieces which extend up to the joint on the pattern board. The pattern is fitted up for making the plain or sleeve-bearing type of cover. The ball-bearing boss is leaning against the front of the pattern. The ball-bearing cover will be dealt with next.

Moulding the Ball-Bearing Cover

The moulding boxes are those used for the shell casting split up into suitable depths. In this case, the 6-in. middle part is used for the bottom part. The 4-in. middle part is bolted to the 17-in. top part which has the loose bars in the centre inserted, and forms the top part. The inside of the cover is moulded bottom downwards. The grid shown on the right of Fig. 11 was of similar proportion to that used in the shell, but is closed at one end. This is used to get the gas away from the mould quickly and to prevent the cod lifting.

By fixing the $\frac{1}{2}$-in. dia. screwed rod gaggers, used in the first two shells, into holes round the rim of the grid, so that they reach to about 1 in. on the inside of the baffle and extend to within 1 in. of the outside of the pattern, the cod is prevented from being lifted when the metal gets under the baffles during casting. The grid is 13 in. deep, and, as in the shell, the rim makes a metal-to-metal contact with the bottom plate, to which it is bolted.

The sand is rammed into the bottom part to a depth of 7 in., and then struck off level with a strickle from the joint of the box to a depth of 6 in. The grid is then placed in position and tapped down until it is perfectly level with the edge of the box. Sand is now rammed in until it is just above the level of the bottom of the baffle. A strickle is again used to strike the sand off level under the baffle, the loose pieces are placed in position, and the rest of the bottom rammed up. The bottom is struck off level and the bottom plate bedded on and bolted down.

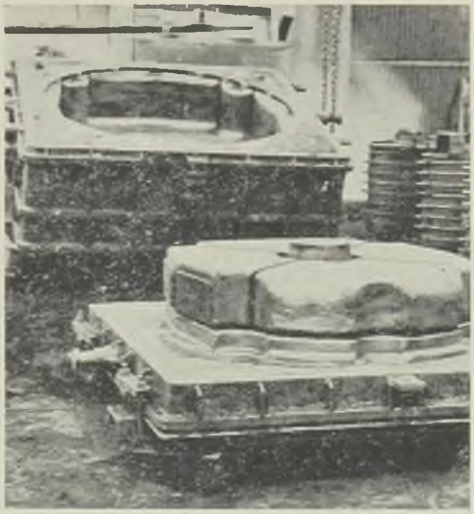


Fig. 12.—Mould for Ball-Bearing Cover.

The bottom mould with the loose pieces withdrawn (shown together with the top box in Fig. 12) illustrates the overhang of the cod to form the baffle. A clearance of 3 mm. is allowed between the window opening facing on the cod and the pattern. The bottom mould stands on weights and clears the floor by 6 in., giving ample room for firing the gas when casting, and preventing an explosive mixture collecting under the box.

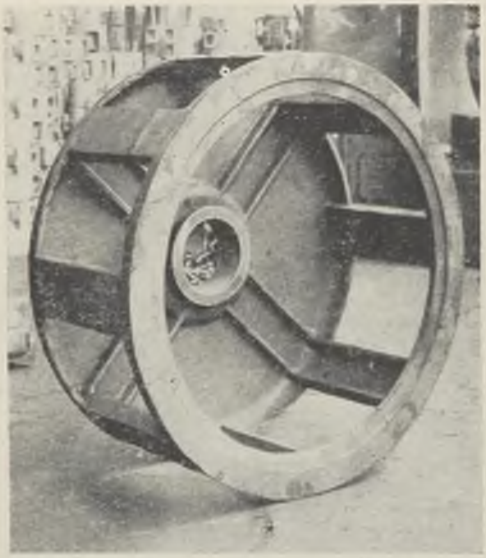


Fig. 13.—Deep End-Cover Casting.

The top mould is quite straightforward. Two 1¼-in. dia. down-runners are placed in each corner on the bottom side of the cover, and ingates are cut into the rim to run round the outside of the cover, missing the windows. Three 1-in. risers are brought off the bearing boss. After the top has been turned over, the runner and riser bushes are made up, and the weight balanced. With this first casting, the top was slung for lowering on with the cross beam and chain slings over the trunnions. Owing to the fact that, so slung, the top can rock on the trunnions, the 3-mm. clearance was insufficient, and the facing was caught during lowering, leaving some loose sand on the top of the windows. This unfortunately was not seen until the casting was knocked out. It was not sufficient to scrap the casting, but to avoid this happening on future castings, the top part is now slung on the four hook adjustable slings from each corner and the box levelled with a spirit level before lowering over the bottom mould. Closed in this way, the 3-mm. clearance is quite adequate.

The Deep End-Cover Casting

This casting, shown in Fig. 13, is 24 in. deep; it has a general thickness of ⅝ in. and weighs 11 cwts. The openings round the side are for accessibility to the brush gear, and the casting really consists of a flat top and a bearing connected to a rim and baffle by eight ribs, 6 in. wide and 18 in. long.

The same methods were adopted for the making of this cover as for the shallow one—a block pattern mounted on a board for the outside with the core part built up into a frame as is shown in Fig. 14. The clearance through the opening was again 3 mm. The baffle and end of the opening are formed by a loose ring cut into two pieces. The core grid is the same as for the shallow cover, except that it is 24 in. deep.

The overhang of the main core caused by the 4½-in. deep baffle is carried by the gaggers in the core grid, which rests on the bottom plate and is placed in position in the mould by strickling off the sand level and bedding down. The top and bottom moulds for the deep end-cover are shown in Fig. 15. The top moulding box is made up of the 17-in. deep top part, to which is bolted the 4-in. deep part, and followed by the 12-in. deep part, making a 33-in. deep box in all. The 6-in. part is used for the bottom part, and all the boxes are in use with the exception of the 2-ft. square extension box.

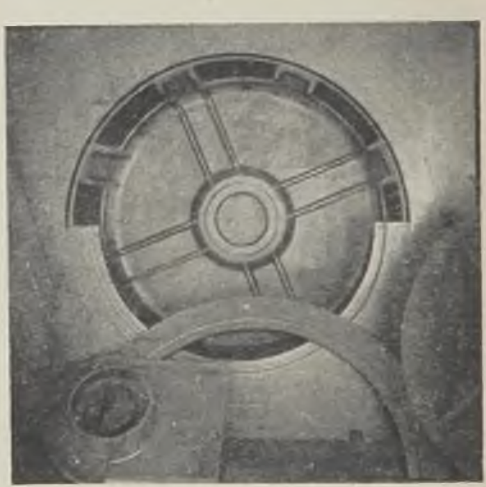


Fig. 14.—Patterns for Deep End-Cover Casting.

It is likely that when the next deep casting is made, the 17-in. deep top part will be used loose, and a joint made across the top of the middle part formed by the 12-in. and 4-in. parts bolted together. This will be done because it is very difficult to ram up the 33-in. top part through the bars in the top and get uniform ramming. On this first casting, the side ribs were swollen and out of shape in one or two places. This did not scrap the casting as the outside of these ribs is machined, to take a band which covers up the openings and protects the brush gear. It is also felt that with this part split it will be easier to handle, although it involves more work.

The runners and risers are the same as were used for the shallow cover, and the same methods are adopted for closing up. The stirrup clamps holding the bottom part to the bottom plate are used so that, after closing up, the 1-in. dia. holding-down bolts can go straight through the holes in the lugs, to the underside of the bottom plate, without releasing the bottom plate from the bottom part, for if there were any spring between the bottom plate and the bottom part it might disturb the mould.

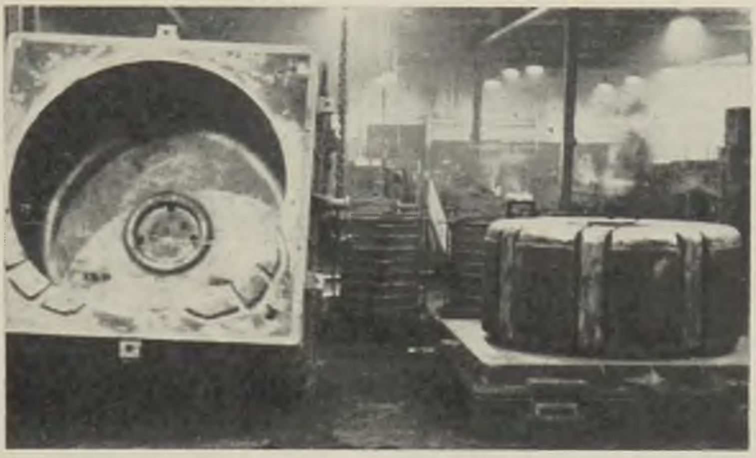


Fig. 15.—Top and Bottom Moulds for Deep End-Cover.

Sleeve Bearing for Deep and Shallow Covers

These are for taking white-metal self-aligning bearings. They are referred to in the foundry as sleeve bearings; to call them plain bearings, in view of their complicated nature, and the simplicity of the ball-bearing boss, led to confusion. The moulding boxes are the same as for the ball bearing with the exception of the top part. The loose bars in the middle of the top part are removed, and two pins are fitted in two of the four holes provided in the fixed bars, and two ¾-in. bolts are put in the two remaining holes for bolting down. A joint is made across the top of the box, as the bearing part of the pattern projects up above the top of the box, and the 2-ft. square, 12-in. deep extension box is used for moulding this projecting part. It is located on the pins and is used for two reasons; first and most important, had a further section been made deep enough to take the bearing extension, that is the full size of the box, the crane would have been overloaded when making the deep cover. Secondly, this method saved a considerable amount of ramming-up work.

The inside of the bearing is formed by three oil-bonded sea-sand cores, and its assembly is shown in Fig. 16. The cores are bolted down on to the grid and do not rely on the prints in the top part to hold them in position. The distance between the bottom of the print, and the top of the grid in the bottom part, is filled in with a block of iron, when ramming up the bottom part. This has a hole through the centre and a ½-in. dia. rod with a nut on the end is threaded through this hole and a corresponding hole in the top of the grid. This rod is put through the bottom core, which rests on the block of iron at the bottom of the print. This core forms the one side of the bearing below the self-aligning pedestal, and half of the oil reservoir. The second core is placed by the side of this, and forms the grooves in the edge of the bearing for returning the oil to the reservoir. This core is bolted horizontally across to the first core. The third core which forms the other half of the bearing and the oil reservoir above the self-aligning pedestal has two sumps extending below the reservoirs for draining out the oil. These protrusions on the core which form the two sumps prevent the top part from passing over the core, and the top part is now lowered on without the extension box. The third core which locates over the first core is placed in position with the ½-in.

dia. rod threaded through it, and then screwed down with a nut on top. This holds the whole assembly firmly fastened down on to the top of the grid and independent of the prints in the top part maintaining its position.

The extension box is lowered on and bolted down. As the metal thickness of the sleeve bearing extension is only ⅜ in., two ½-in. dia. risers are all that can be brought off. The gas is brought through a hole running parallel with the ½-in. dia. rod hole through cores (No. 1 and No. 3, Fig. 16), the top of the print in the extension box is cut away, and a tube placed over the vent, and the sand rammed round it. The gas is brought away from core No. 3, independently, in an exactly similar manner. The runner is built up to ensure there being a good head of metal above the part of the casting in the extension box. All these castings were made in the iron usually used in the foundry, which has an analysis of T.C, 3.16; Si, 2.38; Mn, 0.5; S, 0.09; and P, 1.0 per cent., and has a tensile strength of 14 tons per sq. in.

Facing Sand.—The same mixture of sand is used for both core and mould, on the shell, and also on the end covers. It has a permeability of 33 and a green compression strength of 27 lbs. on a 2 in. dia. test-piece, and is used at a moisture content of 4½ per cent. Sand is mixed in an August Simpson mill, with an aerator attachment, and is then put through a Royer disintegrator. The sand mixture is 50 per cent. returned black sand and 50 per cent. milled red sand, to which is added 12½ per cent. by weight of coal dust. The moulds and core are brushed over with dry plumbago, which is then well rubbed in by hand.

In conclusion, the author wishes to express his thanks and appreciation to Higgs Motors, Limited, for giving him permission to present this Paper, and particularly to thank the works manager, Mr. Patchett, for the practical assistance he has given in preparing the photographs.

DISCUSSION

The Chairman (Mr. A. Tipper, M.Sc.) thought some members would have comments to make concerning the 12 per cent. of coal dust used in the sand mixture.

Mr. B. Hird expressed the opinion that for a job of that size moulded in green sand, 12 per cent. of coal dust by weight would be all right. That, however, was not quite the same as 12 per cent. by measure, which was adopted in most foundries.

Mr. J. Hird explained that, roughly expressed in volume, the mixture consisted of one and a half barrowfuls of red sand, one and a half barrowfuls of black sand, and four bucketfuls of coal dust.

Mr. B. Hird replied that when the Sand Sub-Committee of the Technical Committee of the Institute of British Foundrymen sent out a *questionnaire*, one of the most amazing things was the great variation in the amount of coal dust used. Except from the point of view of economy, light work needed a smaller percentage of coal dust than heavy work. The figures varied from 1 to 30 or 40 per cent., but the quality of the coal dust must be taken into consideration. He wished to pay a compliment to the lecturer, as to make such a job in green sand was certainly a plucky and well-thought-out effort. He thought 75 per cent. of them would never have tackled the job in green sand. The experience gained in regard to contraction with green sand would doubtless save others from the same pitfall.

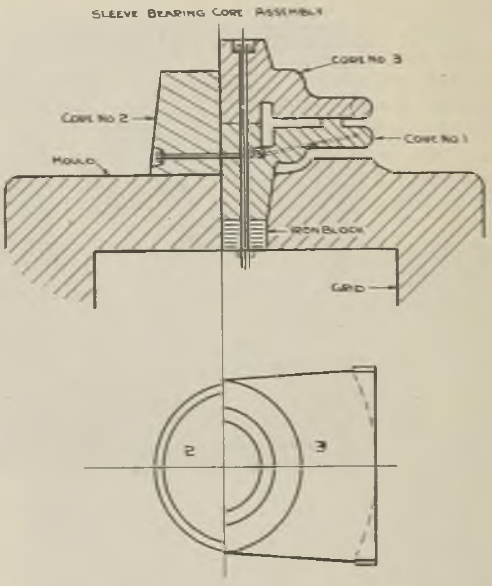


Fig. 16.—Coring Method used for the Inside of the Bearing.

Mr. J. Hird explained that the reason he used so much coal dust was on account of the large percentage of red sand in the mixture.

Another Member suggested that it might have been possible with the larger castings to have made a segment core of one-fifth of a circle with the splits on the ribs, and a quarter core for the end covers. That would have saved expense on patterns, etc.

Mr. J. Hird replied that the difficulty would have been to get the segments to clear the top of the window openings, and also to get the end covers symmetrical with the shell. His firm were prepared to spend money in order to make a good job.

The Chairman remarked that he had expected the question of contraction and distortion to be raised. That seemed to him to be one of the important problems in a casting of that type. He presumed that the degree of accuracy required was of a high order, and for that reason the tackle was well designed rather than built haphazardly. It was a big undertaking, and he wondered how long it took from the making of the first plan to the making of the first satisfactory casting.

Mr. Hird replied that it was about eleven months since they received the order, and two complete motors were now going through the works. So far as the shell was concerned, about three months passed from the time the drawings were received to the first good casting being finished. Of course, the question revolved about the number of men working in the patternshop, and they had to work upon it in conjunction with more urgent jobs.

Mr. J. J. Sheehan remarked that he liked the mechanical ingenuity displayed in the foundry as described by Mr. Hird. In his opinion, the pouring of that weight of metal over green sand was an achievement. He agreed that running the metal in at various points helped considerably, and also assisted from the point of view of distortion.

Mr. Hird said he used four running-in points in order to keep the casting symmetrical. He was afraid of the core lifting and the metal getting out of the bottom of the print. To prevent this, they used oil and plumbago where metal to metal contact took place. The core grids were machined to $\frac{1}{64}$ in., and they worked as accurately as possible throughout. That, he thought, was the reason why they were successful.

Vote of Thanks

On the proposition of Mr. F. J. Cook, seconded by Mr. T. H. Gameson, Mr. Hird was heartily thanked for his Paper. Mr. Cook remarked that it was often said the Institute did not have enough practical Papers, but the one given that night should satisfy anyone from that point of view. It required considerable ingenuity and pluck for a young man to face a job of the sort described, and he congratulated him upon the way he played for safety.

Mr. Hird suitably acknowledged the vote of thanks.

East Midlands Branch **Paper No. 719**

Synthetic Moulding Sand

By A. TIPPER, M.Sc., (Member)

It will be generally admitted that synthetic moulding sand has proved a practical success in this country as well as in America. In the latter, the home of synthetic sand practice, at least half of the steel, cast iron and malleable iron foundries use this class of sand. This is in part due to the lack of deposits of good-quality natural moulding sands, which fostered the early development of synthetic sand practice, but the successful and continued use of such sand in America is a very good argument in its favour.

In both countries cost is a prime factor and local sands are used wherever possible to avoid freight charges. Comparing costs of sand in America and in this country, there is not such a great deal of difference, except that good silica sands are nearly as cheap as United Kingdom moulding sands. The introduction of mechanisation, the use of continuous casting plants and the utilisation of semi-skilled labour have made it necessary to introduce closer control of sand, in order to obtain consistent results, and so have presented favourable conditions for the use of synthetic moulding sands.

In addition, there is the attraction for large foundries of eliminating the necessity for dumping large quantities of used sand at regular intervals. Finally there is the example of a number of members of the Institute who, having seriously studied foundry sands, have shown the way, by adopting some type of synthetic sand in the foundries under their charge.

Naturally, radical changes in such a conserva-

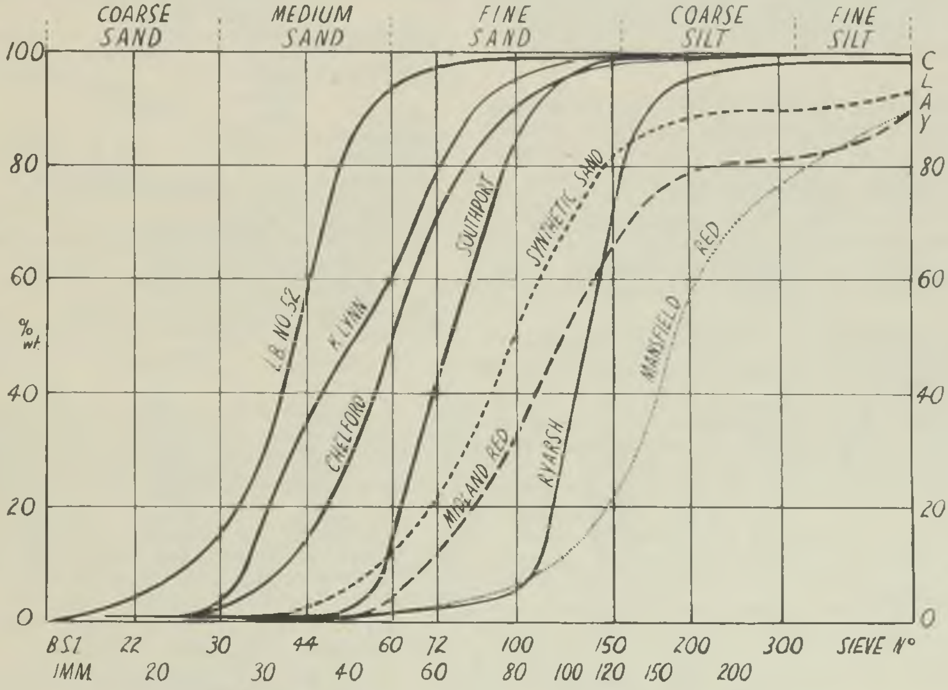


FIG. 1.—CURVES SHOWING GRADING OF SANDS AND CLASSIFICATION.

tive craft as founding only take place slowly, and it is usually not until some big development or change occurs within the foundry or serious trouble arises that a change in sand is visualised.

What is Synthetic Sand ?

A synthetic sand is obviously one which is " built up " from selected materials. These may include old foundry sand or a proportion of a naturally-bonded sand. The term is generally understood to apply to a mixture of silica sands (bondless in the natural state) with a suitable bonding material, but in practice there is *no* sharp line of demarcation between the natural and synthetic sand.

The three principal constituents of synthetic sands are: (1) the sand grains; (2) bonding material, and (3) moisture. These are controlled to give a moulding material having the desired properties.

Choice of Sand

Sand grains constitute about 90 per cent. of the whole, and the selection of a suitable base sand is therefore most important. The character, grain size, and distribution of grain sizes selected will be determined, broadly speaking, by: (*a*) the permeability required; (*b*) the surface finish necessary on the castings; (*c*) the class of metal—steel, malleable, cast iron, non-ferrous—and size of casting, and (*d*) economic considerations.

Present knowledge indicates that the following points are important in selecting a suitable sand:—

(1) Even grading (see Fig. 1).

(2) Low proportions of both coarse sand and silt to prevent fitting in of grains.

(3) Absence of fine mineral matter or clays which are easily dehydrated.

(4) A coated grain (refractory clay or iron compound) helps bond.

(5) Good refractory properties.

It can be shown experimentally that with sands of large grain size trouble with drying out and friable edges on moulds results, whilst angular sands give greater mechanical strength for the same proportion of bonding clay than rounded grain sands. In general any clean refractory sand, reasonably regular in grain size and *uniform* in character, may form the basis of a synthetic moulding sand. Many of the best sands contain 97 to 99 per cent. of grains between 0.1 and 0.3 mm. dia. (see Table I and Fig. 1). Examples of some silica sands suitable as the basis for moulding sands are:—

Steel.	Malleable.	Grey cast iron.	Non-ferrous.
Leighton Buzzard—medium—coarse.	Sea sand . .	Sea sand . .	Bedford.
Chelford . .	Yorkshire silica	Erith silica	Ryarsh.
Kings Lynn	Cheshire silica.	Cheshire river sands	Ipswich.
Ryarsh silica	Leighton Buzzard fine.		New Forest.
Yorkshire and Scottish rock sands.	—	—	Erith.

TABLE I.—*Silica Sands Used as the Basis of Synthetic Moulding Sands.*

Type of sand.	Leighton Buzzard No. 52.	Bedford silica.	Chelford.	Kings Lynn.	Southport.	Ryarsh.
Percentage retained on B.S.S.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
No. 22 . .	3.05	0.3	0.4	0.15	Nil	Nil
„ 30 . .	15.56	1.8	1.8	3.75	0.03	0.05
„ 44 . .	58.4	12.3	13.55	31.65	0.8	0.22
„ 60 . .	21.4	55.4	33.87	25.4	15.0	0.62
„ 72 . .	1.1	26.6	22.4	16.95	21.4	1.67
„ 100 . .	0.42		17.4	17.0	47.2	3.0
„ 150 . .	0.10	2.7	8.7	4.7	15.4	67.8
Passes 150 . .	Nil	0.9	1.9	0.3	0.15	26.4
Permeability, A.F.A. No. . .	Over 200	180	175	165	140	60
Loss on ignition. Per cent. . .	0.32	0.40	0.43	0.62	0.8–1.8	0.64

Use of Two or More Sands Mixed Together

In general this is *not* advisable unless special factors such as (1) cost; (2) surface finish required, or (3) advantages of some natural-bonded material outweigh the importance of permeability, dry strength and freedom from silting-up. The effect on permeability and other properties of synthetic sand mixtures by the addition of another silica sand of appreciably different grain size has been demonstrated by the American workers Dietert and Eggleston, and by Sheehan in this country. The theory of fitting-in of sand grains so ably described and illustrated by Sheehan in his recent Paper on " Core Shop Control "* explains the results obtained when unsuitable sands are mixed together and enables one to calculate the effect of mixing sands whose individual characteristics are known. (See examples of effect of red sand addition to silica sand mixtures, Table II.)

An illustration of a synthetic sand built up from a mixture of two silica sands of very different grain size which has given good results in a modern foundry making malleable iron castings may be termed an exception to the general rule and details of this sand are given in Table III. The use of the extremely fine Ryarsh silica sand is justified by the importance of surface finish and easy fettling required in this mechanised system.

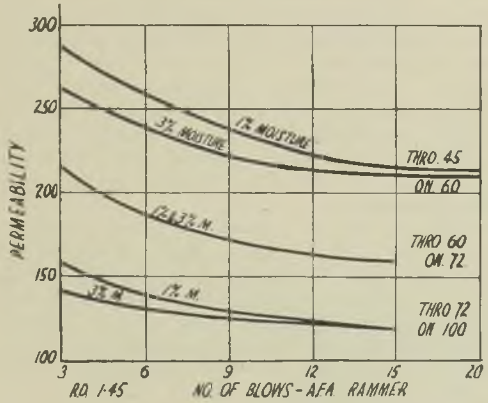


FIG. 2.—INFLUENCE OF GRAIN SIZE AND RAMMING ON PERMEABILITY OF SILICA SAND (SOUTHPORT SEA SAND).

The effect of grain size on the properties of sands has already been referred to. This is very clearly shown by taking a series of sized grains from the same sand (in this case Southport sea sand) and testing under the same conditions. It will be seen from Fig. 2 how permeability is reduced by (1) moisture content; (2) degree of ramming or compaction of the sand grains, or (3) grain size.

Certain properties of sand grains are more difficult to examine and are still not fully understood. The effect of the surface character of the grain on the bond strength and life of the sand is of importance. It is known that a clean sand grain soon becomes coated with a film of carbon and dried clay when used in the foundry process, and masses of sand grains become cemented together by this film. When the dry strength of the film is high (as, for example, when bentonite is used as a bond) it may become difficult to break down these pellets or masses of grains in the normal milling time and in consequence the facing sand becomes full of pellets of hard sand. (Other factors, for example, poor moisture distribution, condensation, etc., may give rise to this trouble.)

TABLE II.—*Effect of Additions of Red Moulding Sand to a Clean Silica Sand.*

Sand.	Chelford silica.	Chelford + 10 per cent. red.	Chelford + 20 per cent. red.
Permeability, A.F.A. No. ..	215	158	125
Dry strength.* Transverse. Lbs. per sq. in.	62	34.5	23.4

* Core compound, 1 to 40 wt. added.

Choice of Bond

The plasticity of sand is primarily due to the presence round the sand grains of a thin film of water. In the presence of a colloidal substance, either mineral or organic, the moisture is partially retained by the finely divided particles even after heating up to 200 deg. or more, and a permanent film is formed on the grain surfaces which acts as a cement.

Mineral Bonds (Refractory Plastic Clays)

The best materials judged on bonding properties are the colloidal clays: (1) Bentonite (American); (2) colloidal clays such as Colbond and London clay; (3) ball clays of the Dorset district; and (4) red clays from Bunter sand deposits (these are not found as clay deposits but associated with sands).

True bentonite gives very high green and dry strength, and is widely used in America. There are certain deposits in the British Isles which are being used successfully, and although not of equal bonding value, they have certain advantages (apart from price) as, for example, refractoriness. Table IV shows the relationship

---

* Proc. I.B.F. Vol. XXXII. 1939, p. 43.

between three clays used in the same proportions, with sea sand as a base. Important features of bonding clays for moulding sand are:—

(1) Extremely fine particle size.

(2) A high base exchange value (measure of the surface energy of the particles).

(3) A good life (or high dehydration temperature).

(4) The presence of hydrated iron oxide or other colloidal matter with moisture absorbing properties.

When clay is heated to a sufficiently high temperature it loses its power of absorbing water to produce a plastic mass and becomes friable or dead. This is due to a change in the structure of the clay, which loses its combined water, as distinct from free water or moisture. The life or property of the bonding substance to be rehydrated after being subjected to heat and consequent drying, possibly to a relatively high temperature in some parts of a mould, varies with the type of mineral bond present. It has been shown by Dr. G. H. Piper that there is a close relationship between the bonding value of a clay and its moisture absorption properties.* This has been confirmed by personal tests, set out in Table IV, made recently on several colloidal clays. This moisture absorption value of clays can be fairly easily tested under laboratory conditions and affords a means of comparing a number of bonding clays without making a number of tests in the foundry.

The author has been using this test to investigate the effect of heat on various clays. Figures for the temperatures at which clays lose their property of rehydration have been given by various authorities. These range from 200 to 300 deg. C. for limonite (hydrated iron oxide) to 500 deg. for bentonite. So far the tests have been made up to 600 deg. C., but are being continued at higher ranges. The results given in Table V are shown in the form of curves in Fig. 3. The moisture absorption or gain in weight of the sample is expressed as a percentage of the original dry weight, all samples being allowed to stand for a week or until saturation is reached at room temperature (approximately 50 deg. C.).

Table IV.—*Properties of Colloidal Clays.*

Type of clay.	Bentonite (Volclay).	Colbond.	London clay.
Moisture absorption. Per cent.	26.3	10.4	11.8
MA/6	4.38	1.73	1.97
Green bond compression. Lbs. per sq. in.	4.37	1.94	2.15
Moisture. Per cent.	3.7	3.7	3.5
Clay. Per cent.	6.0	6.0	6.0
Dry strength compression. Lbs. per sq. in.	89	60–68	60–64

Of the three clays shown, two are largely used in synthetic sand mixtures and the other is the natural bonding clay separated from a Midland red moulding sand (obtained by washing and decantation). The curves show that the change on heating is a gradual one, and similar in magnitude for all three clays. The similarity between the behaviour of the Colbond and natural red clay is noteworthy, and rather surprising in view of the difference in the nature of these clays.

Examination of the clays after heating at 450 to 500 deg. C. shows that the Colbond in particular has lost most of its plasticity, although still showing an appreciable moisture absorption, and it is probable that in this condition after heating the moisture absorption figure is not a true index of the remaining bonding power or plasticity.

Laboratory investigations of these bonding clays all show the marked superiority of the American bentonite for producing green and

Table III.—*Synthetic Moulding Sand for Malleable Cast Iron.*

(Mixture: Ryarsh silica sand 30, Southport sea sand 70, Colbond 6 and coal dust 3 per cent.)

Moisture, per cent.	4.0	*Sieve test.*		*B.S.S. mesh No.*
				Per cent.
Green strength compression. Lbs. per sq.	3.3–4.5	Remains on 30	=	0.2
		44	=	2.35
Permeability No.	55	60	=	9.8
		72	=	11.3
Dry strength compression. Lbs. per sq. in.	42	100	=	27.1
		150	=	31.2
Dry permeability No.	60	200	=	6.5
		300	=	1.5
Volatile matter, per cent.	3.2	Passes 300	=	3.2
Loss on ignition, per cent.	7.3	Clay (washing test)	=	6.8

---

* Proc. I.B.F., Vol. XXXII, 1939, p. 33.

dry strength, weight for weight. Actual economy will depend on several factors, such as price, ratio of green strength to dry strength desired, and efficiency of distribution of the bond. If it were possible to obtain a local red clay, such as that associated with the Midland red moulding sands, at low cost, it would serve as a very useful addition to the available materials for synthetic sand mixtures.

In use, the clay should be ground as finely as possible—a matter unnecessary with colloidal clays, as bentonite and Colbond exist in dry powder form. It may be mixed with a proportion of sand or coal dust to increase its bulk and thereby improve the distribution in a large sand system, or in some cases it is practicable to make the addition as a water suspension or slip where the consequent water addition is not too high.

When starting up with new sand, the full bond is not developed immediately. Not until the sand has been in use for a short time, and the grain surfaces have become coated, does the full bonding value of the clay and distillation products from coal, etc., take effect.

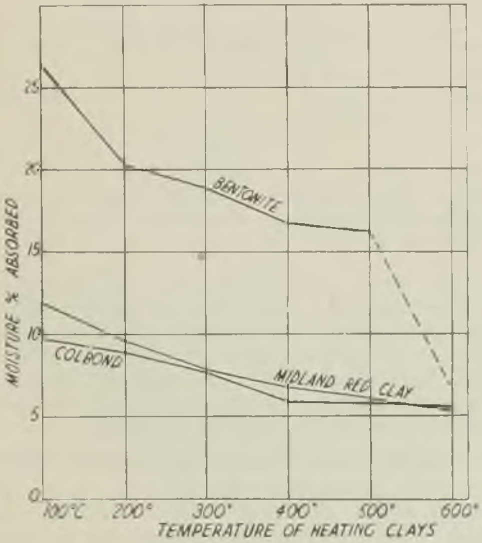


FIG. 3.—EFFECT OF HEAT ON MOISTURE ABSORPTION OF COLLOIDAL CLAYS.

Coal Dust and Coal Oil in Sand

The distillation products of a bituminous coal have a definite bonding value in any moulding sand, natural or synthetic, and in the production of cast iron the addition of fine coal dust contributes not only to the casting finish, but to the sand condition, particularly with continued use of the same sand. This has been proved in practice both here and in America, where in certain foundries substitutes such as heavy fuel oil or tar oil are added to the sand system, partially to replace other bonds in synthetic sand. It is suggested that coal dust for medium and light weight castings should have the following characteristics:—Mineral ash, 10 per cent.; and volatile matter, 30 per cent. minimum. *Grading*—100 per cent. passes 90 mesh, and 40 per cent. passes 200 mesh (I.M.M.).

TABLE V.—*Effect of Heat on Moisture Absorbed by Colloidal Clays.*

Temperature of heating. Deg. C.	Moisture absorbed. Per cent. (wt.).		
	Bentonite.	Colbond.	Red Clay.
100	26.3	9.7	11.86
200	20.3	8.97	9.7
300	19.0	7.71	7.88
400	16.8	5.94	6.65
500	16.4	5.83	6.10
600	6.5	5.47	5.37

Organic Binders for Moulding Sand

There are a number of organic bonding agents used in moulding sands to improve the working properties. For example, to improve green bond without the disadvantage of building up the clay content of an already fine-grained sand, a material such as concentrated sulphite lye is used. The addition of 1 to 2 per cent. of this material is very helpful where scabbing is experienced due to a weak mould surface, or where it is difficult to work at the optimum moisture content of a sand, without falling off in production rate, through difficulty in handling a wet sand.

Concentrated sulphite lye contains from 5 to 8 per cent. mineral ash, which eventually will be deposited on the grain surfaces or form a filling between the grains of burnt sand. So far, experience has not shown it to cause fritting or fusion of the sand to metal in cast-iron and non-ferrous foundry practice. Molasses and dextrin are also used in a similar way, and these also tend to counteract the tendency of synthetic sand to dry off and give friable edges on the moulds when standing in a warm shop. The additions may be dissolved in the water to be added at the mill.

It has been found possible in certain continuous sand plants (and others) to eliminate any addition of new sand or bonding clay over considerable periods of time, using a small addition of an organic binder of this type (and, of course, coal dust if required), but one essential is an efficient milling of the whole sand system for this to be possible. Green bond and dry strength can be maintained without appreciable change in the silt content or permeability of the sand, whilst the bulk of sand is maintained by the addition of suitable silica sand or old core sand. It should not be inferred that the organic binder will in general replace bentonite or other bonding clays, which are essential in building up the system sand to a satisfactory degree of plasticity for moulding, but its use is complementary to either natural or artificial mineral bonds.

Choice of Moisture

In the words of Dietert, "moisture control is the most important step in the preparation of sand for moulding." Generally speaking, the moisture content of synthetic sands is considerably lower than that used with natural bonded moulding sands.* The moisture percentage depends on:—(1) Type and proportion of bond used; (2) nature of the sand system (capacity, design, etc.); and (3) local conditions, type of work and moulding machines, etc. The relationship between the moisture content, green and dry strength of any sand can soon be determined by graphing the results of three or four trial mixtures (see Fig. 4), and the best moisture figure to give the most satisfactory balance of properties is then determined.

Suggested average values for synthetic green sand moulding are as follow:—

	Moisture. Per cent.	Green bond compression. lbs. per sq. in.	Permeability A.F.A. No.
For steel	3.0	4—8	150—180
,, cast iron ..	3.0—3.5	5—8	50—75
,, non-ferrous	3.0—5.0	4—8	30—40

Having decided on the best moisture content for the particular sand mixture, bearing in mind the general requirements of the foundry, it is then the task of the person in charge of sand control to see that the sand is delivered at the moulding machines with this moisture content. With synthetic sand the lower moisture content and higher permeability means a more rapid drying off of the sand. Local conditions which affect the sand temperature and the distance the sand has to travel to and from the mill will also affect the loss of moisture from the sand.

In any mechanised sand system this moisture should be made good as early as possible in the cycle of operations in order to afford the maximum time for tempering before the sand is re-used. If possible the bulk of the necessary water should be added at the knock-out, allowing for subsequent loss before the sand reaches the mill, where the final moisture adjustment is made. In synthetic sand mixtures it is important to keep the moisture content within 0.5 per cent. (*i.e.*, 0.25 per cent. up or down) of the desired value, particularly where the sand shows rapid variation in properties with respect to moisture content. Fortunately most of the mixtures now in use show a fairly flat curve for green strength, but dry strength may vary rapidly with change in moisture content.

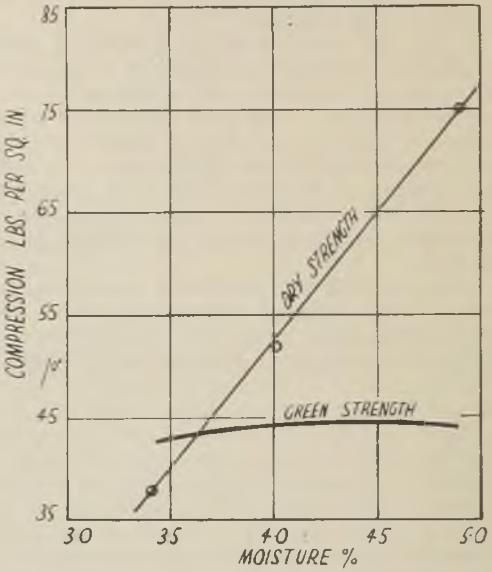


FIG. 4.—RELATIONSHIP BETWEEN GREEN STRENGTH, DRY STRENGTH AND MOISTURE CONTENT OF A SYNTHETIC SAND.

In order to reduce the rate of drying off of the synthetic sand mixtures various means are employed, as for example: (1) Using a proportion of natural bonded fine sand in the mixture or adding silica flour, and (2) adding a moisture-retaining agent such as glycerine or salts of calcium, sodium or ammonia.

Preparation and Control of Synthetic Sand

Mixing and milling may be either continuous or by batch treatment. The batch-type mill deals with individual charges usually in 3 to 5 minutes, according to the nature of the sand, and there is opportunity for adjustment in each batch of sand if necessary. On the continuous mill the amount of milling of the sand is usually limited by the capacity and output of sand required to a very short time (1 to 2 minutes or less). The same sand will be remilled and used about once per hour, and the effective distribution of the small bond addition is not obtained without careful attention and adjustment when the plant is working. Usually there is an excessive addition of bonding material (due to the short milling time) which is subsequently removed by the desilter.

---

* "Naturally Bonded or Synthetic Moulding Sands?" by A. Tipper, Proc. I.B.F., Vol. XXXI, 1938, p. 512.

In planning any type of sand preparation plant, thought must be given to the cooling of the used sand from the cast-up moulds which forms the bulk of the charge to the mill, and proper provision must be made for removal of dust and steam from the region of the mill. Steam condensate upon overhead metal work or sides of the mill, etc., together with clay dust can cause serious trouble by falling down into the sand. Over a period of months these form small masses of very hard strong sand which are not broken down in the mill. Such pellets may in time seriously affect the surface finish of the castings unless they are eliminated by screening, and usually they are too small to be removed by a works screen.

Desilting

Many sand preparation plants make provision for desilting by suction at some point where the sand is falling freely through air, as for example after passing through a rotary screen for removal of coarse sand, rubbish, etc. The material removed in this way by the desilter certainly contains a higher proportion of fines than the system sand from which it is removed, but it also contains valuable bonding material. The details of sieve tests on material removed in this way by air suction are shown in Table VI which demonstrates that valuable ingredients are being lost.

Numbers of foundries are running most successfully without any desilting and do not find any appreciable falling off in permeability. To quote from the valuable Paper on moulding sand by Carter and Walker: "When sand is controlled the problem of silt need not arise." With this statement the author is in full agreement, because in certain cases fine silica dust or flour is added to the sand system.

The amount of breaking down of the sand grains by heat or milling is very small and since some of the burnt-out sand is removed to the fettling shops on the castings, this at least does not re-enter the sand system. With the exception of steel foundries and foundries making heavy iron castings, where refractoriness must be kept up as high as possible, it is not considered that desilting is necessary with synthetic sands.

Conclusion

In conclusion, the advantages and disadvantages of synthetic sand may be reviewed thus:—

Disadvantages.—(1) High first cost is probable. (2) The sand loses moisture more or less rapidly, which may cause friable edges on moulds, lack of dry strength, washes, etc. (3) Patching, unless extra care is taken, may ruin the mould since strength is quickly lost with excess water and the sand collapses. (4) Balling up of sand may be experienced, due to a variety of causes, but often the result of poor distribution of moisture and bond, or the use of excessive bond with high strength. (5) Surface finish of casting may not be as good, but that can be overcome. (6) Necessity for strict control.

Advantages.—(1) Lower cost of sand maintenance and no sand to dump. (2) Improvement in permeability and lower moisture content means less chance of blown or porous castings, chilled edges, etc. (3) The sand is easy to mould with lower moisture content (slower cooling) and gives higher production. (4) It enables semi-skilled labour to be used on machines with satisfactory results. (5) It is possible to use old core sand or reclaimed floor sand, etc., for some classes of work (steel).

Some of the disadvantages can be overcome by special attention to and care in the selection of sand plant, which has undoubtedly been much improved in recent years. This equally applies to the best use of naturally-bonded sands, and it is not desired to give the impression that the author is in favour of eliminating the use of the natural moulding sands, but rather to apply scientific methods to obtain the best use of existing resources.

TABLE VI.—*De-silting of Moulding Sands.*

Source.	Synthetic sand.			Natural bonded sand.	
	Sand to de-silter.	Sand from de-silter.	Silt removed.	System sand.	Silt removed.
Grading.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Coarse sand	2.2	2.3	—	—	—
Medium sand	15.5	16.4	—	9.4	4.6
Fine sand	51.4	55.5	22.6	33.3	21.5
Coarse silt	16.4	11.5	44.8	33.5	38.8
Fine silt	7.4	6.7	20.2	13.4	26.7
Clay	8.3	7.5	12.4	10.5	8.2
Loss on ignition	—	—	15.1†	3.6	5.0

Synthetic sand :—Bentonite + coal-dust additions. System sand :—Midland red + coal-dust additions.

† Carbon content = 11.4 per cent. content.

DISCUSSION

Preventing Loss of Moisture

MR. R. H. BUCKLAND (Branch-President) pointed out that founders in this country were fortunate in having available very large sources of natural moulding sand, the lack of which caused America to develop synthetic sand mixtures. Mr. Tipper had emphasised the permeability of the silica sand. The question of loss of moisture had to be considered, and several antidotes for this trouble had been mentioned, one being the addition of glycerine. Mr. Buckland asked how the glycerine was added to the mixture.

Although definite figures had not been given, it appeared to him that the initial cost of introducing the synthetic sand was considerable, but he believed that once a foundry had been started using synthetic sand entirely, the cost of new sand compared favourably with that of natural moulding sand mixtures. Could Mr Tipper give some figures relating to comparative costs?

MR. TIPPER said that two or three years ago the number of foundries using synthetic sand was small, but he knew himself of twenty or thirty foundries in the Midlands which were using some form of synthetic sand. They were discontinuing the use of large additions of natural bonding sand and were making small additions of glue, to keep up the properties. He thought there were about 3,000 foundries in this country, and not only the iron foundries but the steel foundries as well to-day would be found using the synthetic sand for the green-sand and dry-sand work. They might be using just the same basic sand that they started with.

The glycerine was dissolved in the water which was being added to the sand. Mixing glycerine with an equal amount of water gave a good solution.

Clay Additions

In some cases the clay was added as a liquid. It had been suggested that the best method of adding the clay was to mix it up thoroughly, making a smooth cream with water, and to add it to the sand in that way. If 1 per cent. of clay was being added, about ten times the amount of water would be required to go with the clay, which would therefore increase the moisture content above the amount required. It could be used in some particular cases.

As to the cost of the actual conditions, said Mr. Tipper, this would work out at just about the same in one case, and half the cost in another. Comparing a large system of synthetic sand with a natural bond system, they were both very economical. In one case the figure was about 10s. per ton for the natural bond sand and about 9s. per ton for the synthetic sand. Most natural-bonded sand systems worked on at least 10 per cent. additions.

If a new foundry was being started up with new sand, it would cost much money. The difference in cost was, say, 6s. per ton and 12s. per ton. That was double, certainly, but once started one could go on indefinitely, providing a make-up sand of the right grading was selected, and if one was in the fortunate position of having a core shop where the core sand could be controlled to make an addition to the floor sand, then the cost of new sand could be eliminated altogether.

MR. H. L. SANDERS expressed interest in Mr. Tipper's figures, which represented a tremendous amount of work. He referred to one graph where the permeability dropped as the number of blows of the A.F.A. rammer was increased from 3 to 21, and the ramming density was stated to be constant at 1.45. Surely this was an error, as the ramming density would increase with the number of blows. Mr. Sanders asked for more information about the organic binders, and particularly how tar was added, as this appeared to be rather a problem.

Commenting on synthetic sands, it was acknowledged that the bond was different from that of a natural sand, in that it was more closely held in a natural sand. Would Mr. Tipper give his opinion on this point?

Another matter was the use of old cores in the mix. They had oil in them, which made the cores hard, and it would be an expensive proposition to burn the oil out to make the sand suitable for incorporating in the new mix.

Organic Binders

MR. TIPPER said the organic binders were well worth considering, particularly if, say, working with a sand that had its best properties reduced at rather high moisture content, because moulders probably found it heavy going. He knew of one foundry, engaged on non-ferrous work, which had trouble because the moulders were unable to sieve their sand quickly; by a small alteration, reducing the actual bonding sand and substituting the addition of 1 per cent. of a liquid bond, they were able to develop sufficient plasticity and get much faster moulding results.

At the present time there might be occasional difficulties in procuring all materials, but if the type of mixture and the properties required were decided upon, then, if a few tests were made, it was simple to find an efficient mixture. If the sand coming back from the mill was working satisfactorily, and not causing trouble through scab castings, it could be said that the sand had sufficient strength and was working correctly.

For tar additions to sand, a thin tar of the creosote type could be obtained, which could be added when thinned down with oil or paraffin. Difficulty was experienced when mixing many oils with water. To his knowledge, the method was not used in this country, but in the U.S.A.

Differences in Bond

An explanation of the difference in bond, he said, would require more than his knowledge, but he could suggest several reasons for the way in which the bond was retained. For example, if making a synthetic sand mixing, it lost its bonding plasticity very quickly as it dried up, and did not develop the same bond. Much depended upon the surface character of the grains. If the finished casting was satisfactory and one could get the necessary lift from the sand, then it was satisfactory. The main point was that if the sand paid and gave good results, then it was well worth exploiting.

The re-use of old cores was being effected in one or two cases. As the castings were put on one side, all the burned sand that dropped from them was separated, and the sand that was loose and fine was put into the system, but the strength was destroyed. If a very strong core was being used on thin-sectioned work, there would not be anything like the sand required.

If one wanted to use the cores without incurring much expense, a very weak mixture must be used, or the making of the core must be adjusted so that it would easily leave the casting. Then all the lumps were sieved out and rejected, only the fine sand being added to the rest of the material in the system.

Mr. J. C. Hallamore asked whether, in Mr. Tipper's opinion, it was possible for the ordinary foundryman to change over from a natural bond to a silica sand without calling in outside help.

Transition Difficulties

Mr. Tipper replied that it entirely depended on the reason for the change as to whether it would be worth while. Noting the number of people who had gained as much knowledge as he had by their own work, if the time could be spared to go through the various Papers that had been given on the subject, all the necessary information could then be obtained. The major factor was whether the foundry contemplating a change-over had the equipment and would back its own judgment. Finally, there was the human element to contend with, and much prejudice against the use of synthetic sand existed.

Mr. A. Bill suggested that Mr. Tipper's remarks were not very clear as to why one should change over to synthetic sand. Was it because it was cheaper, or because it was easier to prepare? Could it be said that the castings were definitely better, with fewer wasters and better finish, than when using naturally-bonded sands? He believed Mr. Tipper had mentioned a certain amount of difficulty that had been experienced in actual moulding practice, which he asked him to confirm.

Mr. Tipper said he was not in the position of insisting that they should change over to synthetic sand. He wanted them all to be interested in the subject and decide for themselves. Quite a proportion of foundry wasters was caused by sand, and there was less trouble with synthetic sand. He could say that, with a properly controlled synthetic sand, the general troubles applicable to sand were less. Most of the people who had changed over to it had found a lower cost, otherwise he was quite sure they would not use it. The difficulties in moulding were those commonly experienced when adopting any new material. One had to become accustomed to its peculiarities.

Mr. Bill remarked that, according to Mr. Tipper, there were definitely fewer sand troubles, *i.e.*, there were fewer wasters due to sand defects, when using synthetic sand. He asked if possibly it might not be that there was less trouble due to the synthetic sand itself. If such sand was in use, a very efficient sand preparation system was necessary, and that probably would have a good deal to do with the matter.

Mr. Tipper agreed that the control would improve conditions, irrespective of whether synthetic or natural sand was used.

Vote of Thanks

Mr. Bunting, in proposing a vote of thanks, said there was always a certain prejudice to be overcome when anything new was introduced. Some foundrymen would probably remember that it took a war to start them thinking seriously about sand! Prior to the last war it was deemed unnecessary to bother much about sand, for the simple reason that it was quite cheap, until the Government started seriously to consider the position of sand deposits in this country. From that had arisen the investigation of synthetic sand, which, in his opinion, tended towards the safeguarding of the industry when, in time, there would be a shortage of natural sand.

Whilst at present many of them knew little about synthetic sand from a practical standpoint, and had not the pluck to set about installing it, those people who had done so were getting good results. Mr. Bunting was of the opinion that the future in this country held promise of far greater use for synthetic sand than it had previously.

Mr. H. J. Beck seconded the vote of thanks, which was enthusiastically accorded.

East Midlands Branch **Paper No. 720**

Cast Iron and its Relation to Machine Tools

By P. A. RUSSELL, B.Sc. (Member)

It is proposed to take full advantage of the title and treat the subject under two distinct headings:—(1) Cast iron as a material for the construction of machine tools, and (2) the working of cast iron upon machine tools.

Ordinary cast iron can be regarded as steel broken up by flakes of carbon, called graphite, but this steel may be of any quality from the almost carbon-free dead-mild type, through the strongest or fully pearlitic type with the carbon content at about 0.8 per cent., to the hardest cast steel type containing free iron carbide. This last may be present in large quantities and is the major constituent of hard white iron.

When the groundwork of cast iron consists entirely of pearlite, which occurs with a combined carbon content of 0.6 to 0.9 per cent., this groundwork is in its strongest condition and is also most responsive to heat-treatment.

Cast Iron for Machine-Tool Manufacture

Cast iron is the traditional material for the main constructional parts of machine tools for the following reasons:—(1) Ease of casting into fairly intricate shapes; (2) low cost, compared with other materials; (3) rigidity, and (4) reasonable resistance to wear, including its self-lubricating property owing to the presence of graphite and the penetration of oil into the graphite.

The advent in 1900 of high-speed tool steels, and still more recently the introduction of tungsten-carbide tools, has created a new set of problems in machine-tool design. These can only be met in part by the alteration of design, and improvement in materials is essential. It is therefore proposed to discuss the physical properties of cast iron from the point of view of machine-tool construction.

Strength and Rigidity

Ultimate tensile strength is of little importance in most machines as the sections required to obtain a rigid machine are such that failure by fracture is rare, except in accidental cases. The designer tries to keep his major stresses in cast iron compressive, but bending stresses are bound to occur. Thus the ordinary transverse test as used for cast iron may be a more useful guide than the tensile test. However, as so much depends in cast iron upon the tensile strength, it warrants prior discussion. Improvements in this property of cast iron have kept pace with the demands of machine tools. The old figures of 9 to 11 tons tensile which are quoted in most textbooks are out of date so far as machine-tool irons are concerned. This is not so much because the demand has been for stronger irons as because of the demand for sounder irons which has resulted in an incidental increase in strength.

It is now reasonable to demand that the iron for good machine tools should meet Grade I of B.S.S. 786 for High-Duty Cast Iron, giving a range of 12½ to 15 tons per sq. in. tensile strength over the various sectional thicknesses. For the highest quality of tools, Grade 2 with a tensile strength of 15 to 18 tons per sq. in. can fairly easily be met and should be sufficient to meet every demand except for parts carrying exceptional stresses.

A third grade with tensile strengths of 18 to 22 tons per sq. in. is available for these cases in certain special types of cast iron such as Ni-Tensyl or the higher grades of Meehanite. Even higher strengths can be obtained by heat-treating these materials. A typical range of irons for machine-tool castings with their physical properties is given in Table I.

Much more important than tensile strength is the modulus of elasticity, *i.e.*, the amount of of "spring." Shaw[1] has described "Every machine tool as a bundle of springs." Modulus of elasticity of the material plays a great part in rigidity; the higher the modulus the less the deflection under a given load. For example, an iron having a modulus of elasticity of 20×10^{-6} will extend 1/1,000 in. on a bar 10 in. long under a load of 2,000 lbs., whilst one with a modulus of 10×10^{-6} will extend the same amount under half this load.

The modulus of elasticity in cast iron increases approximately as the tensile strength increases. Thus the tensile strength may be a useful guide. But the modulus does not increase in direct pro-

TABLE I.—*Properties of Cast Irons for Machine Tools*

Type of cast iron.	Tensile. Tons per sq. in.	Transverse R.S. Tons per sq. in.	Brinell hardness.	Impact. Ft.-lbs.	Relative machinability.
Light for guards ..	10	23	210	5	0.08
Normal grade ..	14	30	220	7	0.08
Special grade	18	33	230	9	0.07
Ni-Tensyl ..	22	36	250	9	0.07
Ni-Tensyl heat-treated	28	36	320	9	0.06
Ni-Tensyl + 0.5 per cent. Mo, heat-treated	31	44	350	10	0.04

Brinell hardness—3,000-kg. load, 10 mm. ball.

Impact test—on special B.C.I.R.A. machine using unnotched bar, single blow. Bar 0.798 in. dia. Striking height, 1.3 in.

Machinability—penetration in ins. per 100 revs. of Ardalloy tipped drill $\frac{1}{2}$ in. dia. under 51-lb. load, tested on special Herbert machine.

portion to the tensile strength, and rises from 11×10^{-6} for the weakest irons to about 20×10^{-6} for the stronger irons.[4] In the higher-strength irons the modulus varies considerably, and irons developed particularly for tensile strength do not necessarily have the best modulus of elasticity values.

Whilst the modulus of elasticity has been increased so that demands may be met, this increase has tended to reduce the capacity of cast iron for damping out vibrations. Damping capacity is an important factor about which very little is known. Ordinary soft cast iron has a very good damping capacity, whilst steel has a poor one. This is one of the major reasons why fabricated steel is not favoured for machine tools.

Such evidence as is available shows that the damping capacity of cast iron decreases as the tensile strength and modulus of elasticity increase. Thus, to obtain the rigidity necessary for the production of fine finish on parts being tooled, it is necessary to effect a compromise between the benefits obtained by a high modulus of elasticity and the corresponding increase in tendency to vibration. The presence of graphite seems to give cast iron its good damping capacity, which constitutes one reason why a very low graphite content is not desirable.

Resistance to Wear

The other factor which the speeding up of machine tools has brought into the forefront is resistance to wear. Increased speeds and frequency of motion, combined with increased demand for accuracy, have made this property of the utmost importance. Unfortunately, resistance to wear is one of the most difficult things to measure as so many factors are variable. They include: (1) lubrication, (2) pressures, (3) speeds, and (4) nature of opposing materials.

Cast iron is reasonably good for resistance to wear of the type met with in the sliding parts of machine tools, owing to its being in fact a fairly high-carbon steel broken up by graphite flakes. The graphite flakes act as a lubricant and a reservoir for the absorption of oil. The improvements in cast irons already noted have largely contributed to resistance to wear, particularly the improvement brought about by the change from the old soft type of cast iron to the harder "semi-steel" type, which really consists of the raising of the base of the cast iron from a mild steel to a high-carbon steel, accompanied by a reduction in the size and quantity of graphite flakes. It is by no means certain that the engineer's desire for a cast iron which has so little graphite that it is scarcely visible is really to the best advantage from the point of view of wear. Certainly, in the immediate post-war period, the reduction in graphite size and quantity indicated an improvement in quality, but this can be carried too far, and good wear-resisting iron should not be too low in graphite.

The improvements in wear resistance offered by the normal improvements in cast iron are not sufficient to meet the demands for the most exacting machines, and further methods were evolved.

One of the first was the densening of the important faces of the casting by placing in the mould an iron densener which increases the cooling rate of the metal, thus causing, locally, a higher combined carbon (*i.e.*, a higher carbon in the steel groundwork) and a lower graphite content. This also enabled closer-grained hard-wearing surfaces to be obtained on the "ways" of the casting than could normally be obtained. This is owing to the fact that these "ways" are usually of much heavier section than the rest of a casting, and the use of an iron to get the correct structure in these parts results in an unmachinable iron in the thinner parts.

Densening is still largely employed, and, provided that it is used intelligently and that the quality of the iron used is good and strictly controlled, it will meet the demands of the largest proportion of machine tools. Objections are frequently raised that the use of denseners puts strains into a casting, which are relieved on machining, causing ultimate warpage. It is a personal opinion, however, that, provided that drastic densening is not necessary owing to the use of a poor-quality iron, densened castings warp less than undensened ones. The chief cause of warping in castings is the unequal rate of cooling of thick and thin parts, and if the cooling of the thick part be accelerated by densening, so that it more nearly approaches that of the thin parts, it is natural to assume that warpage will be reduced.

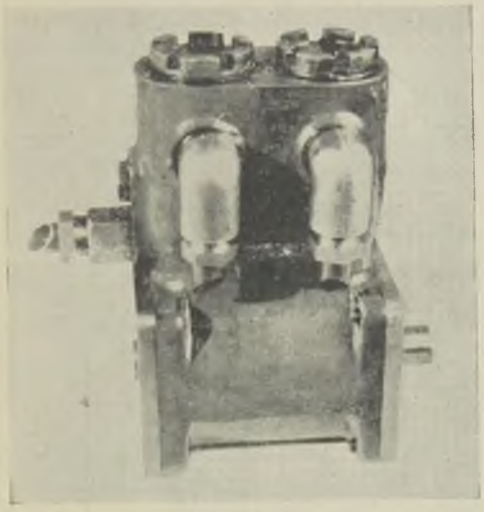


Fig. 1.—Valve Gear for Hydraulic Sawing Machine, Cast in "Ni-Tensyl."

The word "densener" has been purposely used instead of "chill," although the latter is the word commonly used. A chill, strictly speaking, is a piece of iron cast against the mould of sufficient bulk to accelerate the cooling of the iron so drastically that the iron becomes white and unmachinable. Such an iron is very hard and resistant to abrasive wear but is not really suitable for machine tools, although attempts have been made to use it. Machining and warping problems become acute. The border line between "densener" and "chill" is very fine, and the foundryman who uses a densener that is just a little too heavy for the class of iron being poured very soon finds himself in trouble with the machine shop owing to the appearance of hard spots and patches.

The next development in improving the wear of cast iron was by the use of alloying elements, particularly nickel and chromium. These alloys have two main effects when used in small quantities and in the correct proportions:—(1) They raise the hardness of the steel groundwork and thus give extra resistance to wear, and (2) they even-up the structure of the casting so that it is possible to use an iron which is initially harder without the risk of the formation of hard spots in the thinner sections.

The use of these irons (Ni 1.0 to 2.0 per cent., Cr 0.3 to 0.6 per cent.) certainly improves the wear resistance of the iron considerably, but the objection to their use is in their cost, which becomes a major factor for large castings. It is not possible to alloy just one part of the casting, such as the shears of a lathe bed, without alloying the whole of the casting, and the cost is proportionately high. Therefore, for large castings, it is usually sufficient to have a very high-grade unalloyed iron, densened where necessary, and reserve the use of alloys for the smaller components, where the benefits can be better set off against the costs. It is well known that some manufacturers make a great point of the use of nickel cast iron in their machine-tool beds, and in cases of machines for very high speeds and frequencies of operations the cost is certainly justified. It is claimed[1] that the extra costs can be offset by the reduced sections and sizes made possible by the use of stronger materials, but the necessity for rigidity and absence of vibration prevents full use being made of this, and sheer weight is often an important factor.

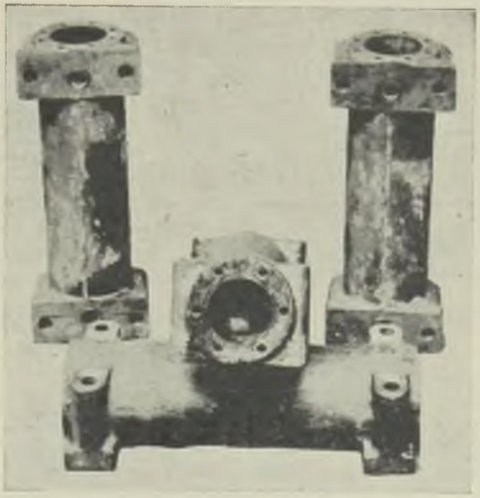


Fig. 2.—Ni-Tensyl Cylinders for Hydraulic Sawing Machines.

In the field of special and highly-stressed parts

M

alloy cast irons offer enormous opportunities. Irons are available with strengths approaching that of mild steel (Ni-Tensyl is guaranteed to have a minimum tensile strength of 22 tons per sq. in.), and if heat-treated they become as strong as mild steel whilst retaining the characteristics of rigidity, ease of casting, self-lubrication, etc., associated with cast iron. It is important to remember that owing to the presence of graphite flakes, these irons have practically no ductility.

For wear resistance, alloy cast irons are even more useful, particularly for cams. An ordinary alloy iron (Ni 1.5, Cr 0.5 per cent.) is very good, but the use of slightly higher nickel (2 to 3 per cent.) combined with hardening and tempering produces an excellent material. Such irons are machinable with a Brinell hardness of 250 to 300 as-cast, even with ordinary milling cutters, and can be oil-quenched from 850 deg. C. with little variation of size to give a final hardness of 350 to 450 after tempering. In this condition the castings may have to be ground, but the "shift" on hardening is frequently so small that grinding after hardening is unnecessary. The use of nickel improves the uniformity of hardness throughout the casting.

Other uses of alloy cast irons include gears, clutch plates, gibs, tool slides, etc.

Hydraulically-Operated Machines

The development in the use of hydraulic power for the operation of machine tools has created a demand for castings which are pressure-tight at very high pressures, in spite of very intricate shapes and rapidly changing sections. The use of alloy irons with their uniform sections, small graphite, and high strength is very frequently essential. Ni-Tensyl is particularly valuable, and is used for valve control gear and hydraulic cylinders. Fig. 1 shows the valve gear and Fig. 2 shows a group of cylinders for hydraulically-operated sawing machines, tested to 1,400 lbs. per sq. in. without any leakage.

TABLE II.—*Flame-Hardening Experiments on Machine-Tool Cast Irons.*

Bars 2 in. sq. treated by Shorter process.

Material.	Original hardness. Brinell 3,000/10.	Final hardness.		
		Brinell 3,000/10.	Vickers Diamond.	Rockwell C.
Normal machine-tool iron ..	190	269	437	42
Special machine-tool iron ..	192	363	491	44
1.5 nickel, 0.5 chrome iron ..	250	358	476	49
2.9 nickel, 0.9 chrome iron..	280	388	506	45

Other methods of improving the "ways" of machine-tool beds are constantly being tried out. Hardened wearing plates attached to the beds have been tried but gave great difficulty in obtaining the necessary rigid attachment. The latest development which is interesting manufacturers is the local hardening of the "ways" by flame hardening. This process was developed in this country by Mr. Shorter and "Shorterised" products are well known, but the adaption of this process to cast iron and particularly large castings such as lathe beds is quite recent. A good machine-tool iron is suitable, provided that the combined carbon (that is the carbon content of the steel groundwork) is at least 0.6 per cent., whilst certain manufacturers claim that the presence of 1 to 1½ per cent. nickel is desirable. This is because nickel lowers the hardening temperature, thus rendering the treatment less drastic.

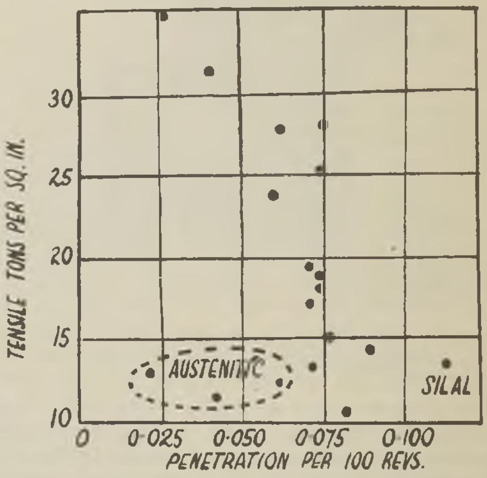


FIG. 3.—TENSILE STRENGTH OF CAST IRON RELATED TO DRILL PENETRATION.

Experiments by the author, given in Table II, and carried out in conjunction with the Shorter Process Company, show that a first-class machine-tool iron of the 18 tons tensile grade gives results almost equal to the nickel cast iron. These bars were ground to 2 in. exact thickness and cleaned up after hardening to not less than 1/1,000 under 2 in. The method of hardening is described by P. A. Abe,[2] who recommends a nickel cast iron, and whilst the author's experiments (carried out on test-bars only) indicate that this is not necessary to obtain the requisite hardness, it is probably correct that the lower hardening temperature and general improvement in hardening properties due to the presence of nickel make the use of nickel cast iron desirable. It would be interesting to compare a series of tests carried out on plain and alloyed irons, working at different speeds of traverse of flame and quench.

Machining Cast Iron

To measure machinability is nearly as difficult as measuring wear resistance. The author has carried out certain experiments which will be dealt with later, but unfortunately these were not finished owing to the outbreak of war. Certain results appeared unusual and required repeat tests.

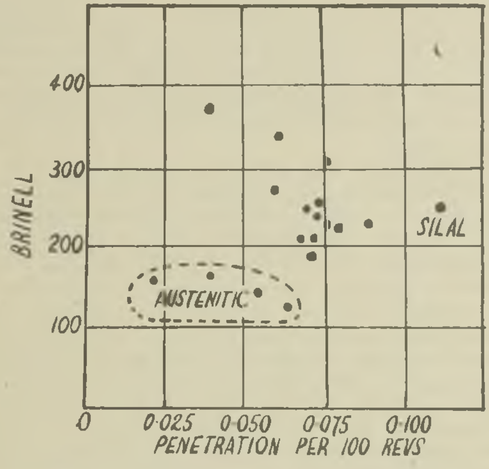


FIG. 4.—BRINELL HARDNESS OF CAST IRON RELATED TO DRILL PENETRATION.

Before the advent of high-speed tool steel, the universal demand was for cast iron that would machine with absolute freedom, and the other properties of cast iron, when used for purposes involving any considerable machining, were entirely secondary, except in hydraulic work. The improvements that have been made in cast iron would not have been possible without the improvements that have been made in cutting tools.

Thus it is found that as cast iron improved in strength and hardness, so cutting tools became available that would deal with them. With the introduction of tungsten-carbide tools no iron can really be called unmachinable. A white martensitic cast iron with a Brinell hardness of over 500 can be machined with the appropriate tool at 40 ft. per min. Mr. H. H. Beeny, of Alfred Herbert, Limited, has carried out a good deal of work on this subject and results of his researches have recently been published.

Personal observations largely confirm his conclusions except in respect to the statement that tensile strength is the main guide to machinability, and particularly is this so when cutting the modern inoculated irons such as Ni-Tensyl. With these it is possible to use just the same cutting speeds as are used for good-quality irons although the tensile strength is 50 per cent. greater. For cutting Ni-Tensyl, speeds of 150 ft. per min. with a cut ¼ in. wide and a feed of 1/48 in. are regularly used, whilst finishing speeds can be taken up to 290 ft. per min. with a 1/96 in. feed. When using these high cutting speeds, the use of a machine tool that is rigid enough to stand up to the job is essential, and the figures given presume that such tools are available.

Undoubtedly the best cast iron for cutting is an annealed iron, and where the strength of the casting is not important this material is the best from a production point of view. One of the most difficult problems in machining cast iron is milling, as tipped tools are not in frequent use. The speed of cut should be very closely controlled.

Other Types of Iron

Some reference should be made to certain types of cast iron which have to be tooled but which have not been mentioned hitherto, as they are not used in machine-tool production. One of these types is represented by the austenitic irons, which demand very much slower cutting speeds and have the disadvantage of work-hardening as machining progresses. Cutting speeds for these should not exceed 80 ft. per min. and heavy cuts are preferred to light cuts. The castings should be annealed if they are under ½ in. thick, and this annealing should be followed by quick cooling, preferably quenching in oil, to obtain a fully austenitic, and therefore machinable, structure.

"Silal," a special heat-resisting cast iron, is very easy to machine owing to the complete absence of pearlite, except that it has a tendency to chill on thin corners. A normal anneal quickly restores full machinability. "Ni-Hard," an iron with martensitic structure, in which the background is the same as that of a fully-hardened steel, is best ground, but as indicated above it can be machined with tungsten-carbide tools at very slow speeds. This has a limited use in machine tools, sometimes being used for centreless grinder rests.

A series of tests covering a wide range of cast irons has been carried out using the tungsten-carbide-tipped drill-testing machine as used by Mr. Beeny. Some of these results are given in Table I. As previously indicated, the results are not absolutely final. The figure for relative machinability is the depth of penetration of the drill per 100 revs. using a slow spiral drill, ½ in. dia., under a load of 51 lbs. These results are plotted against tensile strength in Fig. 3 and against Brinell hardness in Fig. 4. They show that neither tensile strength nor Brinell hardness is a true guide to machinability. The results for " Silal " are comparable with the machinability of annealed cast iron, except that the Brinell hardness would be about 160. The austenitic group cannot, of course, be considered with the others. This bears out a fact which is not sufficiently appreciated—that Brinell hardness only gives comparison of properties of similar materials.

Hard Spots

Finally, occasional difficulties are experienced by engineers owing to hardness and unmachinability. It is germane to point out that in his endeavour to obtain the optimum properties from cast iron the ironfounder has to make his iron as hard as possible for the section concerned. If the iron is slightly harder than expected, owing to some irregularity in the working of his melting plant, or to a quicker cooling rate than expected owing to an isolated thin part or some extraneous cause, then free carbides appear and give machining troubles.

In conclusion, the author wishes to thank Alfred Herbert, Limited, for carrying out the machinability tests; the Shorter Process, Limited, for treating the flame-hardening samples; the British Cast Iron Research Association for performing the impact tests, and the Mond Nickel Company and others for loan of slides.

REFERENCES

[1] F. W. Shaw, " A Talk on Machine Tools," Mond Nickel Co., Ltd., Publication No. 426.

[2] P. A. Abe, " Flame-Hardening Lathe Beds," " Metal Progress " Vol. 36, No. 1.

[3] H. H. Beeny, M.Met., " A Study of the Machining Problem, with Particular Reference to Cast Iron," "Foundry Trade Journal " Vol. 53, No. 297.

[4] Institute of British Foundrymen, Special Report No. 1.

DISCUSSION

Rigidity of Soft Irons

Speaking of the application of soft grades of cast iron for machine tools, where rigidity was very necessary, MR. R. H. BUCKLAND believed that within limits the softer the grade, the more rigid the cast iron. He asked for Mr. Russell's confirmation of this point. He agreed with the remarks in the Paper about denseners, and asked for the composition of " Silal."

MR. RUSSELL said that a soft weak iron would absorb vibrations, and was not necessarily rigid. " Silal " was a heat-resisting cast iron with about 5 per cent. silicon and 2.3 per cent. of carbon. It had to be made very carefully to secure the fine flake graphite. In spite of the presence of the high silicon, one obtained an easily machinable material, as it was devoid of pearlite.

Factors in Machinability

MR. W. C. MARSHALL, who referred to machinability compared with microstructure, said it was usually assumed that pearlitic iron was the ideal iron from the point of view of both wear and strength. Recently he had examined two specimens, both of which would be described as pearlitic irons from the general structure. The major difference apart from the disposition of graphite was that one contained traces of free ferrite with the pearlite whilst the other contained free cementite in a similar matrix. Would Mr. Russell expect an appreciable difference in the machinability of these two irons?

Although it was universally agreed that a low phosphorus content was desirable from the point of view of soundness, what was the effect on the hardness produced by the variations in phosphorus content usually experienced? A further question was a request for the author's experience as to appropriate methods for machining machine-tool castings. With medium-sized castings the old-fashioned planer machine appeared to be giving way to the planer-miller type. If this was the case on the castings referred to, had Mr. Russell carried out any machinability tests with this type of cutter? It was believed that the Americans used this method of testing machinability, it being possible to measure the torque on the cutting tool.

Referring to the Shorter process of hardening wearing faces, Mr. Marshall asked for information as to the effective depth of hardness. He would also like to have a description of the microstructure at the hardened face.

MR. RUSSELL referred to microstructure *versus* machinability, and said he had really given the Paper before its completion. Pearlite and graphite were the two controlling factors. Free cementite should be avoided as far as ever possible. As to phosphorus and its effect on machinability, he had had one or two discussions on that subject, and he repeated the remarks of Mr. Beeny which had been previously quoted in the Paper. Mr. Russell personally felt that Mr. Beeny placed far too much stress on the tensile strength of the iron.

He had not, he continued, thought about the idea of a planer-miller for measuring machinability, and it seemed to be worth following up when opportunity arose. He was unable to give the absolute maximum depth of the penetration of hardness with the Shorter process. That, he thought, would depend very much on the type of casting, but he would say that $\frac{1}{8}$ in. was quite a reasonable figure.

Phosphorus and Wear Resistance

Mr. H. L. Sanders said one point not mentioned in the Paper was the use of phosphorus in connection with wear resistance. It was generally admitted that phosphorus was helpful in that way, and where a high content would cause porosity, a medium content could be the useful compromise.

He confirmed, from his own experience, the information on the Shorter process given by Mr. Russell and agreed that low nickel content (less than 1 per cent.) added very little to the ultimate hardness. It was an extremely promising process on cast iron; unfortunately the cost was rather high. "Shorterised" lathe beds would be like chilled-surface beds and have to be finished by grinding, scraping being impossible.

He asked Mr. Russell as a leading authority on Ni-Tensyl, what amount of nickel he added; originally that was stated to be $1\frac{1}{2}$ per cent. Mr. Sanders also suggested that the author should have included information about hard spots and chilled corners, and how to avoid them.

Mr. Russell agreed that with the ordinary types of iron the presence of the phosphorus was desirable from the point of view of wear. It was interesting to learn that Mr. Sanders confirmed that small percentages of nickel were of no advantage for obtaining the necessary hardness when using the Shorter process. The cost of the process was a factor he had not yet studied much, but he could believe that it would be fairly costly. On the other hand, buyers of machine tools nowadays put such stress on accuracy that he believed it to be a case when cost became only a secondary consideration. The amount of nickel added was 1 to $1\frac{1}{2}$ per cent.

On the proposition of Mr. W. H. Smith, seconded by Mr. H. Beck, the lecturer was accorded a very hearty vote of thanks.

Mr. T. Makemson (General Secretary of the Institute) was present at the meeting (which was held in the messroom of Ley's Malleable Castings Company, Limited, Derby) and briefly addressed the members on the subject of the wartime activities of the Institute.

Lancashire Branch **Paper No. 721**

Gating and Pouring Temperatures in Non-Ferrous Foundry Practice*

By J. LAING (Associate Member)

The executive of a foundry producing both ferrous and non-ferrous castings can count himself fortunate if he has at his disposal skilled ironmoulders with sufficient knowledge of brassfoundry practice to enable them to be transferred to the non-ferrous foundry as the occasion arises. The greatest factor which operates against the successful transfer, and one which also largely operates against the success of an ironfoundry foreman when set to make non-ferrous castings, is the lack of knowledge of the fundamental principles of gating, coupled with inexperience of the effects of pouring temperatures.

In bringing forward this subject, the writer hopes that he will stimulate the interest of the practical man, in other branches of the industry to that in which he is directly engaged, which in turn will do something to remedy the lack of versatility which does exist.

GUN METALS

These alloys enter the tin-bronze group, the best known of which is Admiralty gun metal containing 88 per cent. Cu, 10 per cent. Sn, and 2 per cent. Zn with small amounts of other elements. Although the compositions of gun metals vary widely, there being literally scores of different mixtures in use, the successful methods of gating a particular design in castings can be applied to almost all the alloys that are listed under this heading.

Broadly speaking, the points to bear in mind are so to design the gates as to allow the mould to fill rapidly with reasonable freedom from turbulence and at the same time maintain progressive solidification to the gates, from those points most remote from them.

The general rule with cast iron is to place the ingate or gates, as the case may be, so as to feed directly into the thinner or less massive parts and thereby level up, to some extent, the solidifying of the metal in the mould. In effect, the method acts in a twofold manner: hot metal flowing through the thin parts superheats the mould and, in consequence, arrives in the massive sections in a cooler condition, resulting thereby, to some extent, in a levelling-up of the solidifying range of the metal inside the mould.

With the gun metals, very little use can be made of this practice, mainly because, however well the gates are distributed, complete levelling up of the solidification is seldom, if ever, accomplished. The best successes are therefore achieved by reversing the procedure and feeding the hot metal directly into the massive sections as shown in Fig. 1. By this means, there results a super-heating of the mould walls, which action is progressively diminishing in severity from the gate to the remote parts of the casting.

Another very important point, which is the reverse of cast iron practice, is that it is essential, when dealing with gun metals, to place the vertical gate very close to the casting in order to reduce surface heat conductivity and ensure adequate feedings from the head. The theoretical line of solidification is illustrated by the arrows in Fig. 1. Runner cups or bushes are also differently constructed on small and medium work, and are made to form a funnel leading directly into the gate.

Although it is essential to use large runner gates, for commercial reasons they must not be unnecessarily large, as, besides increasing the melting costs (fuel and labour), they increase melting losses and, what is more important on high-class work, cause an unnecessary large percentage of gate scrap, with the consequent reduction in the value of the metal.

In Fig. 2 is illustrated diagrammatically a choke type of runner by which a considerable weight of metal can be saved while adequate feeding is maintained. Simply explained, it consists of a feeding knob, sufficiently massive to feed the casting, very similar, although larger, to the feeding knobs used in malleable iron practice. The desired shape can readily be formed by means of a suitable wood pattern, preferably split on the dotted line, the two parts being held in position by a centre dowel. When the pattern had been withdrawn, a comparatively small tube is pushed through the cope to form a downgate.

---

* The Author was awarded a Diploma for this Paper.

By following the method described, much cleaner casting conditions are obtained because the downgate can be more easily kept choked during the pouring operation. The method can also be applied to small castings moulded in batches either by hand or machine, and Fig. 3 shows the method of application.

Top Gating

Whilst top gating can be used successfully on small castings or even on comparatively large, thin castings, it is not recommended for medium and large work. When soundness or density of the metal is important, the pouring temperature has to be lower than will allow entrained air-bubbles to escape, with the result that air, or blow holes, are revealed on machining.

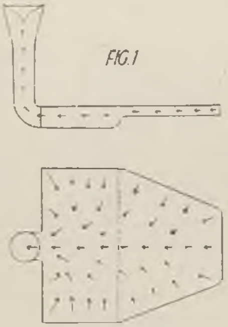


FIG. 1

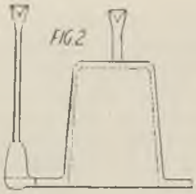


FIG. 2

Risers

Although very great use is made of the runner gate for feeding purposes in the non-ferrous foundry, there are many types of castings that have to be fed by means of risers. A common practice in the iron foundry is to use the top riser almost exclusively when its sole function is the providing of an adequate supply of feed metal. On the other hand, the brass foundry can generally obtain greater soundness by means of side risers, and Fig. 4 illustrates the application of a side riser to a heavy bush casting.

Although side risers of this type adequately provide for solidification shrinkage when correctly proportioned, should they be applied to important work designed to withstand hydraulic pressures, the pouring temperature must be carefully controlled, or a speckled, open grain will develop under the riser. This is caused by the massive riser prolonging the solidification unduly at that point and allowing the dissolved gases to fall out of solution. If, for any reason, the top feeder must be applied, it should be designed so as to ensure the prior solidification of the casting. It is also very essential that generous fillets be used at the junction of all gates, but they must not be made so large as to increase the mass at the point where the casting and gate connect, until it is in excess of the gate above.

Pouring Temperatures

The correct pouring temperature varies with the mass of the casting and the composition of the mixture. Very small, thin castings in Admiralty gun metal may be satisfactorily poured as high as 1,280 or 1,300 deg. C. For heavy castings, 1,150 deg. C. will be sufficiently high. Very good mechanical tests are obtained when the test-bar is near the gate and, provided the other conditions are correct, by using a pouring temperature of 1,200 deg. C.

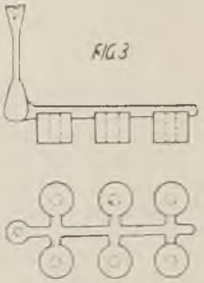


FIG. 3

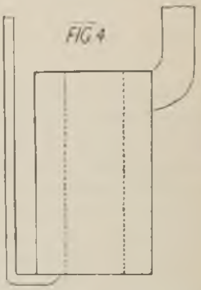


FIG. 4

For gun metals containing larger percentages of the low-melting-point additions, tin, zinc, or lead, the pouring temperature naturally decreases. The metal known in U.S.A. as red brass and containing 85 per cent. copper, 5 per cent. tin, 5 per cent. zinc and 5 per cent. lead, should be poured between 1,100 and 1,200 deg. C., depending on the size and mass. The alloy known as T.F.F.4, which is for all practical purposes 88 Cu, 10 Sn, 2 Zn, plus traces of phosphorus, has a pouring temperature about 60 deg. C. lower than straight 88 Cu, 10 Sn, 2 Zn.

Rejects due to incorrect pouring temperatures are more numerous than is generally realised. They are usually much more serious when arising from too high a pouring temperature than are those due to cold-pouring. The latter will cause drawn areas at the junction of thick and thin sections and at the junction of runner and riser gates; small blow holes on upper surfaces, revealed after machining, and a tendency to show hair-line cracks along the crystal boundaries.

The effect of too high a pouring temperature is to cause inter-dendritic cavities. If the temperature be excessively high, it may result in very pronounced cavities being formed under the skin, which are only revealed on machining. More often it shows as a rough, speckled surface on the roughing cut, and as minute cavities on the finishing cut or polished surface. In some cases it may not even be visible to the naked eye, but will cause the casting to leak under pressure.

An examination of the fracture is an excellent guide as to whether the temperature has been too high. Correctly-cast gun metal has a dense, golden, crystalline structure. When cast too hot, the fracture may show a mixed blue, gold and red colour, with the crystal structure scarcely, if at all, visible. Should such a fracture be examined under low-power magnification, it will show a network of inter-dendritic cavities closely connected one with another. Needless to say, metal in this condition always leaks on machined surfaces when subjected to pressure tests.

PHOSPHOR BRONZE

The extremely fluid character of the medium and high phosphor bronzes, together with their very wide solidifying range, calls for a somewhat different gating technique. It is usually advisable to run from, or at least near, the top of the mould, in order to assist progressive solidification from the bottom upwards. With large work, where the design may be such as to make top running impracticable, a series of gates will do much to prevent the formation of excessively hot regions in the lower parts of the job.

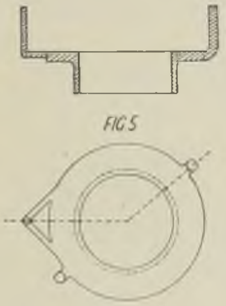


FIG 5

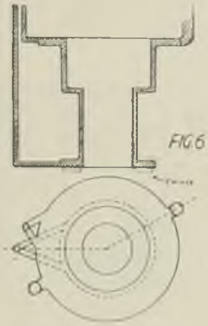


FIG 6

Fig. 5 illustrates a method of gating gland rings and similar castings. It will be seen that the runner gate follows much the same lines as would be used for cast iron. For a small ring, one feeding riser only is necessary, and should be placed near the runner so as to ensure it being filled with reasonably-hot metal. As the diameter increases, so must the number of feeding risers, one being sufficient up to about 10 in. in dia., two from 10 to 20 in., and three from 20 to 30 in.

Fig. 6 illustrates another type of fairly large casting which, owing to its particular shape, is not suitable for gating from the top. In this instance two downgates are employed, the first entering the bottom flange, and when the mould is almost full the plug is lifted off the second gate, allowing hot metal to enter into the top flange. When gating in this manner, it is desirable to chill the face of the bottom flange heavily, to ensure it solidifying prior to the side walls. Heavy flow-off risers are employed to take care of the solidification shrinkage of the upper portion of the casting.

Excepting the very small work, it is preferable to use large runner bushes, such as are employed for cast iron, and almost to cover the gate with a piece of copper plate or strip, which will allow the bush to be filled almost instantaneously. Plugs can, of course, be used if desired, but, owing to the fluid nature of the metal, there is a tendency for them to leak, particularly when dry-sand runner bushes are used.

Pouring Temperatures

For important castings, the pouring temperature is more critical than that of any of the commonly used non-ferrous alloys. Examination of the fracture is an excellent guide as to whether or not the correct temperature has been used. When correctly cast, the fracture will show a dense structure, bluish-white in colour in the thin section; the thicker ones will have a dense outer skin of similar colour, the interior being golden with the crystal structure very clearly defined. With incorrect temperature, instead of a golden crystalline interior, there is a fracture showing mixed colours of bluish-grey, yellow and red, with the crystal boundaries invisible.

There are so many variable factors which govern the casting temperature of the phosphor-bronzes that no hard and fast rules can be established. The following figures will, however, serve as a useful guide: Small and medium castings having wall thickness up to about ½ in. and poured in low phosphorus alloys, 1,120 to 1,150 deg. C. For castings of similar size and mass, poured in high phosphorus alloys, 1,070 to 1,100 deg. C. For wall thicknesses from ½ in. to 1 in., the requisite temperatures will be between 1,090 and 1,120 deg. C. for the former alloys, and between 1,025 and 1,070 deg. C. for the latter group.

YELLOW BRASS

Gating for yellow brass follows the practice indicated for the gun metals. It has, however, a greater solidification shrinkage and therefore requires larger feeders. Many yellow brass castings are of thin section and comparatively large in area, and on work of this character, a high pouring temperature must be used. For this reason, it is desirable on work of large surface area to skin-dry the runner gates in order to prevent scabbing and erosion of the sand. The ingates should be well distributed and be placed to enter as near as possible into the heavier sections as illustrated at AA in Fig. 7, otherwise shrinkage cavities may occur at the points BB.

Risers used to feed bosses, etc., should be enlarged almost down to the casting as shown in Fig. 8. It is sometimes difficult on small work of this nature, where several castings are made in one box, to accommodate an adequate number of risers and runner bushes. An alternative method, and one which often gives superior results, is to place separate direct runner gates on to each casting. The hot metal, passing through them, prolongs the solidification and promotes good feeding.

Pouring Temperatures

The pouring temperature of the brasses is not nearly so critical as is the case with tin bronzes. High percentages of zinc prevent the absorption of reducing gases during melting, thus the speckled gas-holed appearance, which often causes rejection of gun-metal castings, is entirely absent. The pyrometer is therefore not often used, although unnecessary high temperature causes greater zinc losses, increased liquid shrinkage, and an increased tendency to erode the mould, particularly in the runner gate.

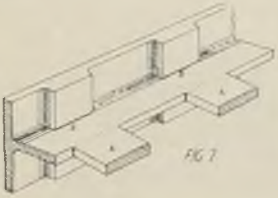


FIG 7

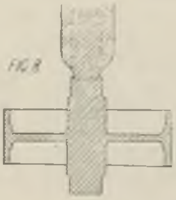


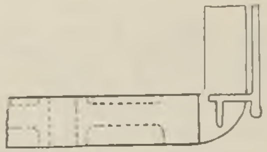
FIG 8

MANGANESE BRONZE

As quite a large number of non-ferrous foundrymen fight shy of this metal, there may be some excuse for the ferrous foundryman refusing to handle it. Successfully to cast the metal, a very highly-developed gating technique is necessary. The alloy must enter the mould entirely free from turbulence and, furthermore, any oxide formed in the runner gate has to be prevented from passing into the casting, as, once oxide has been formed, it is never reduced or re-absorbed by the metal. The solidification shrinkage is also extremely high and ample provision must be made for feeding, and for ensuring directional solidification towards the feeding heads.

Excepting for extremely thin work, very slow pouring should be adopted, as quick pouring will always tend to create turbulence. For the same reason the metal must enter from the bottom of the mould, or at least on the lowest level. Any cascading effect will certainly cause dross inclusions. It is a decided advantage to arrange, wherever possible, for the runner to enter immediately under a feeding riser so that the flow may be observed during casting and, furthermore, if small particles of dross are formed, they may be piloted up the riser by means of a mild steel rod.

The runner gates must also be so designed as to avoid any jet-like effect being given to the metal as it passes through them. When a number of gates are fed from a larger one, special attention should be given to surface friction which may cause an increase in the speed of the metal passing through the centre of the small gates. Another important point when dealing with multi-gating is the prevention of an increase in pressure being given to metal in the small gates situated nearest to the main downgate. Dross traps and dross sumps are also used extensively on larger work, and such a trap is shown in Fig. 9. It is readily formed by bridging the gate with a core at A. It is also very desirable slightly to choke the gate at the runner-bush end by means of a core as shown in Fig. 9.



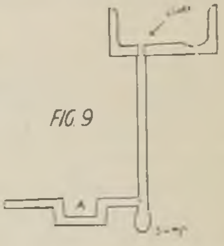


FIG 9

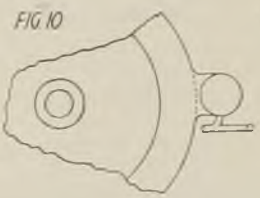


FIG 10

Fig. 10 illustrates a method of gating that can be applied to small and medium shallow castings. Here the metal first enters the bottom of a feeding riser from which it flows very quietly into the mould.

The most successful method of gating deep work is by means of a series of runners entering from below as shown in Fig. 11. The vertical runners increase slightly in cross-sectional area as they approach the casting. Gating a large casting in this manner causes the metal in the lower flange to solidify later than the walls of the casting, with disastrous results, unless special precautions be taken to hasten the solidification. The method most readily applied is the placing of cast-iron or copper chills on the base between the gates.

Pouring Temperatures

As with yellow brass, the density of manganese bronze is very little affected by pouring temperature. As, however, high temperature causes the shrinkage to increase, especially near the runner gates and near severe changes of section, and also increases the dross-forming tendency, all castings should be poured as cool as possible, having due regard to the avoidance of mis-runs. About 1,000 deg. C. is a good average temperature which may be varied 50 deg. C. or so in either direction, according to the size and mass of the casting.

ALUMINIUM BRONZE

The main problems to be met in casting the alloys under this heading are the prevention of oxide inclusions and drawn areas, problems which can only be solved by correct gating technique. The apparent solidification shrinkage is very high; therefore, large risers and feeding heads are essential. The latter may, in extreme cases, have to be considerably larger than the casting. As a general rule the methods described for manganese bronze can be applied, but it is even more important not to allow disturbance of the metal surface as it fills the mould. The oxidised skin should lap gently to the sides as the metal quietly rises. On important work, the slightest ripple may be sufficient to cause rejection.

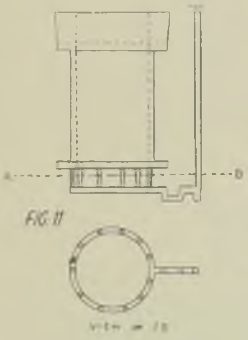


FIG 11

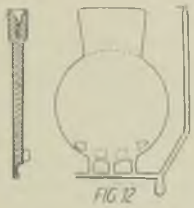


FIG 12

Disc-type work generally lends itself to casting on edge as shown in Fig. 12. Light chilling near the base, as illustrated by the dotted lines, will be a decided advantage, as it will counteract the tendency to prolonged solidification due to the gates superheating the base of the mould.

Castings resembling the design shown in Fig. 13 are more suitable for casting on the flat, when a heavy feeding riser can be used to take care of the shrinkage in the boss. In all cases, where suitable arrangement can be made for feeding, greater soundness can usually be obtained in bosses and other heavy sections by leaving out the centre core and casting such masses solid. Should coring be essential, chills may have to be resorted to.

A useful point to bear in mind when dealing with aluminium bronze and, indeed, with all the high-shrinkage alloys, is that hot metal poured into feeding heads and risers considerably improves their efficiency, but when applying the practice to the dross-forming alloys, the metal must be poured in with a very short stream, or oxide may be carried down into the casting.

Pouring Temperature.—The average range of castings made in aluminium bronze can be poured between 1,170 and 1,200 deg. C. but special massive ones may be poured considerably lower.

ALUMINIUM ALLOYS

The commonly-cast aluminium alloys, especially the high silicon ones known as "Alpax," "Wilmill," etc., can be regarded as easy to cast by the average foundryman and call for no special comment. Into quite a different category enter the high-duty alloys such as "Y"-alloy and their derivatives—R.R.50, R.R.53, Ceralumin, etc. All these alloys possess high solidification shrinkage and, due to their magnesium content, dross-forming tendencies.

Taken generally, it is desirable to use the multi-method of gating so as to avoid excessive overheating of one part of the mould, and to assist in levelling up the solidification. Bottom gating, because it reduces turbulence, is usually more successful, and pistons, liners, etc., can be cast with a continuous runner down the side of the mould, such as is used by die-casters. This type of runner also serves to supply hot feed metal to the upper part of the mould. A suggested method of multi-gating is given in Fig. 14. The feeding knobs, adjacent to the entrance of each ingate, are noteworthy. On deep work of a similar nature, it is often desirable to chill the base of the casting lightly in order to control the direction of solidification towards the feeders.


FIG 13

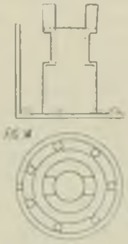


FIG 14

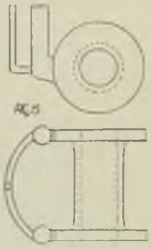


FIG 15

Pouring Temperatures

The aluminium alloys in general should be poured as low as possible consistent with obtaining a finished casting free from cold-shuts and trapped air bubbles. About 700 deg. C. is an average figure, which may be lowered to 670 deg. C. for massive castings and raised to 780 deg. C. or so for very thin ones. With the high-silicon alloys, the actual pouring temperature is controlled to some extent by the modifying temperature which, when using metallic sodium, is standardised at about 760 deg. C. Allowing a modification period of 2 minutes, a pouring range of 700 to 725 deg. C. is usually obtained.

Very thin castings of comparatively large area may be found difficult to run completely within the range, and for this category it is often found desirable to modify at 20 or 30 deg. above the recommended temperature. On very important work of a repetition character, one should obtain the correct temperature by trial in order to standardise it for future use—a procedure which should also be applied to almost all non-ferrous work of a similar character.

NICKEL-COPPER ALLOYS

While gating and pouring temperatures of the high-nickel alloys are not the most important consideration in the successful production of good castings, they are, nevertheless, worthy of serious consideration if scrap is to be avoided. The difficulties involved are largely due to the extremely short solidification range, the fairly high solidification shrinkage, and the extremely high pouring temperatures.

The main consideration to bear in mind is the provision of adequate feeding gates. At the same time one should remember the difficulties involved in removing the heads and risers of the high nickel alloy group by means of the ordinary dressing shop equipment, and design the gates accordingly.

A runner-gate, small enough to be kept choked and entering *via* the risers, as is sometimes used in manganese-bronze practice, gives the best results. Owing to the much shorter freezing range, the runner must, however, be considerably larger and very similar in size to that used in iron foundry practice. An example is given in Fig. 15 which shows a short, double-flanged pipe. The runners passing through the heavy feeding risers ensure very hot metal rising up into them and, therefore, efficient feeding is assured.

Pouring Temperatures

Broadly speaking, one should pour as hot as possible, but, of course, stewing in the furnace in order to make sure of obtaining a high temperature is fatal. Owing to the very high temperatures used it is difficult to determine them satisfactorily, although they can, of course, be obtained by means of a protected thermocouple, but the time lag is a drawback. The approximate casting temperature of the 70:30 Cu-Ni alloy is about 1,400 deg. C., and the 30:70 Cu-Ni alloy (Monel metal type) is about 1,540 deg. C. As a general rule, the more adequate the feeding, the wider is the pouring range.

Finally, a word of warning against the "foundryman's" cure for porosity—increasing the height of the gates. This is usually described as "giving pressure," but unfortunately very often it does more harm than good. What is essential is the maintenance of a liquid passage of metal from the head to the casting until the latter has become solid, and this can usually only be accomplished by increasing the mass of the risers and bringing the head as near to the casting as possible.

DISCUSSION

Phosphor-Bronze Casting Temperatures

Mr. A. Phillips (Manchester), opening the discussion, said that Mr. Laing had given a range of casting temperatures for a 0.2 per cent. phosphor bronze and he asked whether when the phosphorus was found to be lower, an appropriate adjustment should be made to the casting temperature in order to give the best test bar result.

Referring to the trap runner as used for manganese bronze, he thought that if the well underneath, if a bridge core was inserted, were a little deeper, and the other one made a little higher, a better reservoir would result, and so form a better means of holding back the scum. Should both sides of the trap runner be made to agree?

Mr. Laing said that when dealing with pouring temperatures for phosphor bronze he was referring to sound castings and not test bars. He did not, however, give the figures 1,070 to 1,180 deg. C., but 1,070 to 1,100 deg. for light castings in the higher phosphorus alloys, a range of only 30 deg. Generally speaking, it was necessary to ensure that the test bar was adequately fed by receiving a good supply of hot metal. Personally he always attached the test bars direct on to the runners and not on to the casting.

Gating Manganese-Bronze Castings

The runner on the casting side of the trap was always a little larger than that on the gate side, in order to avoid any further turbulence. It should theoretically get slightly larger from the bottom of the sump right to the casting; so there would be no increase in speed and no jet-like effect past the trap, while the choke on the runner top was specially designed to eliminate any undue speed of the metal beyond the trap.

Mr. A. Jackson, referring to pouring temperatures, said when taking temperature readings in connection with different classes of phosphor bronze, it should be borne in mind that bought material and back scrap might be incorporated. As the latter might get mixed, it was obvious that a temperature adequate for one type of phosphor bronze would yield unfavourable results with another. The pouring temperatures of phosphor bronze which he used usually ranged from 1,080 to 1,120 deg. This alloy sometimes carried a certain amount of lead and he would like to know its effect on the casting temperature.

With gunmetal the lead was added to improve the machining properties, but why was lead added in the case of phosphor bronze?

Mr. Laing, after pointing out that the discussion was getting away from the subject of the Paper, said he personally only added lead to gunmetal for two purposes: for improved machining and for cheapness. Occasionally its addition was made (although he did not endorse the practice) to pressure resisting castings in order to increase soundness. Many people recommended the use of lead with hydraulic metals, but personally he could obtain pressure-tight castings, or perhaps sounder castings, without it. Leaded phosphor bronze was used extensively for railway bearings, where there were heavy loads associated with low speeds. It was actually used as a bearing metal because there were, so to speak, hard and soft spots in the bearing for wear resistance. It was thought that as lead was a separate constituent in the alloy, it flowed about until it filled up the spongy areas in bosses, but, personally, he did not think it did anything of the sort.

Lead was not used in phosphor bronzes which had to be subjected to hydraulic pressure. High-class phosphor bronzes did not carry lead; at least, he did not know of any.

Mr. Jackson again referred to suitable casting temperatures for phosphor bronze, and suggested that it might be possible to construct graphs showing the relationship between the phosphorus content and the casting temperatures.

Mr. Laing, agreeing, said the difficulty was, of course, in ascertaining the phosphorus content of the shop scrap. The only way one could be sure of getting a definite phosphorus content in the alloy was to add the phosphorus immediately prior to pouring, preferably even after the crucible was lifted out of the furnace. The only way he could guarantee a phosphorus content within set limits was to add a small amount of phosphor copper sufficient for the purpose of de-oxidation, as soon as the copper melted. After adding the tin and when the required temperature was reached, the crucible was withdrawn, and the requisite phosphorus in the form of 15 per cent. phosphor copper was added. The metal was allowed to cool to the correct temperature and poured. Stewing resulted in a loss of phosphorus. The more lead there was in the phosphor bronze, the lower was the casting temperature. With 10 or 12 per cent. of lead as occurred in some phosphor bronzes, pouring could take place at an extremely low temperature, certainly below 1,000 deg. C. High lead content necessitated thorough stirring, or lead might remain at the bottom of the pot.

Phosphorus in Leaded Bronze

Mr. E. Longden also referred to the use of lead in phosphor-bronze mixtures. Generally speaking, phosphorus was not introduced to a leaded bronze. The term was seldom used correctly. Phosphorus present in quantity in leaded bronze tended to precipitate. With the introduction of lead in any alloys, particularly for massive sections, the difficulty arose of preventing collection into pools, *i.e.*, its actual segregation. After all, a pure copper lead alloy would only carry in solution about half of 1 per cent. Therefore, he thought, to introduce phosphorus into a leaded bronze would be incorrect, except perhaps just a modicum to deoxidise before introducing the lead.

Mr. Laing said that, of course, it was very often necessary to make bearings, etc., to specification, and there was a call for lead in phosphor bronze on the part of some of the railway companies. They specified bronze which would not break or crack. They did not want a particularly hard bronze, but a material which would withstand the shocks on the railway, and yet be sufficiently plastic to conform to the shape of the shaft. Many of the foreign railways also demanded a high-lead phosphor bronze.

Mr. Longden said this might be quite a good practice in the case of thin sections. If, say, 0.15 per cent. of phosphorus was introduced to 10 per cent. tin-bronze the freezing range increased by about 25 deg. Roughly, there would be something like 240 deg. freezing range in such an alloy. Even though the specification demanded leaded alloys he would invariably keep on the minimum side, and definitely on the minimum side with the phosphorus. With a heavy section he would be still more reluctant.

Mr. Laing pointed out that in the case of the railways they were all heavy sections about 1 in. thick, and some specifications demanded very close tolerances in respect to phosphorus content.

Mould Dressings

Mr. E. Sutcliffe, jun., inquired as to the nature of the mould dressings used in connection with non-ferrous castings. If blacking were used it would give a black surface to the casting, which was usually objectionable. If flour were used then personal experience showed it to be rather dirty. If Mr. Laing had, say, a few hundred gauge cases to cast in gunmetal, what would he add to his alloy to eliminate the gases inherent in and arising from the scrap?

Mr. Laing said that normally blacking was ruled out unless the castings were shot-blasted, after which there would be no evidence of its use. If shot-blasting was not employed then china clay or talc was quite satisfactory as mould dressings, or half each of plumbago and china clay could be used, or again an equal mixture of plumbago and talc. Ground lime was quite a suitable dressing for green-sand moulds provided there was a minimum quantity used. Talc and china clay would also serve. The only way he knew to remove gas was to cast at the correct temperature.

Teeming Speeds

Mr. A. Hopwood said that Mr. Laing's method of bottom-running manganese-bronze castings with a pencil gate was usually adequate, but due regard must be had to the speed and pressure with which metal was admitted through pencil ingates. This was governed largely by the choke in the head and the size of the down runner.

Did Mr. Laing favour the use of draw plugs at the top of bushes for manganese-bronze work? It was possible to postulate from experiment that a ¾-in. down peg, which was practically the average size for the majority of manganese-bronze castings, would cast a 1-cwt. casting probably in about 6 secs. It had been stated that from the cupola tap hole ¾ in. in dia., 15 tons of metal per hour could be run. On this basis it required 12 secs. to run a 1-cwt. casting. To his mind, such a rate for a manganese-bronze casting was too prolonged, for the simple reason that the longer the time the metal was in creeping over the cores in a complicated casting the more likelihood there was of having gas present in the top of the cores and blowing off just as the metal covered the core. He had seen such an occurrence. This could be easily overcome by proper sand control; but it must be remembered that the work was undertaken under actual manufacturing conditions which were not ideal.

He asked what was a suitable casting speed for a manganese-bronze casting having a ⅜-in. metal section? The casting would have to withstand, say, 3,000 lbs. pressure when finished. He was not in favour of the use of a draw plug for the reason that there was not the same control over the metal entering the mould, no matter how the runners were choked. There always seemed to be a certain amount of leaking into the mould cavity.

Mr. Laing said he did not wish to be misunderstood. The runners were not intended to be pencil runners as generally understood by the iron foundry. They were much larger. He did not favour pencil type runners on manganese bronze; the runners must be larger in order to take the metal more freely. They must be larger in cross-section than the main gate that was feeding the runners. Otherwise there would be a jet effect. The cross-section of the gate must be increased as it met the casting.

He always used plugs for castings down to 56 lbs. One would certainly get some dross in the gates if plugs were not used. The very fact of the metal splashing on the bottom of the runner was sufficient to create a certain amount of dross. This did not happen when the plug was drawn as had been suggested. Naturally, there must be no leakage. Six seconds for teeming a hundredweight casting was inadequate except for very thin sectioned work. He would not mind if it took as long as a minute if it ran quietly and without turbulence. Danger from cold shuts apart, the slower the metal crept over the cores, the better. Rapid heating all over gave rise to a tendency for gas to be evolved from the core face. A small bubble of air might then rise through the metal over the core and create a sort of flare. One could be quite certain there was a small amount of dross wherever that flare occurred. This experience was also applicable to aluminium bronze.

Value of Fracture Tests

Mr. E. White asked for additional information concerning fractures of small castings as a means of surmounting some of the current difficulties.

Mr. Laing said that with non-ferrous castings examination of fractures was insufficiently practised. For gunmetals and phosphor bronzes, it was an extremely good guide as to whether a casting was likely to be sound. If the runners were partially cut through and broken off, then an appreciation could be obtained as to whether the casting was sound or otherwise. A golden crystalline fracture always gave the best results, and not the fibrous, mixed or slate-coloured fracture. Sometimes one would think a fibrous fracture would be best, but with the others one could obtain a good sound casting on water test.

Mr. W. N. Cook, B.Sc., said that the practice at his foundry was to saw the runner half way and break it. If the fracture was satisfactory, it went forward, but when it exhibited a brown patch, which was not very often, then the corresponding casting was scrapped without the slightest hesitation. Through this practice the amount of machine shop waste was reduced to a very low figure indeed.

Mr. A. Phillips said that if a large casting had to be made, say, one of about 6,000 lbs. of metal, it was necessary to take a fracture test before pouring into the mould. The method was to take a sample out of the furnace with a scoop and pour it into a chill mould, cool it quickly, and submit it to the fracture test. From shop tests it was possible to observe whether the elongation and tensile strength were likely to be attained; otherwise, it was a waste in casting. This system was practised in many non-ferrous foundries. He was referring particularly to manganese bronze, but the same observations applied to gunmetal and nickel-lead bronze castings.

Melting Temperatures

Mr. Laing said that when one was familiar with a particular composition of manganese bronze it was possible to judge the approximate mechanical strength by means of the size of the crystals, the particular shade of colour and the angle of bend before fracture. Whilst the system might be useful for the tin bronzes where quality depended upon correct casting control and not on compositional changes due to melting losses, he had never tried it.

Mr. E. Longden said it was generally understood when melting alloys that gases were increasingly absorbed with increasing temperature. Did the author favour reaching a very high temperature—when melting gunmetal and phosphor bronze—before removing the pots from the furnace, with the object of ensuring effective action by, say, fluxes or alloying elements? He thought it would be of general interest if Mr. Laing would indicate how he alloyed gunmetals.

Mr. Laing said that melting temperatures for gunmetal should not be higher than necessary. It was possible to attain 1,300 deg. C. with gunmetal without any consequential serious effect, provided the metal was allowed to cool down to the correct temperature before pouring. There was really no point in superheating beyond the point necessary to obtain a suitable casting temperature.

Gunmetal Practice

With regard to the making of gunmetal, it was fairly common practice to melt the copper under charcoal. Some people used flux, although it was not really necessary, but some found it advantageous. When the copper was molten, the tin was added and finally the zinc.

Mr. Longden agreed that the modern tendency was not to exceed any higher temperature than was necessary in order to allow for the handling of the metal.

Mr. E. Earnshaw asked whether large nickel alloy castings could be cast without drying the moulds. Up to a certain weight it was possible to cast in green sand, but beyond that it appeared necessary to use dry sand. Could Mr. Laing confirm this?

Mr. Laing said it was desirable to dry all moulds for high-duty heavy alloys unless they were quite small. He preferred to use a synthetic sand for high nickel alloys—a silica sand bonded with bentonite or Colbond—in order to obtain an open-grained sand. It had to be dried in order to prevent penetration and to get a good skin. Drying increased the permeability—an important factor when handling these alloys.

Protection of Thermocouples

Mr. R. S. Turner inquired whether Mr. Laing used silica or steel sheaths for protecting thermocouples. Also, did he de-oxidise yellow brass—60 : 40—before casting?

Mr. Laing said that most laboratory assistants preferred to have a covered couple for use with phosphor bronzes as there was a very rapid burning of the couple but the time-lag was somewhat troublesome. A steel sheath was generally used, but it should be preheated to reduce the length of time taken for the reading.

Yellow brass did not need de-oxidising, it could be melted successfully under a slightly reducing atmosphere, without any ill-effects. With a high zinc content, he had never found it necessary to de-oxidise.

Mr. Turner remarked that he had in mind the necessity of ensuring a clean top surface to the casting after machining.

Mr. Laing said that such defects were probably due to excessive turbulence. It was desirable to insist on a reasonable machining allowance for top surfaces of yellow brass castings, as it was more "drossy" than gunmetal. Fortunately large yellow brass castings were not often used, and apart from ships' windows one did not get many large yellow brass castings. Naval brass carrying 1 per cent. tin was still worse in this respect.

Mr. Hopwood, referring to the use of high head pressures, thought that Mr. Laing did not appear to favour their use to any great extent. This occurred within his own experience, which had indicated that fettling costs could be materially reduced. It was possible to reduce considerably the area of junction of the riser by using pressure plus the intelligent use of a correctly-shaped riser. It was also possible to reduce the number of risers on the job, even in manganese bronze.

Mr. Laing could not say that that was his experience. To increase the riser beyond a certain height was useless because it solidified across the narrow neck.

Steam Feeding

Mr. Phillips inquired whether the lecturer had applied steam feeding to large manganese-bronze castings. In the case of cast iron there was a practice of steam feeding, by sealing the top of the riser with wet loam and then putting weights on it. This was a very successful practice with certain types of iron castings. Had Mr. Laing seen or heard of it being done in the case of large castings involving large heads, where, generally speaking, a feeding rod would be otherwise used?

The Branch-President (Mr. A. L. Key), answering the question for Mr. Laing, said that within his experience it was possible for Admiralty bronze, and it would appear that steam feeding was thus applicable to manganese bronze.

Mr. Longden thought that most of the sketches displayed did show a reasonable head. He quite agreed it was useless to increase the head in a case of a thin section.

Mr. Hopwood thought they were labouring under a misapprehension with regard to what he termed " making use of the pressure."

In replying to Mr. Hopwood, who had raised a point about runners being higher than risers, Mr. Laing stated that if the runner gate was very small it would be useless. The effect was only momentary, and as soon as the runner solidified head pressure ceased to exist, one would then get normal feeding from the riser.

Replying to Mr. Jackson, who had asked a question concerning a choke runner and how it affected temperature, Mr. Laing said there must be a slightly higher temperature to allow for the time lag in filling the mould. Concerning dressing, which was another point raised by Mr. Jackson, it was very difficult to prevent phosphor-bronze metal penetrating into massive green-sand moulds. In the case of very large moulds, it was much better to dry them, having previously applied a wet dressing. Mineral blacking, of course, was useful mixed with the sand for very small castings. He did not approve of coal dust in green-sand facings, although he had used it in dry-sand cores. It was fairly effective so used.

If much phosphorus was present there would be great difficulty in preventing the occurrence of tin sweat unless the mould face could be chilled. If it could be chilled and the metal rapidly solidified it would definitely stop tin sweat. The usual method was to flood the top of the heads with water and cover them up with sand, and weight down; but even then it was very difficult to prevent. One could not, in fact, prevent sweat from exuding if the casting was sufficiently massive, unless it was rapidly cooled. That was providing the phosphorus content was fairly high. If the phosphorus content could be lowered then there would be less tin sweat.

Lancashire Branch **Paper No. 722**

Melting Operations in the Non-Ferrous Foundry

By FRANK HUDSON (Member)

The non-ferrous foundry has many immediate problems, more so perhaps than iron and steel foundries. Every engineering project is developed from a casting of one kind or another and production, particularly of copper-base cast articles, constituted the first metallurgical development that the world has ever known. Accordingly, the uninitiated might anticipate that brass foundries and ingot casting shops are model exponents and possibly originators of works metallurgy. Indirectly the last thought may be true, and if one undertook to trace the first application of works metallurgy it might conceivably be found to originate from a dispute, shall we say, about an unsatisfactory article.

So far as the direct application of metallurgy is concerned, the brassfounder, with few exceptions, has shown little initiative. There is some excuse for this as the very antiquity of the art promotes habits and methods unreceptive to modern developments, and it is not unusual to find that the whole fabric of bronze and gunmetal casting production has been built upon rule of thumb methods without the presence of guiding fundamental facts. Such a state of affairs is, of course, entirely wrong, and to-day, more than ever before, there is profitable scope and application for research of a practical nature.

For many years the practical man has been, and in some cases still is, labouring under entirely erroneous ideas as to how metals should be melted. Until quite recently it was considered satisfactory practice to employ neutral or slightly reducing furnace atmospheres using charcoal as a cover. Following investigation into the effect of gases on copper and degasification methods it is now known that such practices are incorrect and that the best results are obtained with oxidising conditions—a complete reversal of the old ideas. It is also now appreciated that the composition and condition of the metal being melted, in conjunction with alloying technique, bear an important relation to thermal reactions.

Practical application of these discoveries has led to pronounced improvement of casting quality in a wide variety of alloys, both as regards density and mechanical properties. They have exploded the theory widely held amongst practical men that virgin metal heats, say of 88:10:2 gunmetal, give inferior results to the use of remelted metal such as ingots. They provide information as to why various brands of copper behaved differently when used for alloy production in the foundry, particularly so far as sand castings are concerned, and indicate means by which these differences may be corrected—a most important point at the present time.

During the past two years it has been the privilege of the author to come in close contact with many brassfounders, large and small, antiquated and modern, throughout the length and breadth of the British Isles, and it would appear that more efficient results would undoubtedly be obtained if melting operations, in

Table I.—*Vapour Pressure of Zinc in the Industrial Brasses.**

Composition.	Partial pressure of zinc vapour at various temperatures.				
	Melting point (liquidus).		Approximate casting temperature.		Boiling point. Deg. C. (Vapour pressure Zn 760 mm.)
	Temp. Deg. C.	Vapour pressure. Mm. Hg.	Temp. Deg. C.	Vapour pressure.	
Zinc	419.5	0.139	500	1.27	918
60 : 40	900	160	1,040	600	1,070
65 : 35	930	170	1,070	595	1,100
70 : 30	955	150	1,100	540	1,145
80 : 20	1,010	85	1,150	265	1,300
90 : 10 .. .. (estimated values)	1,055	20	1,200	80	1,600

* "The Casting of Brass Ingots," by Genders and Bailey, Research Monograph No. 3, British Non-Ferrous Metals Research Association.

the full sense of the term, were better understood. In the first place, it might be mentioned that it is not essential to rely upon furnace control to promote oxidising conditions, as suitable treatment can be given even in the presence of reducing atmospheres. Furthermore, the degree of oxidation required is not such as to cause abnormal metal loss. It would simplify the problem to compare the melting operations entailed in connection with, say, three groups of alloys, brass, gunmetal and the true copper-tin alloys such as the 90:10 alloys and phosphor bronze, etc., and it is proposed to adopt such a course in this Paper, keeping all remarks as simple and practical as possible so that they may be the more readily understood.

TABLE II.—*Zinc Loss of* 70 : 30 *Brass under Reducing, Neutral and Oxidising Surface Atmospheres.**

Alloy.	Treatment.	Loss. Per cent.
70 : 30 brass	800 deg. in air	0.25
	1,050 deg. in air	1.7
	1,050 deg. in nitrogen (+ 2 per cent. oxygen)	4.7
	1,050 deg. in hydrogen	12.6
Aluminium brass (0.2 per cent. Al)	800 deg. in air	0.27
	1,050 deg. in air	0.92
	1,050 deg. in nitrogen (+ 2 per cent. oxygen)	2.52
	1,050 deg. in hydrogen with flux	13.8
Aluminium brass (2.5 per cent. Al)	800 deg. in air	0.003
	1,050 deg. in air	0.007
	1,050 deg. in nitrogen (+ 2 per cent. oxygen)	0.071
	1,050 deg. in hydrogen	15.3
Silicon brass (2.0 per cent. Si)	800 deg. in air	0.12
	1,050 deg. in air	0.67
	1,050 deg. in nitrogen (+ 2 per cent. oxygen)	6.0
	1,050 deg. in hydrogen	12.8
Phosphorus brass (0.05 per cent. P)	800 deg. in air	0.36
	1,050 deg. in air	15.1
	1,050 deg. in hydrogen	16.4

* "The Casting of Brass Ingots," by Genders and Bailey, Research Monograph No. 3, British Non-Ferrous Metals Research Association.

Brass Melting

There is no doubt that hydrogen is the gas which causes most trouble in melting operations, and the first point which the foundryman should bear in mind is that the solubility of hydrogen varies with different metals. For example, the affinity of zinc-free bronze for this gas is infinitely greater than, say, 70:30 brass. It is now known, in fact, that 70:30 brass is relatively immune to hydrogen unsoundness. Genders and Bailey have shown in their book, "The Casting of Brass Ingots"* a standard work of reference on the subject, that the soundness of sand-cast 70:30 brass melted in an atmosphere of hydrogen was unaffected, whilst a 5 per cent. tin-bronze treated under similar conditions showed 150 per cent. increase in porosity. It is surmised that the factor responsible for this exceptional behaviour of brass can be attributed to the high vapour pressure of the molten alloy as shown in Table I.

It is well known that liquids under certain conditions tend to give off vapour, and this process of transformation is called evaporation. At constant temperature the space above the liquid contains a definite amount of the vapour of that liquid, and this exerts a pressure known as the vapour pressure. Liquids which readily evaporate give high vapour pressures; for example, ether at 20 deg. C. has a vapour pressure of 442.2 mm. of mercury, whilst water at the same temperature has a value of 17.41 mm. Molten copper at 1,320 deg. C. has a vapour pressure of only 0.001 mm. of mercury. Vapour pressure increases with rise of temperature and a liquid boils when its temperature is such that its vapour pressure equals the pressure of the atmosphere, namely, 760 mm. of mercury. The solubility of gas in a liquid, providing it does not react chemically with that liquid, decreases with increasing vapour pressure of the liquid, becoming zero at the boiling point. Water contains air and if one watches the effect of heat on water in a glass vessel, this air can be observed coming out, long before boiling point is reached, and it is all expelled on boiling, and, so long as the water is boiling, no air can be re-dissolved.

A similar analogy exists in connection with molten metals. As the vapour pressure rises

---

* Research Monograph No. 3, British Non-Ferrous Metal Research Association.

the solubility of gas becomes increasingly less until a value of 760 mm. of mercury is reached, when the liquid boils and gas is all expelled. In Table I it will be observed that the addition of zinc to copper increases the vapour pressure, and alloys containing not less than 20 per cent. zinc have boiling points well within temperature ranges arising in normal foundry practice. For example, 70:30 brass boils, *i.e.*, its vapour pressure equals 760 mm. of mercury, at 1,145 deg. C. As a matter of interest, it might also be mentioned that the boiling point of liquids is reduced as the atmospheric pressure decreases. At an altitude of 90,000 ft., water would boil at 10 deg. C. A similar position arises in the vacuum melting of alloys.

In connection with removal of gas from alloys, it is possible that there are other metals which will act in a similar way to zinc by lowering the vapour pressure or the boiling point, and an investigation into this matter might lead to some very interesting results.

Whatever the reason, the fact remains that alloys in this group are outstanding in that they are practically unaffected by variations in melting conditions so far as gas absorption is concerned. In other words, it does not matter whether one employs melting furnaces giving reducing, neutral or oxidising atmospheres. It is important to note, however, that the evolution of zinc vapour should take place in order to obtain satisfactory results. Care must therefore be taken to ensure adequate superheating temperatures and, of course, there must be enough zinc present for free evolution. This latter point is particularly mentioned as it is not yet certain that alloys containing, say, less than 15 per cent. zinc are free from gas absorption during melting. However, it can be accepted that brasses containing over 15 per cent. zinc, including manganese bronze, etc., are relatively fool-proof so far as melting technique is concerned.

In view of brasses being immune to hydrogen pick-up, it must also be evident that the initial gas content of the virgin metals employed for making up the alloy is of little moment. For example, cathode copper, which contains appreciable quantities of hydrogen, can be readily used for brass production although special precautions would have to be taken if such were used for the manufacture of sand-cast gunmetal or bronze castings.

Genders and Bailey also draw attention to another very interesting point which clears up a past misconception. Most foundrymen hold the opinion that in the melting of brass, oxidising conditions lead to greatest metal loss. This appears incorrect as the above investigators have proved that reducing conditions lead to highest zinc loss. The experimental method utilised consisted in heating small quantities of alloy in a tube furnace through which either air, nitrogen or hydrogen could be passed in a regular stream. The furnace atmosphere obtained from the passage of these gases duplicates oxidising, neutral or reducing conditions obtained in practice. The losses in weight of the metal samples after treatment were as are shown in Table II.

Pure brass in the molten state, when exposed to air or oxidising conditions, is rapidly covered by a surface film of oxide which has the effect of reducing the evolution of zinc. The thinner film formed under nearly neutral conditions permits a greater zinc loss to take place, but this is still much less than that obtained when the formation of the oxide film is entirely prevented, as arises in the presence of hydrogen. Furthermore, it is interesting to observe that these conditions do not apply to molten brass containing even small amounts of phosphorus. This is due to the fact that phosphorus removes the oxide film from the surface of the brass and high zinc losses arise with any type of melting atmosphere. This property of phosphorus in reducing metallic oxides should be particularly noted as its action in this direction is of considerable importance in connection with alloys such as gunmetal and bronzes, to be discussed later. Oxides containing aluminium are one of the few oxides that phosphorus will not reduce and it has therefore no effect on the high tensile brasses containing aluminium. The affinity of aluminium for oxygen at melting temperatures is so much higher than that of phosphorus that a phosphorus-aluminium brass behaves as if phosphorus were absent.

To summarise the position in connection with the melting of alloys in the brass group the following main points emerge:—

(1) Melting atmosphere does not seem to play an important part in the production of the usual copper-zinc alloys so far as gas adsorption is concerned providing zinc fume is evolved.

(2) The raw material basis of the metal charge has little effect.

(3) Lowest metal losses, particularly of zinc, are obtained with oxidising furnace atmospheres, but this does not apply when even a trace of phosphorus is present in the alloy, except in brasses containing aluminium.

Gunmetal Melting

With the gunmetals containing copper, tin and zinc, melting operations become of increasing importance, and greater care must be exercised if the best results are to be obtained. All the commercial gunmetals absorb hydrogen, and the degree of absorption depends on several factors. From what has been said in regard to brass it will be apparent that the amount of zinc present will constitute one factor. From the practical point of view it will be agreed that the less zinc present in gunmetal the greater the possibility of trouble. Another factor of even greater importance is the composition of the furnace atmosphere, whether reducing, neutral or oxidising. Melting time, superheat temperature, nature of furnace charge and method of alloying bring up other problems which must be taken into account.

So far as the melting operation is concerned, much can be done to prevent the metal absorbing harmful gases by ensuring an oxidising atmosphere or the presence of active oxides in or on the molten metal. It is useful to note that one has these two alternatives.

In connection with the first alternative, hydrogen is formed during melting as a variable according to the operation and type of furnace employed. In coal and coke fired units the moisture in the air used for combustion reacts with carbon in the fuel at temperatures over 850 deg. C. to form hydrogen and carbon monoxide. (As a matter of interest it might be mentioned that industrial hydrogen is principally made by passing steam over coke at a high temperature.) Reducing conditions assist this reaction, but it tends to be reversible in the presence of carbon dioxide or oxygen, hence the modern tendency for utilising oxidising melting conditions as far as possible.

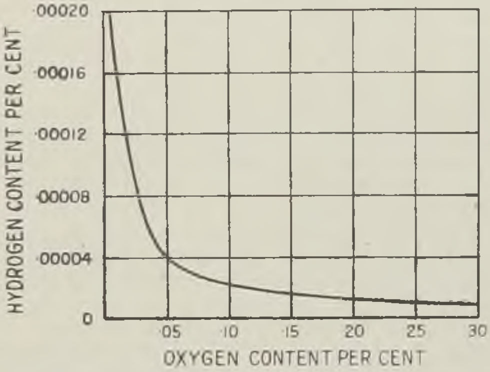


FIG. 1.—EFFECT OF OXYGEN CONTENT ON HYDROGEN SOLUBILITY (ALLEN).

When using coal for firing, as is common for the production of large quantities of metal in reverberatory or air furnaces, hydrogen can result as a direct decomposition product from the coal. Coal gas, as used for melting purposes, contains around 15 per cent. hydrogen. In the arc furnace, hydrogen is formed through the decomposition of water vapour in the air by the electric discharge. In addition to the above, nearly all the common metals decompose water between a red and white heat with the formation of hydrogen. In view of these examples it is obvious that all industrial melting furnaces are hydrogen producers, if given the opportunity, to a greater or lesser degree. The presence of oxidising gases in furnace atmospheres, either as oxygen or probably as carbon dioxide, limits the amount of free hydrogen produced either from direct reaction or from the dissociation of water vapour. Accordingly, the first effort in the production of good gunmetal castings should consist of ensuring that the melting furnaces in service are capable of giving oxidising atmospheres.

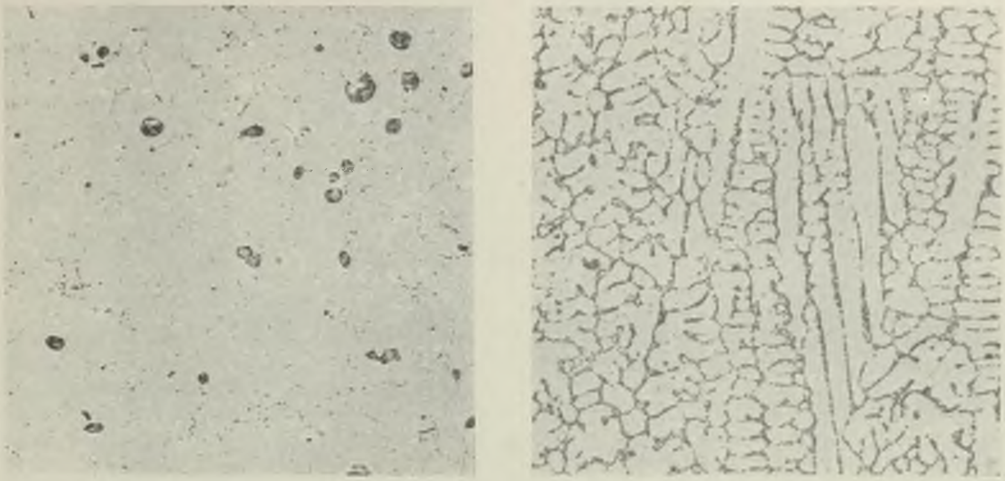
The electric induction furnace of either the low or high frequency type is undoubtedly the best unit available so far as this matter is concerned. Unfortunately, the price of such equipment is beyond the reach of many foundrymen and, furthermore, it does not possess sufficient elasticity for general needs although extremely useful for specialised work. For all general purposes, either oil or forced-draft coke-fired furnaces are hard to beat, providing a plentiful air supply is available. In fact, with proper control, uniform fuel and judicious selection of charge materials, correct melting conditions can be so maintained as to require no additional oxidising technique.

Unfortunately, the present conditions in most non-ferrous foundries in this country preclude this ideal being readily obtained, and some degasification treatment will usually be found necessary. Coke-fired natural-draft furnaces as a class are inferior to oil or forced-draft units in view of the inadequacy or wide variation in the air supply available and the consequent difficulty of obtaining oxidising conditions. With these types of furnaces the addition of oxidising agents becomes more or less essential. Coal-fired, gas and electric arc furnaces, unless handled with skill and special precautions taken, are liable to give gassy metal, and degasification should be thoroughly conducted by one or other of the methods shortly to be described.

Another method of preventing hydrogen absorption mentioned earlier is to ensure the presence of active oxides in or on the molten metal. It has been shown that by ensuring an oxidising atmosphere during melting the presence of furnace hydrogen is minimised. A still more important point is that under such conditions metallic oxides are formed *in* the metal capable of removing hydrogen. For example, hydrogen has a greater affinity for copper oxide than metallic copper and will combine with the oxide to form water vapour, which is evolved from the melt providing an adequate quantity of oxide is present, and metallic copper which is redissolved. Similar reactions take place with nickel oxide.

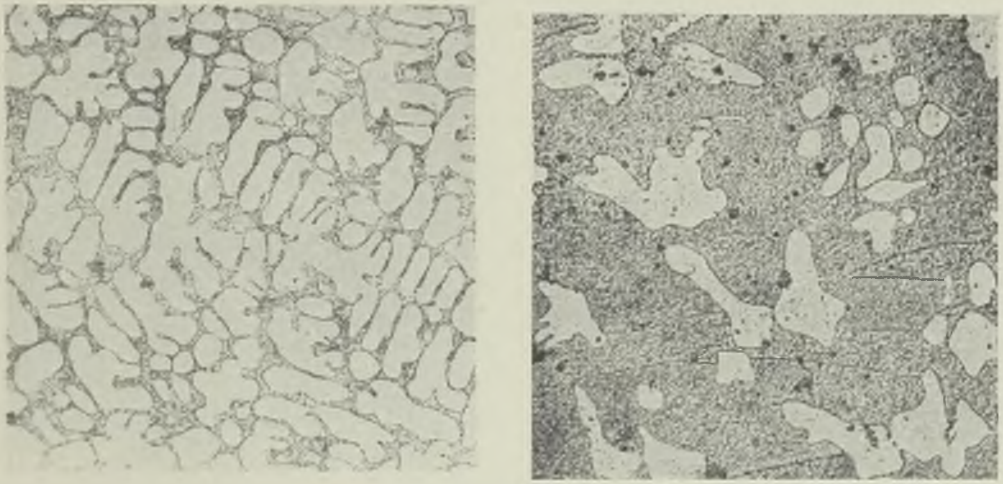
It is thus evident that the presence of copper or nickel oxides in an active form in their respective alloys either as a result of melting conditions, composition of metallic charge or as a definite addition, provides a practical means of overcoming troubles due to dissolved gas. In fact, many founders have already found that degasification conducted by oxide additions is more suited to routine foundry purposes than furnace control.

These may be utilised with the initial charge or added after the metal is molten and superheated. Black cupric oxide, added in an



A.—0.05 PER CENT. OXYGEN.

B.—0.10 PER CENT. OXYGEN.



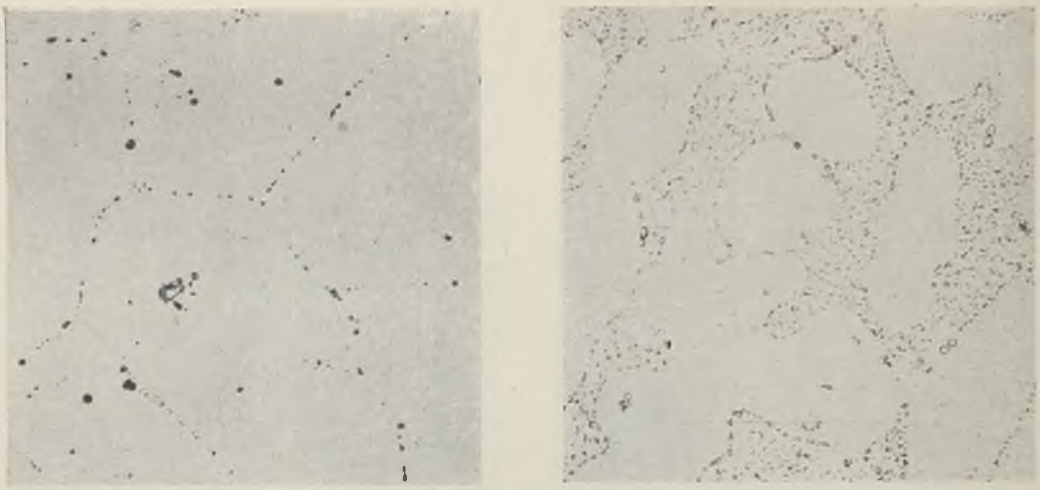
C.—0.15 PER CENT. OXYGEN.

D.—0.32 PER CENT. OXYGEN.

FIG. 2.—MICROSTRUCTURE OF CHILL-CAST COPPER CONTAINING VARIOUS OXIDE CONTENTS. × 100. ELECTROLYTICALLY POLISHED.

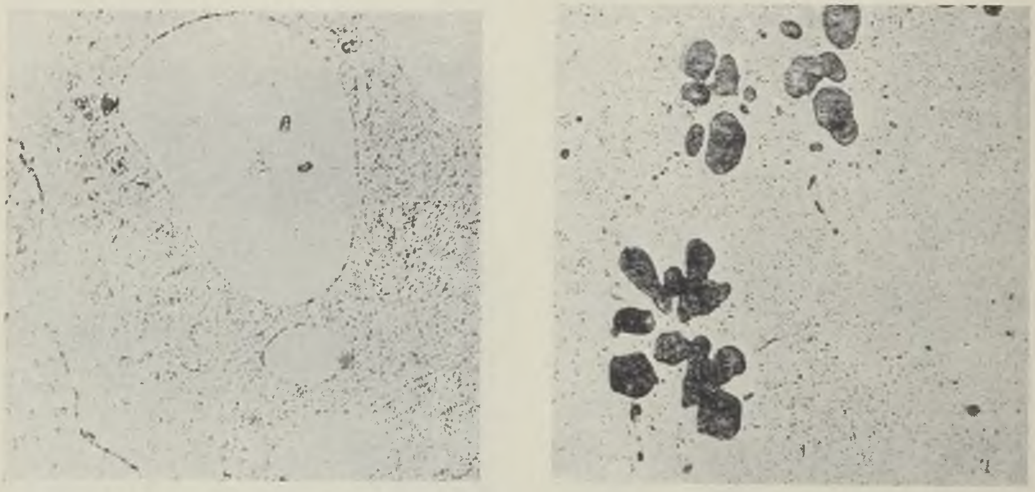
Oxygen in cast copper can be readily detected and the amount present estimated under the microscope at 75 to 100 magnifications. Specimens should be taken at least ½ in. away from a cast or " set " face as the oxide content in surface areas is usually much higher than in other parts. Examination should be conducted after polishing and light etching with a *freshly prepared* 10 per cent. aqueous solution of ammonium persulphate. Small percentages of oxygen begin to show in cast copper as a thin grain boundary of copper-cuprous oxide eutectic, as shown by the above photomicrographs, gradually thickening and filling up the grains until approximately 0.39 per cent. oxygen is reached when the structure consists entirely of eutectic. Above this content spangles of free primary cuprous oxide appear as shown in micrograph 3D.

amount equivalent to between 1 and 2 per cent. of the charge weight (as well as certain proprietary fluxes) is a satisfactory addition material for incorporating with the charge, whilst red cuprous oxide can be utilised for molten metal degasification. In this latter case around 0.2 to 0.5 per cent. should be sufficient, and this is added and stirred into the metal, preferably in the furnace, a few minutes before pouring.



A.—0.05 per cent. Oxygen.

B.—0.15 per cent. Oxygen.



C.—0 32 per cent. Oxygen.

D.—0.50 per cent. Oxygen.

Fig 3.—Microstructure of Chill-Cast Copper Containing Various Oxide Contents. × 500. Electrolytically Polished.

It is, of course, important that these oxide additions should be perfectly dry. Treatment of the metal after melting has an added advantage inasmuch as crucible attack by the flux is negligible. The use of oxidising slags in the manner suggested is particularly valuable when melting must be conducted under reducing conditions. It must also, of course, be appreciated that gunmetals treated with oxidising media must be properly deoxidised, preferably with phosphorus, before being poured into castings. Phosphorus, as was shown in the case of brass, has the property of reducing nearly all the metallic oxides except that of aluminium,* and such an addition will effectively remove the oxides present in gunmetal if the oxidising treatment has been overdone.

Up to this point in the Paper, it will have been noted that the absorption of deleterious gases by gunmetal can be mainly counteracted by either the use of oxidising melting atmospheres or the direct addition of suitable metallic oxides. There are, however, two subsidiary factors which come into the picture, namely, the initial oxide or gas content of the metals making up the furnace charge and their surface condition and nature. The solubility of hydrogen in copper, for example, has been demonstrated to be dependent on the oxygen content, as shown in Fig. 1. It will be observed that in the presence of 0.05 per cent. oxygen, or above, the hydrogen solubility is at a low level, but rapidly increases with oxygen contents below 0.05 per cent. " Best Selected " copper ingots favoured by the non-ferrous founder contain between 0.05 and 0.10 per cent. oxygen, and there is no doubt that this materially assists casting production by tending to prevent gas absorption and constitutes a probable reason for the popularity of the grade. Fig. 2 illustrates the microstructure of cast copper containing various oxide contents. There are, however, many other grades of copper available with less or even no oxygen at all, and trouble can arise through using such material unless certain precautions are taken.

The author came across a typical example of this recently. A certain foundry producing Admiralty gunmetal castings had made these copper ingots melted in natural-draft fires without any special precautions being taken. When they changed over to a brand of oxygen-free copper actually of higher quality than " Best Selected," and they melted this material in their usual manner they were unable to meet test-bar requirements, obtaining about 11.0 tons per sq. in. tensile. These low results were principally due to gas pick-up, probably caused by melting under slightly reducing conditions in conjunction with a lower initial oxide content in the charge. The higher oxide content in the previously used " Best Selected " copper was just sufficient to prevent the absorption of hydrogen.

The trouble was eliminated by adding a small quantity of black copper oxide to the oxygen-free copper during melting, when test-bars giving 20 tons tensile were readily obtained, a value somewhat higher than those previously obtained when using " Best Selected " copper. The detailed melting procedure adopted was as follows:—

(1) Oxygen-free copper ingots melted with 1½ per cent. of black copper oxide and superheated to around 1,250 deg. C.

(2) Molten copper deoxidised with 0.01 per cent. phosphorus.

(3) Zinc added.

(4) Tin added.

(5) Metal deoxidised after skimming and just before pouring with a further 0.01 per cent. phosphorus.

Oxygen-free copper such as " cathodes," an electrolytic form which has not been changed into the tough pitch state by remelting, must be very carefully controlled in the foundry. This type of copper contains appreciable quantities of hydrogen, and in the absence of oxide is liable to give erratic results. Melting under oxidising conditions alone may not provide enough oxygen to meet requirements, but satisfactory results can always be obtained by the addition of cupric or cuprous oxide during melting. In fact, in these days when foundrymen as a whole must work economically, the use of oxide additions to gunmetal is a practice which can be thoroughly recommended to give uniform results regardless of the raw materials employed.

Many foundrymen hold the opinion that remelted metal gives better results than virgin metal for casting production, and in most instances this is no doubt true. A possible explanation may lie in the fact that, with remelting, the oxide content tends to be increased, and this reacts as previously described. It should, however, be clearly understood that in the presence of excess oxygen or oxides no difference is likely to be detected between remelted and virgin materials.

So far as scrap is concerned, it will be obvious that material carrying hygroscopic corrosion products may accentuate gas troubles due to the reaction of moisture in the corrosion product with the base metal and the consequent formation of hydrogen. On the other hand, scrap having an oxidised surface, for example copper firebox scrap, or a large surface area in relation to weight which will oxidise readily, such as tubes, borings or light foundry scrap, assists in preventing trouble.

To summarise the position in connection with the melting of alloys in the gunmetal group, the following points should receive consideration:—

(1) Melting atmospheres begin to become of importance, and oxidising conditions should be obtained wherever possible.

(2) The raw material basis of the metal

---

* There is not sufficient evidence as yet to indicate the true effect of phosphorus on tin oxide. Stannic oxide, the tin oxide likely to be formed during melting operations, appears to be reduced by phosphorus to stannous oxide. The latter is soluble in molten soda ash and also probably reduced by phosphorus. On the other hand, reaction between phosphorus and tin oxides may lead to the formation of phosphates. Potassium and sodium reduce tin oxide.

charge has an effect on the results obtained, and quality production is facilitated by the presence of oxides in or on copper or its alloys.

(3) The use of direct oxide addition in conjunction with phosphorus deoxidation affords a convenient way of obtaining uniform melting control.

Bronze Melting

In the production of the copper-tin alloys careful attention to the melting operation becomes of paramount importance, as this group of materials is most susceptible to hydrogen absorption. The author considers that an oxidising treatment by one or other of the methods already described, in conjunction with judicious use of zinc and phosphorus, is essential if the best results are to be obtained, especially so far as sand castings are concerned. Certain precautions are, however, necessary in the presence of appreciable amounts of phosphorus.

The presence of small percentages of zinc appears to lessen the risk of unsound work being produced. It is interesting to note that the well-known 88 : 10 : 2 gunmetal was developed, it is thought, because of the difficulty encountered in casting the 90 : 10 copper-tin alloy originally chosen for high-class steam and water fittings. Even to-day this latter alloy is still specified "zinc-free" by many engineers where maximum resistance to corrosion is required. Phosphor and gear bronzes are further modifications of the 90 : 10 alloy in which the presence of zinc is looked upon with suspicion. So far as can be seen, there is no evidence whatsoever that small amounts of zinc, say around 0.5 per cent., have any noticeable effect on wearing properties or on resistance to corrosion.

Suggestions have been made in the past that traces of zinc have a deleterious effect on bearing or gear bronzes and on corrosion resistance, but so far as one can see this has never been actually substantiated in service. Personally, it is felt that the presence of under 1 per cent. zinc in bronze is unlikely to deteriorate any of its properties. In fact, it is much more likely that the reverse will apply. Founders should, wherever possible, bring these points to the notice of engineers with the view of getting specifications amended so that at least 0.5 per cent. zinc may be allowed. So far as this Paper is concerned, one of the principal actions of zinc additions to bronze is that this prevents excessive oxidation of tin. In the melting of copper-tin alloys, either from virgin metal or from scrap, under oxidising conditions it may happen that the copper becomes over-oxidised, with the result that tin oxide may be formed in the metal. So long as the copper contains zinc, tin oxide cannot form due to the preferential oxidation of zinc, which thus tends to act as a safety device. The best method of introducing small amounts of zinc is by means of Muntz or brass bar scrap with the initial metal charge.

In addition to zinc, phosphorus will also have to be relied upon for deoxidation purposes. In small quantities, say up to 0.05 per cent., it has little effect upon oxidising melting processes as the reaction, such as was mentioned in connection with brass, between metallic oxides and the small amount of phosphorus present is soon finished with more or less complete loss of phosphorus. Similarly, larger amounts of phosphorus, such as are present in phosphor-bronze, are of little moment, providing they are added *after* the copper has been oxidised. Thus, in the production of phosphor-bronze from all virgin metal an oxidising treatment may be applied to the copper *via* furnace atmosphere or by direct oxide additions with beneficial results. When, however, ingots or scrap containing appreciable amounts of phosphorus form the basis of the charge, direct oxide additions during melting result in a large decrease of phosphorus. When appreciable phosphorus is present during the melting-down perod, probably the best procedure is to try to arrange for rapid melting with oxidising furnace atmospheres so that the presence of deleterious gases available for absorption by the metal will be as little as possible.

In the melting of the bronzes it would thus appear necessary to modify the technique required according to the type of bronze being made along the following lines : —

(1) Melting atmosphere is of special importance for all the true copper-tin alloys, and this must be oxidising.

(2) A small addition of zinc improves production and casting quality.

(3) Deoxidation with phosphorus should always be practised after oxidising and before and after the addition of tin.

(4) Direct oxide additions can be utilised to counteract the effect of hydrogen pick-up providing the basic furnace charge is free or low in phosphorus.

(5) Should the basic charge be high in phosphorus, gas absorption should be minimised by the use of oxidising furnace atmospheres in preference to a heavy direct oxide addition unless followed by an adjustment to make up for loss in phosphorus content. The use of relatively small additions (0.2 per cent.) of red cuprous oxide after the metal has melted assists degasification with less phosphorus loss.

In the melting of special alloys for sand castings such as nickel silver, which, unlike brass, is highly susceptible to gas reactions, cupro-nickel and Monel, etc., it can be truly claimed that the use of oxidising melting treatments followed by adequate deoxidation have been primary factors in establishing satisfactory foundry technique.

In conclusion, it might be noted that the remarks made in this Paper are principally directed in connection with the production of sand castings. It will be appreciated that the amount of gas evolved bears a relation to the rate of solidification, less being given off the more rapidly the casting is cooled. Accordingly, in the production of chill or centrifugal castings careful control of melting operations is not so important.

DISCUSSION

Vote of Thanks

Mr. Norman Cook, B.Sc., who proposed a vote of thanks to the author, said that he thought the Paper was the most interesting, from the practical point of view, that he had ever listened to at an Institute meeting.

Mr. R. Turner endorsed Mr. Cook's remarks, adding that he personally had learnt much from the Paper.

The vote of thanks was carried unanimously.

Mr. Hudson, responding, said there was much to learn about non-ferrous melting conditions, and he had described in the Paper one or two of his experiences which he could vouch for.

Segregation of Scrap

Mr. A. Sutcliffe asked how the presence of manganese in gunmetal would affect colour and shrinkage, and what the effect of aluminium would be on the colour and skin of the castings. What had impressed him in brass foundries, where a number of heavy alloys were being handled, was the liability of the scrap runners to become mixed. An easy way of overcoming that difficulty was to mark the head or runner of each alloy used.

Many foremen did not like making alloys with a limited range of tin content, but preferred to have a free hand, asserting that better results could be obtained by using a small excess. Mr. Sutcliffe also asked for an opinion as to whether Mansfield red sand or yellow sand was to be preferred for brass moulding. He did not know whether the industry used the cheapest method of melting brass, but one firm at least was using the cupola with very good results.

Influence of Mn and Al on Gunmetal

Mr. Hudson doubted whether small amounts of manganese had much effect on the colour, density or porosity of gunmetal, but aluminium had. Even a trace of aluminium (as low as 0.05 or 0.1 per cent.) would cause a white skin to form on the gunmetal castings, with appreciable porosity. So marked was this that if gunmetal containing aluminium were used for pressure work, leaky, unsound castings would be produced. Mr. Sutcliffe had remarked on segregation of scrap to the appropriate mixing. Such mixed scrap, however, could usefully be used for making the cheaper gunmetal, such as red brass (85:5:5:5). Every foundry should control tin within about ½ per cent. accuracy, although a variation of that magnitude would not seriously affect the properties.

Choice of Sands

The choice of Mansfield or yellow sand was quite open. Personally, he did not think there was one sand better than another, providing each possessed the suitable physical characteristics for producing good castings. In the production of special high-melting-point alloys in the brass foundry, such as Monel, etc., brass sands should never be employed. Ironfoundry sands carrying coal dust were called for. Brass foundries had received initial orders for these special alloys, and naturally had used Mansfield sand. The sand fused on to them, and created ugly castings. Brass foundries making such castings nowadays used ironfoundry sands, containing 5 per cent. or so of coal dust, and produced a beautiful blue skin like a grey-iron casting. For normal bronze work, a good Mansfield sand was in every way satisfactory. Many firms in the South used Erith sand, with equally good results.

Bronze Plate Castings

Dealing with some slides which were shown by Mr. Sutcliffe, Mr. Hudson said that for a bush which was depicted, his advice was to use no risers, but rather a good heavy ingate. A plate which was also shown reminded Mr. Hudson of a recent visit to a foundry specialising in the production of large bronze doors for buildings. Those doors were made up from a back and front plate, each only about ¼ in. thick, and the two were ultimately joined together to form the finished door, which would be about 10 ft. high and 6 ft. wide. It was no easy task to produce a bronze plate of those dimensions free from blemish. This particular foundry obtained very good results by pouring from about 10 ingates on each side, and using two big down-runners fed from two pouring ladles. To obtain the best results on plate castings, one should use dry-sand methods, and cast horizontally, with as many gates as one could get down one side or (if necessary) both sides. For bronze castings, risers should be avoided if at all possible.

Melting Losses

Mr. A. Phillips remarked that in the table showing the melting losses under oxygen, nitrogen and hydrogen, no test had been taken on the phosphorus alloy melted under nitrogen. As to sodium-zinc additions for releasing gases, he would like to know how to add the sodium-zinc under foundry conditions. The same remark applied to the copper oxide. It had been stressed that alloys containing aluminium could have the oxides reduced by phosphorus additions except the actual aluminium oxides. What could be suggested for the reduction of the alumina in such cases?

Mr. Hudson, referring to the table showing the effect of phosphorus on brass and the zinc losses under reducing and oxidising conditions, suggested that the only reason that the nitrogen test was omitted was because there was no difference between oxidising and reducing conditions. It was not worth while doing a test on the phosphorus brass with the neutral atmosphere, because quite obviously the result would be the same.

The sodium-zinc development had not made (so far as he knew) any progress in this country, but it had been employed in America. Apparently this deoxidiser was an alloy containing 2 per cent. sodium and 98 per cent. zinc in metallic form suitable for adding to the metal by plunging. Copper oxide could be added in two ways. Cupric oxide was usually added in the crucible with the initial charge, while cuprous oxide was usually made up into a packet using copper foil as an envelope, or packed inside copper tubing, and was then plunged below the metal surface.

He did not know of the existence as yet of any positive method of reducing aluminium oxide. He believed that one or two people specialising in the production of aluminium bronze used a certain flux, which effectively reduced aluminium oxide. This probably contained a cryolite base. In the refining of aluminium, bauxite containing aluminium was dissolved in cryolite. He thought a flux containing cryolite might be effective, but he could not put it forward with any degree of confidence.

Mr. N. Cook said a proprietary flux was being sold to remove small amounts of aluminium from gunmetal and bronzes.

Mr. Hudson, although aware of such a flux, said that he had had no experience of its use in practical conditions.

Mr. Cook added that he was informed that excessive additions would make it ineffective.

Mr. Phillips said that for some time the firm with which he was associated had observed the practice stressed in the Paper of having oxidising conditions in melting. He was fully in agreement with the author; oxidising atmospheres were quite satisfactory for the brasses and the bronzes, but with aluminium alloys such atmospheres during melting were the reverse and must be avoided at all costs because they were unable to free the liquid metal from the oxide.

Mr. Hudson agreed, and said he had purposely confined his remarks to the copper-base alloys, because he did not want to give an impression that his remarks referred to the aluminium alloys or to alloys containing aluminium.

Use of Sodium-Zinc

Mr. D. Fleming said his firm had tried using 2 per cent. sodium-zinc alloy made by adding sodium to zinc in the molten condition. This might sound a highly dangerous procedure, but was quite easy. He used the sodium-zinc in place of the normal zinc. Tensile tests of over 20 tons for gunmetal had been claimed, but he had not found it to be as beneficial as it promised to be initially, and its use had been suspended for further investigation.

Mr. Phillips thought sodium-zinc was beneficial in certain directions. He had tried some experiments, but was not yet fully convinced, or he would have given the results. He did think that sodium-zinc would help to remove aluminium oxide. He had no definite data as yet, but work had been done in that direction which revealed very favourable aspects.

Mr. Hudson pointed out that both sodium and potassium were much more powerful reducing agents than phosphorus, and there were very few metals which sodium and potassium would not reduce from the oxide to the metallic state. There was every reason to think that tests with either of those two metals would be very satisfactory.

Mr. Fleming said he was not referring to sodium-zinc as a remover of aluminium oxide, but as a deoxidiser.

Mr. Vickers asked whether the remarks on aluminium oxide were in reference to aluminium bronze, aluminium itself, or aluminium alloys.

Mr. Phillips said he was referring to aluminium oxide in any of the many alloys containing it, such as aluminium bronzes, or any other bronzes containing aluminium. That was his initial inquiry.

Zinc Chloride Championed

Mr. Vickers then observed that in those circumstances with the three alloys mentioned, zinc chloride would remove aluminium oxide. That fact he had actually proved. He had seen material containing so much oxide that one could melt and obtain only a spoonful of metal, and one would get back 98 per cent. of the material as metal when using zinc chloride.

Mr. Turner said that for gunmetal his firm was using 0.2 per cent. zinc as deoxidiser and the best results were obtained. He believed that Mr. Hudson had recommended phosphorus. Did any of the phosphorus remain in the metal, and did it improve the strength or otherwise?

Mr. Hudson replied that the amount which remained was practically undetectable by normal routine analysis.

Mr. Turner inquired whether phosphorus gave better results than zinc as a deoxidiser.

Mr. Hudson replied that phosphorus, in conjunction with zinc, would give better results, as there was 2 per cent. zinc present initially.

Mr. Turner said his firm always added a further 0.2 per cent. as a deoxidiser.

Mr. Hudson thought that, in the circumstances, the addition of 0.05 per cent. phosphorus would give even better results than increasing zinc solely, or using zinc as deoxidiser. The most important factor was to obtain oxidising melting conditions in the first place. Phosphorus additions did not degasify and their full benefit was not developed if the metal was improperly melted in the first place.

Cupola Melting

Mr. Sutcliffe asked what Mr. Hudson thought of the practice of melting gunmetal in the cupola.

Mr. Hudson thought that under certain conditions this could readily be done. He knew of at least one foundry which made large quantities of gunmetal in the cupola, but it was not employed for direct casting operations. Non-ferrous foundries producing large outputs of gunmetal and bronze castings could put all the more contaminated products from the reclamation plant through the cupola, at the end of the day, and cast the metal into ingots for remelting purposes. A good yield of ingots was thereby obtained. That was one way of utilising the cupola, but they still remelted in crucibles afterwards. Cupola melting was an uneconomical way of melting gunmetal, unless one had large quantities of low-value material which had to be cheaply reverted to a more marketable or usable form.

Mr. J. Masters recalled that, some 30 years ago, his then employers rigged up a cupola purposely for melting copper, with a view to adding the alloys after the copper was melted, but it proved a total failure. There was not a sound casting in a batch consisting of about 15 tons, mainly of brass axle boxes.

Mr. A. E. McRae Smith said that on one occasion his firm was compelled to use the cupola for a huge supply of high-pressure copper tubing. Melting was accomplished by using a very low blast pressure.

Mr. W. Holland said that up to 12 months ago, a firm in Gloucestershire was actually melting bronzes in a cupola. They maintained a cupola specially for that purpose.

Mr. Hudson said it had frequently been done in America.

Mr. Holland added that the castings were not for pressure-resistance, but were statues and art castings. The metallic losses were high.

The Chairman (Mr. A. L. Key) recalled that at the time he served his apprenticeship, all his firm's heavy non-ferrous castings were cupola-melted, and they passed Admiralty tests quite successfully. One could imagine the care necessary with a condenser taking 4 tons of metal which were melted in the cupola. The zinc and tin had to be alloyed in the ladle. There was no other means then of doing the job. Now an air furnace was invariably employed. Mr. Key added that he knew of one firm which had recently erected a cupola for the purpose of making antimonial lead, which had always been melted in pots previously. The firm was employing this cupola quite successfully, and as economically as the crucible process.

Lancashire and Scottish Branches **Paper No. 723**

Production of Some Engineering Castings*

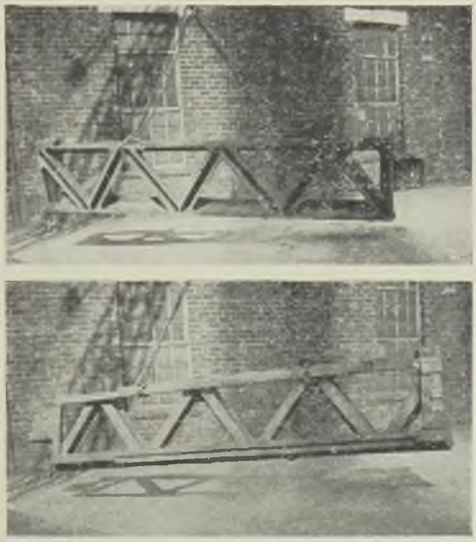
By A. MARSHALL (Member)

Judson, in an Exchange Paper† entitled "The Founding of Pressure Castings," made the following statement:—

"Generally speaking, engineering grey iron castings can be divided into two broad classifications, viz., structural castings and pressure castings.

"Structural castings are designed from a mass and rigidity standpoint: the provision of sufficient iron to satisfy the mass or inertia requirements automatically meets the rigidity and strength requirements. The iron used in this type of casting need not be of such composition that, throughout any one casting, a close-grained homogeneous metallic structure exists. An open-grained structure in the centre of massive sections is not detrimental.

"There are exceptions to this, however, noticeably machine-tool beds and frames.



Figs. 1 and 2.—Views of 23-ft. Long Machine-Tool Bed, Cast in Green Sand.

"Pressure castings, on the other hand, are quite dependent upon the absence of draws, shrinks, spongy spots, coarse graphitic carbon, and demand a dense, fine-grained homogeneous structure in order to be serviceable.

"The structure of the iron, as, for instance, the amount of graphitic carbon present, and more important still, the condition in which this graphite exists, is of paramount importance in castings subjected to pressure."

The foregoing statement contains, probably, the results of a lifetime of experience—an experience in which some decisions may have been made which proved highly successful, while others may have been just as unsuccessful. From these very failures, there may have emerged new ideas, which ultimately led to the successful solution of yet more difficult problems, and brought with them the satisfaction of a wider experience and a greater knowledge.

Considering the responsibilities resting on the foundry executive of to-day, first he must recognise that success or failure depends largely on his ability to develop the enthusiasm of the team spirit.

The experienced executive will study every individual over whom he has control, so that he may make the best possible use of whatever talent or ability is available. This study is of great importance, and while he may make mistakes, let him remember that people may learn as much from mistakes as from successes.

Decisions covering all phases of manufacture may have to be made in conjunction with executives in charge of other departments, and having satisfied himself, finally, that as far as he could he had influenced design to secure economy in production and efficiency in operation, the foundry executive can now proceed to plan production.

Costing of Patterns

The costing of patterns is a point upon which the cost office and the patternshop rarely agree. In the patternshop a large amount of work is done by hand, whereas in a machine shop most of the work is done by machines. The speed of a machine can be ascertained, and a fairly

---

* The Author was awarded a Diploma for this Paper.

† Proc. I.B.F. Vol. XXIX, 1936, p. 295.

accurate estimate of output be made, but when one considers the construction of a pattern, of the necessary core boxes, and the finish (the bulk of which is done by hand), it can be easily realised how difficult it is to obtain an accurate cost. Experience gives one a good idea of the time likely to be taken on certain classes of work, but even then a few lines or altered dimensions may necessitate a complete change in the construction of the pattern and, consequently, may modify greatly the cost of pattern-making. Taking into account, also, the necessity of carefully selecting the class of timber to be used, it becomes evident how difficult it is, even for a practical man, to estimate costs; and it must be much more difficult for anyone with no practical experience of the craft to prepare these estimates.

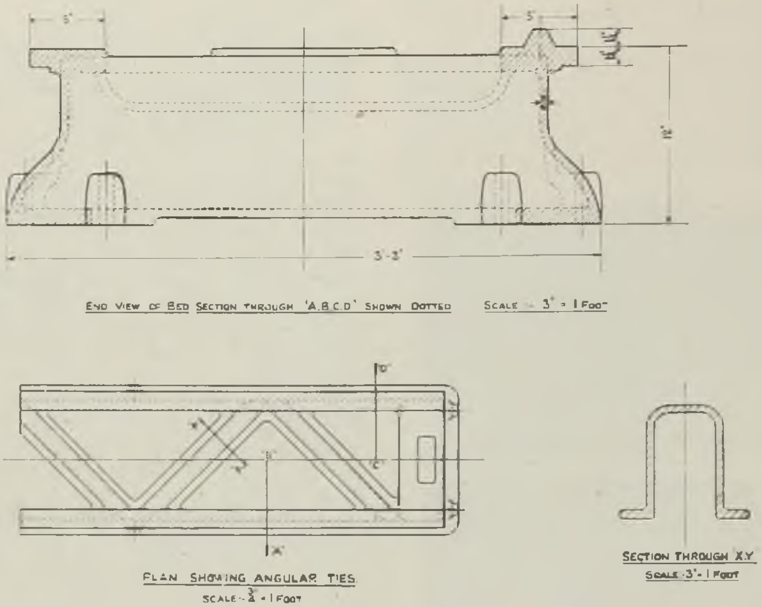


FIG. 3.—SECTION OF MACHINE-TOOL BED.

Having decided on the design and the cost of the pattern, the foundry executive must plan the method of procedure in the foundry, taking into account the method of moulding, whether in green sand or dry sand, whether by hand or on a machine, the construction of cores, the use of denseners (if any), and provision for closing, gating, feeding, etc. He must then consider the metallurgical problems involved, so that the metal structure may be suitable for the stresses to which the casting will be subjected, and a suitable mixture from his available supplies of pig-iron and scrap must be determined. This problem will have to be more carefully considered in the case of a general jobbing foundry, where a large range of castings—varying from fire bars to pressure castings—has to be made.

The human element must also be given careful consideration, and the selection of the operative for the job be determined according to his ability and experience. This must be made clear. The author is no advocate of the policy of keeping men engaged on one class of work because they are particularly efficient at it. The foundry executive, however, must be a practical psychologist, able to say the kind of work which best holds the workman's interest, and giving to him, as far as orders will permit, this kind of work. By so doing he will have a contented and efficient personnel, and will have taken his first step towards success.

This Paper is essentially practical, and is compiled from notes on the manufacture of machine tools—principally wood-working machinery—and pressure castings for steam and Diesel engines. Surveying those classes of engineering, one finds designers continually introducing improvements of one kind or another, with a view to increasing the capacity or the performance of a unit under service conditions. Consequently new problems continually arise, most of which must be solved in the hard school of actual practice. All the castings selected for discussion are

Fig. 4.—Mould for Machine-Tool Bed Partly Cored.

for service on first-class engineering jobs, and the modern machine shop demands castings of the highest standard.

MACHINE-TOOL BED

Figs. 1 and 2 show the casting of a machine-tool bed, approximately 23 ft. long, made in green sand and bedded in the foundry floor. The pattern construction leaves room for improvement, but, because of the variation in lengths and the alteration to the number and the angle of supporting ties, it has been found most suitable for the pattern to leave its own core, with the exception of the U-shaped section of the tie bars.

Projecting slides and facings are made loose, and are screwed or dowelled in position, so that they can be slackened during the process of ramming. All pieces working loose are distinctly typed, and, where possible, dovetailed on the pattern to prevent mistakes being made through the facings being placed out of position. The loose pieces are made in duplicate in all the larger standard patterns, since it has been found that, by moulding and drawing the pattern, the second set of facings can be fixed in position, and the second mould proceeded with while the first one is being finished, this sequence being continued till the finish of the order.

The pit is prepared and the ash bed laid and rammed in position, and then covered with sand and firmly rammed. The necessary camber is made on the bed, the procedure being to place, at 3-ft. intervals, straight battens of timber about 3 in. square section. A master straight-edge is used and the short straight-edges adjusted to give full camber at the centre—in this case $\frac{7}{8}$ in.—gradually bearing towards either end in the form of a curve.

The short straight-edges are secured in the position shown in Fig. 3, the sand rammed between them, the bed "struck-off" to their level, the short straight-edges removed and the holes rammed up. The pattern is placed in the pit on the cambered bed and weighted, and is held there until completely rammed up. The outside of the mould is rammed completely along the slides and the internal flange, facing sand being used for about $1\frac{1}{2}$ in. from the pattern face. The drawback carries the down-gates, and these connect with the in-gates, which enter the mould at the bottom and directly in line with the slides on each side of the mould.

Method of Core Setting

The first two cores from each end, shown in Fig. 4, are dried. The remaining cores, forming the internal shape of the casting, are in green sand with the exception of the inside shape of the tie bars, these being in oil sand. Vent pins are placed in position; the top part is rammed and is in two sections. Hangers are used to the full extent.

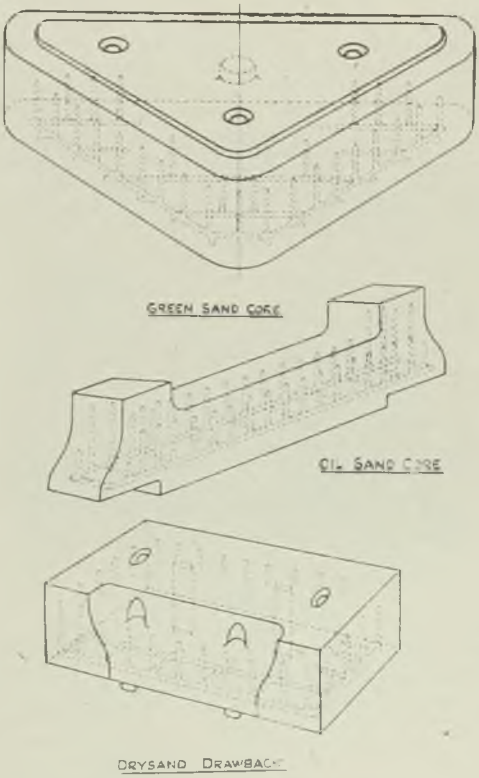


Fig. 5.—Cores and Drawback for Machine-Tool Bed.

Fig. 6.—Mould Cored Up.

Parting is followed by cutting a gutter round the joint and about 6 in. from the edge of the mould. A "pricker" or vent wire is used to connect this gutter to the ash bed with a line of holes extending the full length of the mould on each side. Along with this are two vent tubes spaced at convenient intervals and clear of the top part. They, too, are connected with the ash bed. Sprigging is carefully carried out round all facings and particularly along the bottom slides. The importance of the finish must be emphasised, and good-quality plumbago must be used. The centre cores (Fig. 5) are placed in position, and supported along the internal flange by chaplets where necessary. The cores for the tie bars are also placed in position, and are also supported by chaplets. The end drawbacks are fixed in position, the top part is placed on, and the gates made up, all core vents coming through the top. The cored-up mould is shown in Fig. 6.

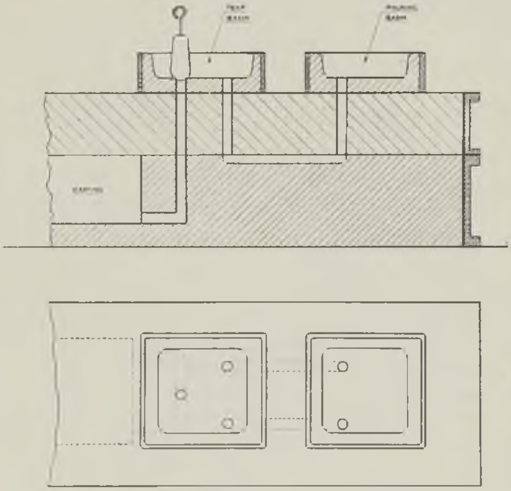


Fig. 7.—Trap Runners for Machine-Tool Bed.

Rectangular pouring basins are made up to a depth about half the length of the down-gate. Trap-gate and ball plugs, illustrated in Fig. 7, are used, and the plugs are removed immediately the second basin is filled with molten metal. Casting takes place simultaneously from both ends. The speed of casting is fairly fast; in the case of the larger size, the complete operation took 40 secs. The weight of the castings varies, according to length, from 30 cwts. to 45 cwts.

About one hour after casting, the top parts are eased and the hot sand is knocked out on the top of the casting. The sand between the down-gates and the casting is released and the drawback iron broken. This precaution is taken to ensure against the risk of a hot tear or fracture at the junction of the casting and the gates. The following morning the gates are broken off, and the core irons removed, care being taken that hot sand is covering any part of the casting that might otherwise be exposed.

Fig. 8.—Cast Planing-Machine Frame.

Analysis.—An average analysis of these beds is:—T.C, 3.3; Si, 1.6; Mn, 0.8; S, 0.08 (max.); and P. 0.6 per cent. The tensile strength is 16 tons per sq. in., and the Brinell hardness 170 on machined slides.

PLANING MACHINE FRAME

Figs. 8 and 9 illustrate a type of planing machine frame. This casting is an example of what the designer can do to eliminate work in the machine shop, as he has incorporated the soleplate, side cheeks and distance pieces all in one casting. One may wonder where there is any economy to an attached foundry if 10 per cent. is saved in machining costs, and 50 per cent. is added to the moulding charges, ignoring the question of greater risk in manufacture. In fairness, one must admit that the finished machine is a first-class engineering product, and one cannot help admiring the beauty, in design, of a number of these machines, incorporating several castings in one piece.

The pattern is constructed to facilitate the telescoping in sizes of 6 in., this being the difference in the width of machines of this type made from this pattern. Expansion or reduction, when desired, is carried through by making the pattern in two pieces, with panels for the required sizes separate, the telescoping taking place on guide bars inside the pattern. The main core box takes out the section of the casting which includes main slides, and main bearings, necessary bosses and supporting ribs. The side panels have separate boxes which core-space for carrying enclosed gearing. It must be borne in mind that these machines are of a compact design. Clearances are, on an average, about $\frac{1}{8}$ in. It will be seen, therefore, that no liberty can be taken with the sizes or the thickness of metal. The main frame shown is $\frac{7}{16}$ in. thick metal and weighs 15 cwts.

FIG. 9.—ANOTHER VIEW OF THE PLANING-MACHINE FRAME.

The mould is made in three parts—top, middle and drag—and parting lines are indicated in Fig. 10. This job is in dry sand with oil-sand cores throughout. Gratings are made for the drag and the middle part, and are in two sections, but taking in the entire outside shape of the mould. The middle iron is placed about 3 in. from the joint, having lifting irons cast on, which are fixed with " toggles " to the bar passing across the middle part on the first joint.

Gating takes place at the bottom flange, as indicated in Fig. 11. Due to the variation in metal thickness and in design, which is of box section, the drag and the top part are taken off about one hour after casting, the mould is turned on its side, and the core iron broken; and the main bearing section and slides are freed from sand. This allows the section to cool at a similar rate as the other section of the casting In this class of engineering, with the tendency for box section in place of H-section, close collaboration on this point with the designer is advised, and a study made before proceeding with the mould if a casting free from distortion or probable fracture is sought.

MARINE STEAM CYLINDER

Figs. 12 and 13 show a steam cylinder for a marine engine. This class of work must be tackled with the utmost care, as the overlooking of a single factor may lead to an erroneous decision which, at a later stage, may mean a scrap casting. Cylinders of the type shown are, in most cases, moulded and cast on end and would consist of three parts—top, mid and drag—although in many cases the mid may have to be split, this depending, of course, upon the design of the job.

Moulding throughout is in dry sand with the main barrel cores in loam, the remaining cores being in dry sand or oil sand, depending on the practice followed. The example cited is of the high-pressure type and includes the piston valve chamber. The cores, consisting of main and piston valve, are made in loam, and the remaining cores in oil sand. On what is recognised as the bottom side, the entire flange is worked loose, the procedure being to place this in the drag half of the moulding box; parting is made and the remainder of the job rammed up.

FIG. 10.—MOULD FOR PLANING-MACHINE FRAME.

It must be remembered that supporting

gratings, drawbacks or cake cores are introduced where found necessary. Both the main barrel and piston valve cores are swept on end, the bottom irons being constructed to carry the weight of the core. The practice generally followed is a 4½-in. wall, built with half-bricks, with about ½ in. space for building between them. It is often found necessary to use, to some extent, the loam brick in this type of core, and cores have been swept with every alternative brick made in loam, this depending on diameter, metal thickness, and design. The advantages obtained with the use of loam bricks are easier contraction and absorption of any dampness. For the larger cores, 9-in. brick is used for a few courses at the bottom as a precaution against the extra strain.

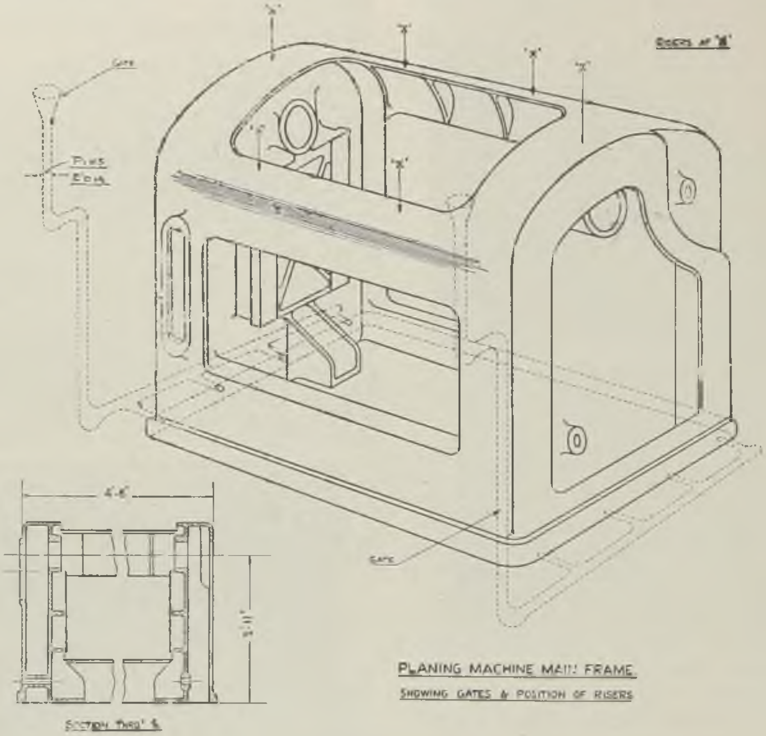


FIG. 11.

Closing

The moulds are closed and cast in one day; in the case of low-pressure cylinders, the casing core, with port cores and exhaust chamber, is built the previous afternoon. This section is now ready to take its position in the mould. Closing a job of this description is highly important, and the chief points for success are to ensure that the mould and cores are properly dried, and that all loam stamps are thoroughly dried before the top part is put on. The importance of these points cannot be over-emphasised, as castings of this sort can quite easily be scrapped in the machine shop due to the appearance, after the first cut by the machining tool, of a group of small blowholes round an area not far from the position of the stamp.

It can be seen that skin drying of loam stamps, or relying on the heat in the mould to do the drying, is simply courting disaster. Connecting and seaming up vents is another further important operation, as many a first-class casting has been rejected on account of a small blowhole appearing on some machined surface other than the barrel or slide valve face.

The "bottle-shaped" core on the drain boss is very often the source of this trouble, due to its design not allowing a reasonable vent to pass off before the metal has set.

Design of gates and casting temperature play a decisive rôle in producing cylinders free from defects, and pressure tight. In the type illustrated, top and bottom running is incorporated and many of the large ones have a suitable head cast above the bore. The runner basin is dried, reducing the risk of sand being washed in with the stream of metal. The in-gate on the bottom joint is placed to allow the metal to enter the mould tangentially on the bottom flange, and along with this there is an in-gate in the flange of the piston chamber or casing.

The pencil runners are directly above the barrel and all are ball-plugged along with the upright taking the bottom gates. Care is necessary that the drop runners have a clear passage down the barrel of the mould and spaced at suitable intervals, say, 9 in. apart and kept well clear of all port cores. When the basin is filled with metal, plugs over the down-gates are released, and when it is estimated that the mould has been about a quarter filled, the plugs over the drop runners are lifted out. The casting temperature sought is about 1,280 deg. C. minimum and the speed of casting can be classified as fast.

Fig. 12.—Steam Cylinder for Marine Engine.

The analysis is as follows:—T.C, 3.10; Si, 1.4; Mn, 0.7; S, 0.08 max., and P, 0.3 per cent.

SCAVENGE PUMP CYLINDER FOR DIESEL ENGINE

Fig. 14 shows a sketch of a Diesel scavenge pump cylinder, and, as in the steam cylinder, machined faces are everywhere. The mould is reasonably plain and is made in dry sand, the cores being made in oil sand. The design of this cylinder may classify it as a core assembly job. Partings are made at the points indicated, and a combination of top and bottom runners is used here also, plugs being used on the down runners. When the mould is half-filled the top runner plugs are released.

The flange around the spigot has a bead cut round the outer edge to assist in taking away any particles of dirt that may find their way into this area. Chills are used at the junction of the heavy and light sections. Drying, venting and hot metal again play important parts in the successful production of this type of casting.

MACHINE-TOOL PRESS BED

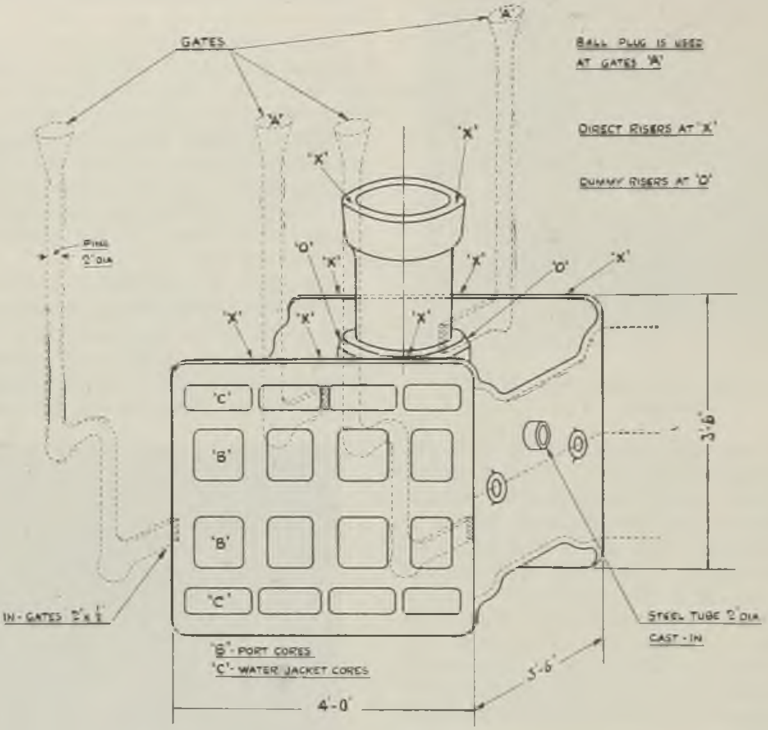
Fig. 15 depicts a machine bed weighing 2 tons 5 cwts. This casting had to meet a specification of 18 tons tensile and a Brinell of not less than 170 on the machined slides. The mould and cores were made in dry sand, the top cores being bolted to the bar provided in the top part. This allowed the cores to be "skin-dried" and fixed in position before the mould was passed into the stove for drying. By this method a large reduction in closing time was effected, and the actual closing operation consisted of placing in position, in the drag, the slide cores and main bearing cores, and any small cores attached to the facings. The top part was ready to be placed in position. The parting line can be followed in Fig. 15.

The gates were situated at the bottom and entered the mould along the slide face. Risers were taken off at the stool faces—four on each end—in two of which rod feeding took place directly above the bosses carrying the main drive. The diameter of the risers is about 2½ in. It is impressed on the man feeding the casting that he must go down into the casting with the feeding rod and keep pumping at that depth, not raising the feeding rod until the metal is solid below the rod. Fresh metal is added at intervals, and while one must admit that this is an exhausting operation, premature

Fig. 13.—Another View of the Marine-Engine Cylinder.

withdrawal of the rod will show its results in the nature of a hole directly underneath the riser.

The faces of the stools were cast upwards and some dirt was shown on the surface, although it was not of great importance as this was the down side when the bed was erected. Nevertheless steps were taken to obviate this defect, and two dummy risers were taken off at each side of the facing. These, plus $\frac{1}{8}$ in. extra machining, making in all $\frac{5}{16}$ in. machining allowance, cured the trouble. In the casting mentioned, densening has been applied, as a rule, on the wearing parts, particular care being taken to ensure that the chills were clean and dry. In this casting they are on the bottom side, and if possible kept clear of the runner in order to reduce the risk of burning-on. Oblong chills, about 4 in. long, are the type generally used, and their thickness is about 60 per cent. of the thickness of metal being densened. Some forty castings of this type have passed through the foundry, and all of them were entirely satisfactory.



SCAVENGE PUMP CYLINDER FOR DIESEL ENGINE

SHOWING GATES & POSITION OF RISERS

FIG. 14.

Analysis:—T.C, 2.90; Si, 1.6; Mn, 0.70; S, 0.08 max., and P, 0.60 per cent.

MAIN COLUMN FOR SAW FRAME

Fig. 16 shows the front and rear view of the main columns of a large saw frame, the tubular section of which must be clean and free from defect. It may be considered, and rightly so, that the correct method of producing this casting would be to mould it in the horizontal position and turn it up on end for casting, with an allowance for the usual head metal. At the commencement of the manufacture of this type of casting, a combination of factors forced it to be moulded in the horizontal position, and to cast on a " bank " of approximately 10 deg. The main circular core, which is 14 in. dia., was swept in loam, mild steel bars being inserted at an equal distance from each end, and at the top and bottom side of the core. The bars are in the vertical position, one end bearing on the main core bar, and the other flush with the outside diameter of the core. This provision is necessary, as plugs are fixed in the mould to support and prevent lifting of the core during casting.

The supporting section core was made in dry sand; prints of liberal length were allowed for at the top circular end of the column, where 9-in. head metal was incorporated. The open side of the supporting section was moulded on the down side. This allowed the dry-sand core to be placed in position, and the main loam core located in the print provided in this core. The print is D-shaped, and is made up after coring is completed. It may be wise to stress the necessity of an accurate division of metal thickness, as this casting has to carry a considerable load, and the metal section has been cut down to the limit. The parting in a job of this type is relatively simple; it travels along the bottom side of the rounded edge of the box section and steps down to the centre of the tubular section.

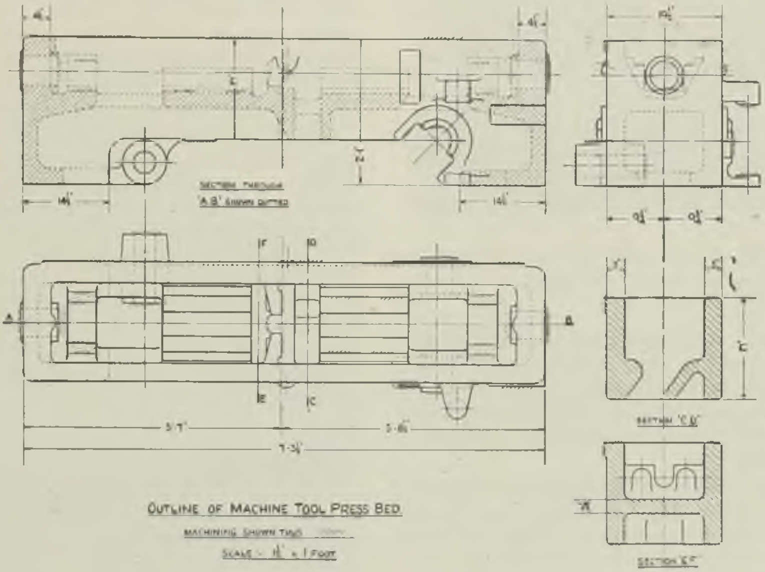


Fig. 15.

Gating took place at the box section, and two in-gates entered the mould along the thickness of metal, having a cross-section of about $\frac{3}{4}$ in. by 3 in. A deep pouring basin was, of course, necessary when casting at an incline, and a dirt-trap runner was used similar to that in the machine-tool bed previously described. A raised ridge was provided for, extending for a distance of about 3 ft. from the head end of the mould, rounded on the top edge, and about 2-in. by $1\frac{1}{2}$-in. cross-section. It was thought that any particles of dirt, entering the mould and being washed through with the flow of metal, would find their way into this trap. After the first casting was produced, this piece of metal was removed and machined, sawn into sections and examined thoroughly, and no trace of defect could be found. One riser was taken off at the circular end of the mould, and one at each corner of the box section. The vent was carried through to the top end for the loam core and through the bottom for the dry-sand core. The casting weighs 32 cwts. and is 20 ft. long.

MAIN FRAME FOR LARGE SAW

The casting shown in Figs. 17 and 18 is made in green sand. The pattern is bedded in the foundry floor, and panels at suitable points on the pattern are made to lift out. This enables the moulder to ram the pockets and webbing, shown in the casting, with little difficulty. Core holes and pockets along the machined slides are cored out, oil-sand cores being used. The top-part moulding box is in two sections, each section being the part of a standard size box. This enables each part to be turned over easily, as these boxes are of the shallow type, no great depth being required for this frame in the top part. Making the top part in two sections reduces the risk of yield, which may mean the "starting" of the mould, and the patching of which very often results in sand dropping from the cope and being washed into the casting with the flow of metal.

In many frames of this description, it has been

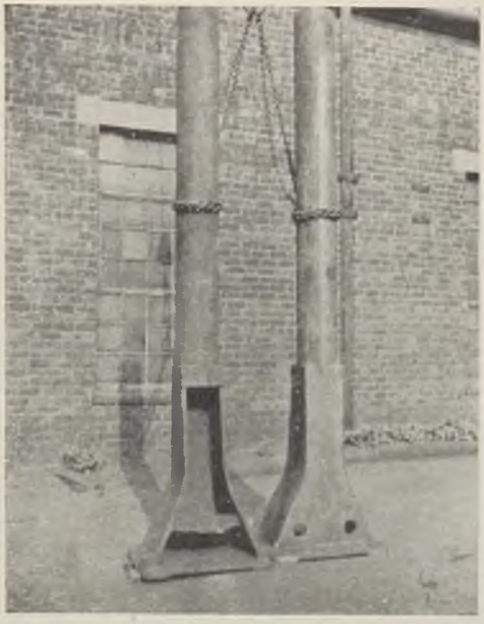


Fig. 16.—Main Columns of Saw Frame, Showing Front and Rear.

found necessary to introduce strengthening bars through the panels, this being a precaution against fracture of the casting during the cooling period, as in some of the designs heavy bosses and slide facings tend to prevent a uniform cooling rate.

Casting takes place from both ends, this being advisable, since the metal thickness is $\frac{5}{8}$ in. and the tendency for dull metal at either end must be avoided, as machined faces are situated there. The in-gates at the feet end of the casting enter the mould along the webs on each side, and the same method was adopted at the other end. The casting weighs 25 cwts., and is approximately 20 ft. long.

WOOD-TURNING LATHE BED

Fig. 19 shows the casting for a wood-turning lathe bed. The castings in this design weigh from 10 cwts. to 25 cwts., and are made in green sand. The cores consist of the bottom core, which cores out the distance between, and the thickness required for the slides. This core is made in two sections, and has the print forming the guide for the cores that shape the diagonal ribs. The gating takes place along the slide face. Two in-gates, and in some cases two small gates, are cut at opposite ends, and pouring from a 5-cwt. ladle takes place when it has been judged that the metal from the larger ladle has filled the mould to the level of the top of the main slide section. This ensures solidity on the fitting strips at the top end of the casting, since it can be quite readily seen that the metal is cooling during the process of filling the mould. Defects had been noticed in previous castings, due to dull metal at this point. The gap shown on the slide is a provision for turning face plate work of larger diameter.

MARINE ENGINE CASTINGS

Fig. 20 depicts a mould for a marine cylinder cover and is swept in dry sand. Many castings of this type are produced similar in design and with very satisfactory results. The method of gating can be clearly seen, twelve pencil gates striking the mould directly in the centre of the supporting ribs. Three risers are situated on the outside flange.

Fig. 21 shows a group of main engine castings, including medium- and low-pressure cylinders, soleplates, columns, pistons and cylinder covers with miscellaneous castings. All the large castings are made in dry sand. In the case of the soleplate, this is made in the pit. The centre portion between the bearings is lifted out and dried in the stove. The remainder of the mould is dried with portable dryers. Castings of this type may weigh from 50 cwts. to 6 tons, and are mounted and cast in the position shown in Fig. 21.

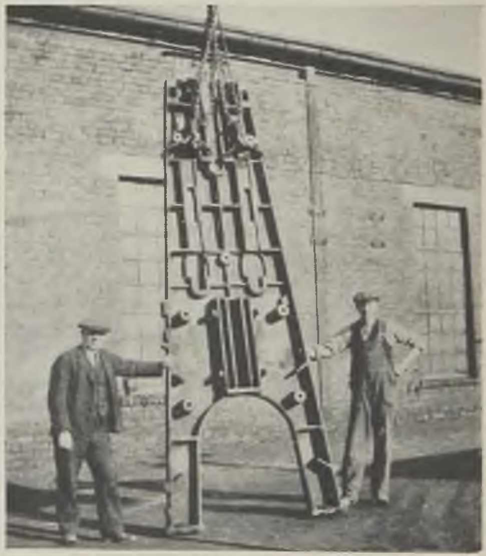


Fig. 17.—Main Frame of Large Saw.

LIGHTER CASTINGS

It is now proposed to deal very briefly with a few types of castings which may be classified as light, that is from 1 lb. weight to 1 cwt. Here again a close study of production is essential, and a costing system that will give an accurate cost of each individual type of casting is indispensable. Those in control should be able to see at a glance the cost of producing each casting and the selling price. There are many systems in operation that will serve to give a fairly accurate return.

This point is mentioned because light castings in the general jobbing foundry are often taken at an overhead rate. This is not a satisfactory arrangement, as it may allow a considerable number of castings to be produced at a loss before the loss is discovered.

FIG. 18.—REVERSE SIDE OF MAIN FRAME SHOWN IN FIG. 17.

The following examples are all made in green sand.

Gear Guard and Pulleys

Fig. 22 is a typical example of a design of a gear guard, the castings weighing from 7 lbs. to 30 lbs. The mould is made complete in the drag half of the moulding box; the core is made in oil sand, and the gating arrangement can be clearly seen, four spray inlets at the wide side of the casting proving satisfactory. Quite a number of plain and stepped pulleys are produced by similar methods, gating taking place with a drop gate on the boss. Many thousands of these castings have been produced, both by hand and machine moulding, with abnormally small scrap losses.

FIG. 19.—CASTING FOR BED OF WOOD-TURNING LATHE.

Standard belt pulleys (Fig. 23) are made from metal patterns. Two designs—the solid centre web, and the spoke pulley—are continually in production, the sizes ranging from 6 to 30 in. diameter, the patterns of which leave their own core. All those pulleys are gated in the boss, and " whistlers " are cut in the top joint. The average thickness of the rim is about $\frac{1}{16}$ in., and the " whistlers " have been found of great assistance in helping to take away any trapped air in the rim, and they have become a standard practice in the production of all pulleys of this type.

In cases where the designer has called for an exceptionally heavy centre boss, it has been considered advisable to turn the moulding box on

FIG. 20.—DRY-SAND MOULD FOR MARINE CYLINDER COVER.

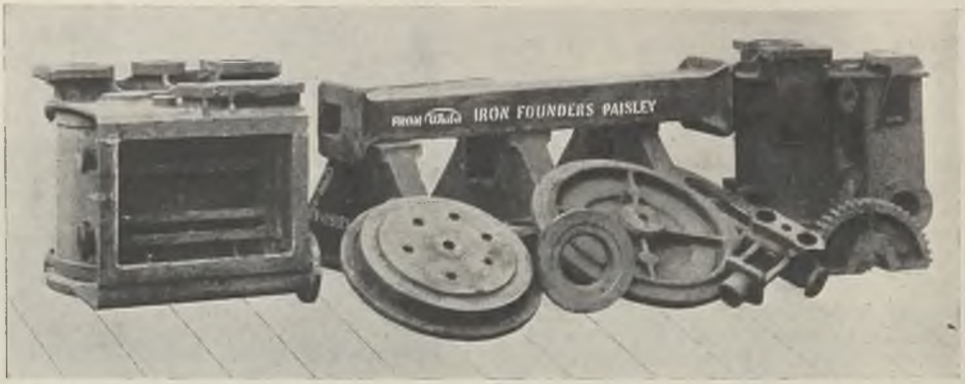


FIG. 21.—GROUP OF MAIN ENGINE CASTINGS, INCLUDING CYLINDERS (MEDIUM AND LOW PRESSURE), SOLEPLATES, COLUMNS, PISTONS AND CYLINDER COVERS.

its side and bare the boss of sand. This has the effect of balancing the cooling rate between the lighter section of the arms and the boss, thus reducing the risk of wasters due to the fracture of the casting through the arms. Large quantities of these castings are being produced yearly, and over five years defectives returned from the machine shop show an average figure of 0.5 per cent.

Examples of other castings produced under this group include gear blanks, liners, valve bodies, gear mountings, cams, etc. The liners are moulded and cast in the perpendicular position, the ingate entering the mould tangentially, giving a spinning action to the metal as it is filling the mould. Strainer cores are used in the bushes. The small liners in green sand are remarkably free from dirt inclusions.

In a number of the other castings, top runners are incorporated with satisfactory results. All castings are cast at fairly high temperatures, as 90 per cent. of them are machined all over.

In summing up, the words of C. H. Lorig in "Grey Iron Metallurgical Practice"* may well be quoted: "After all, properties of castings should be looked upon from the point of view of the engineer or customer and hence castings should be provided with such qualities as make them satisfactory for the intended service and should not be merely made to satisfy some arbitrarily imposed physical test standard."

In conclusion, the author wishes to record his indebtedness to the directors of Thomas

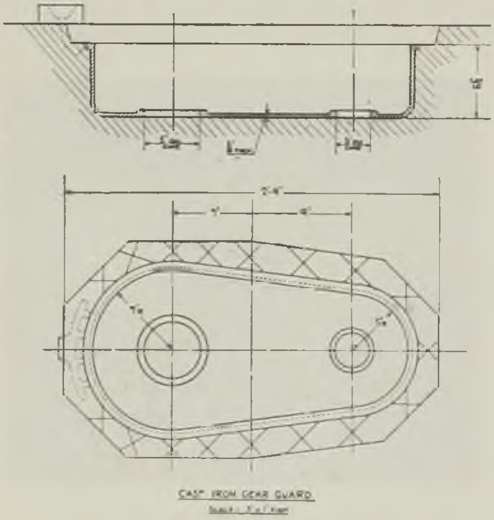


FIG. 22.—DESIGN FOR GEAR GUARD.

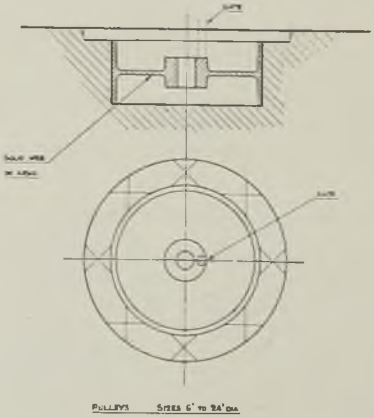


FIG. 23.—DESIGN FOR BELT PULLEYS.

---

* "The Foundry," March, 1939

White & Sons, Limited, Paisley, for permission to publish this Paper and for the use of the company's equipment and material.

DISCUSSION BY SCOTTISH BRANCH

When the Paper was presented to the Scottish Branch of the Institute of British Foundrymen in Glasgow, the BRANCH-PRESIDENT (Mr. N. A. W. Erskine) said that the author was to be congratulated on the Paper, both from its interest and from the clear and concise description of the methods. Referring to the photograph of the casting (Fig. 20) showing 12 down-gates, Mr. Erskine wondered if the number and size of the gates were calculated to give a definite speed of pouring. Secondly, he noticed the very close analysis the author attempted to get. Was he right in assuming that Mr. Marshall was making a variety of mixtures?

MR. MARSHALL replied that he calculated the sizes of the gates for a definite pouring rate. The marine cylinder cover was poured in 40 secs. with metal as hot as possible—1,320 deg. C. approximately. He did get a variation of analysis because of the variety of castings. While he did not like to have too many mixes, he tried to satisfy the customer.

MR. CRAIG referred to his association with Mr. Marshall's firm during the period of his apprenticeship and confessed to having seen very few defective castings. He recalled the very high speed of the machines which were made by the firm and which called for the best of material and finish.

MR. J. E. O. LITTLE asked about Fig. 4, showing the bed with eight cores, four of them made in dry sand and four in green sand. He thought it was risky to use green-sand cores in such a job and that it would have been just as cheap to have dried them all.

MR. MARSHALL explained that he had to consider the stove capacity. He would have made all the cores in green sand, but as the metal was running over them continuously he thought it better to make the first two in dry sand.

The BRANCH-PRESIDENT said that the Paper had been of great interest and no doubt of great benefit to many members. He asked them to accord their thanks to Mr. Marshall.

The AUTHOR, replying, said that no one ever reached the limits of possibilities in a given field of endeavour, because the initiative which embraced the opportunities of to-day also constantly unfolded those of to-morrow.

Phosphor-Bronze Castings of Heavy Sections*

By A. HOPWOOD (Associate Member)

The object of this Paper is to describe the successful production of some bronze castings which are not difficult to mould, but which require special production methods to obtain correct structure and soundness. This is especially true where castings have heavy machinings and sections thicker than normal. It is also proposed to stress the importance of correctly-rammed moulds, using permeable sands, to resist the hydrostatic pressures, particularly when making full use of high heads for this purpose. Obviously, many variables can influence the creation of a casting. Many castings which are not up to standard in respect of Brinell hardness and density are ascribed to inadequate casting temperature and furnace practice, whereas the mould condition and material, coupled with the slow cooling consequent upon mass, can be responsible, and very often are, when using sand moulds. A few years ago castings made in relatively short freezing-range alloys and cast in green sand moulds were suitable for the engineer. Castings made in phosphor bronze of specified Brinell test on sliding and bearing faces and required to show no porosity on inspection, even after heavy machinings, call for more careful treatment. The cost of moulding methods has to be considered in the light of the best possible casting that can be produced, depending upon its requirements in service.

Fig. 1.—Chill-Cast Bars after $\frac{1}{8}$ in. Machining.

Fig. 2.—Fractures of the Chill-Cast Bars.

One of the most important problems of modern machine-tool production is the bearing and sliding surfaces. Additionally there is the tendency to increase speeds and loads on the smallest possible size of bearing faces, because an increase in the size of the faces involves more horse-power to overcome frictional resistance. This requires more attention to be paid both to materials and methods of lubrication. The production of alloys tested and proved in the laboratory is by no means sufficient; the results must be reproduced in the castings. When the design and material have been proved to be correct, there are many factors which affect the life of bearing faces, not all of which are foundry influences, although this department has to be responsible for the raw material and the initial "as-cast" structure. A hot bearing is usually the first indication that all is not well, the oil breaking down under the retention and amount of heat generated.

Causes of Hot Bearings

Some of the main factors affecting these conditions are:—(1) Faulty machining where the final surface has been plucked and disturbed.

---

* The Author was awarded a Diploma for this Paper.

leaving the delta phosphide eutectic loose and liable to come adrift early on in the running period; (2) insufficient clearances allowed and wrongly disposed oil grooves, bad fitting, bedding and scraping; (3) sand left in the main casting which may foul the oil supply and choke the filters; and (4) one which is always open to the first investigation—the incorrect structure of the bearing materials.

It is therefore obvious that the foundry, to fulfil its obligations, must produce a casting not only true to size and shape, but also internally sound and true to structure irrespective of design or planned machining methods.

The manufacture of castings in standardised alloys involves in many cases specialised production. The slow cooling and mass-effect in heavy castings and the quick cooling in lighter ones indicate that ordinary sand methods are not always sufficient to produce the structure required, and more care and expense are demanded to produce the successful casting. The practice of altering the mixture to suit the type and section of the casting as practised in the ferrous foundries has much to be said for it, but is not permissible where the alloy is specified, as is usual in non-ferrous practice.

Experimental Details

Table I details a simple test carried out to ascertain the effect on the structures and chilled faces of deliberately overheating phosphor bronze and casting it into a series of chill and green sand moulds at definite temperatures. The density and two Brinell numbers, one after ⅛-in. machining and the other after ¼-in. machining, were taken. The bars were 6 in. long, 2 in. wide by 1¼ in. thick, there being five " green-sand " and five " chill-cast " bars available. The latter group was chilled on the faces equal to their section thickness (1¼ in.). No dressing was used in any of the moulds to avoid any conflicting elements, and no feeding was applied to any of the bars. The runners and gates were standardised at ¼ in. by ⅜ in. by 1 in. long; the down peg at ½ in. dia. associated with a head pressure of 4 in. The alloy was melted in a rapidly operated coke-fired pit furnace to just over 1,350 deg. C., and the metal was withdrawn and cast into the bars at temperatures detailed in Table I. No dressing was used on the chills, but precautions were taken to see that they were completely dry and cold when rammed up in sand. The outer appearance of the chill-cast bars was very interesting, for bars cast at 1,300 and 1,250 deg. C. showed deep-seated blowholes on all faces in contact with chills, the bar cast at the higher temperature being the worse as in this case the casting contained a wormhole defect.

Table I.—*Effect of Casting Temperature on Phosphor Bronze.*

Chill-cast.

Casting temp., deg. C.	1,300	1,250	1,150	1,100	1,000
Density	8·47	8·53	8·62	8·83	8·84
Brinell No.—					
After ⅛-in. machining	96	96	107	114	117
After ¼-in. machining	93	93	104	110	114

Green-sand cast.

Casting temp., deg. C.	1,300	1,250	1,150	1,100	1,000
Density	7·92	7·95	8·37	8·62	8·57
Brinell No.—					
After ⅛-in. machining	69	92	95	112	85
After ¼-in. machining	69	72	78	85	85

Fig. 3.—Green Sand Bars Cast under the Same Conditions as the Chill-Cast Series.

This represents a trouble which can always be associated with over-heated chills during the casting period, and can arise from several faults, individual or collective. All the bars were true to shape, except the one cast at 1,000 deg. C., which had a badly sunken top face, whilst one side had " pulled " a little. The chill-cast bar cast at 1,100 deg. C. had just a trace of sink showing.

Fig. 1 shows all the chill-cast bars after machining ⅛ in. of one face and Brinell testing. The worm holes on the bar cast at 1,300 deg. C. are visible on the one at the extreme left. Fig. 2 shows chill-cast bars after fracturing cold; worm holes are present in No. 1, whilst No. 5 shows a large hole with a porous discoloured area beneath it. This was cast at 1,000 deg. C.

The fractures were sound generally, there being no discoloration due to gas liberation or intercrystalline cavities; a gradual decrease in grain size from 1 to 5 was exhibited. The general colour of bars Nos. 1 to 3 was fawn with a greyish-blue area in the centre. This increases outwards as the casting temperature decreased, until at 1,100 deg. C. (No. 4 bar) it practically covered the whole of the fracture. The greyish-blue colour represents the normal segregation of the delta phosphide eutectic to the centre. No. 4 cooled too quickly to allow it to segregate. The condition of the No. 5 bar showing the large cavity with a porous area beneath is due to lack of time for the gases to escape and the metal feed properly. A riser or flow of metal through the mould would have given sufficient time for the gas to be driven out; the general structure, however, is perfectly sound and free from discoloration.

When tin bronzes are cooled quickly through the solidification range, the structure increasingly tends to be thrown out of equilibrium, involving an increase in the amount of delta constituent. This is inevitable where the use of quick cooling is resorted to, and can be an advantage or drawback, depending on its situation. Also, with an increase in the cooling rate, there is more latitude in casting temperature, but this latitude, if made use of in every case, would lead to defective work. For instance, where there is a chilled outside with a small diameter bore of 5 in. or less, then by making use of a higher casting temperature than is normally used on a similar all-sand mould, there would be ideal conditions for a porous bore due to the segregation of the last metal to solidify towards the hottest area. This would be the area around the core. The use of chills is to increase the rate of cooling and so obtain a smaller grain size, better distribution of delta phosphide and easier feeding. By increasing the casting temperature this is defeated; moreover, the higher the casting temperature the greater is the danger of blown castings due to overheated chills. The initial chill temperature is also of primary importance and, the lower it is, the more rapidly the liquid metal commences to solidify and build up on it. If this is not observed, trouble from overheated chills, particularly at parts where relatively hot metal is flowing (as from ingates), is likely to occur.

Fig. 4.—Fracture of Green Sand Test Bars.

Fig. 5.—Green Sand Bars after $\frac{1}{4}$ in. Machining.

Porosity cannot be readily overcome in massive castings by the intelligent control of casting temperature, although it has a profound influence on it; the solidification range for any particular alloy remains the same, but the rate of cooling can be accelerated by low casting temperatures and greater heat abstraction from the cooling metal as by the use of chills or some similar materials.

Green Sand Tests

Fig. 3 shows the green-sand bar series cast under exactly the same conditions as the chill-cast bars. There was a difficulty in getting a clear Brinell reading on No. 6 bar, due to the openness of the metal. The general appearance of the machined surfaces was very unsatisfactory, because of this pronounced porosity, the No. 9 bar cast at 1,100 deg. C. being the least contaminated.

Fig. 6.—Density Test Casting.

The fracture of green-sand bars is shown in

Fig. 4. The No. 6 bar, drawn at the runner gate, had gas holes showing after fettling. The fracture showed a "broken-up" appearance, with the well-known red patches covering the whole of the section. Bars Nos. 7 and 8 were similar, but not quite so bad. Bar No. 9 had no unsoundness showing at the runner gate after fettling, but the fracture did not show any red spots, although it had not a good appearance, generally looking "loose" in character. No. 10 bar was sunken badly on the top face and on one of the side faces. On removing the gate, it showed soundness, whilst the fracture displayed trapped gas-holes and a return of red spots, probably due to intercrystalline shrinkage caused by the extremely low casting temperature and insufficient time for feeding.

Fig. 5 shows the bars cast green with another $\frac{1}{8}$ in. machined off, making $\frac{1}{4}$ in. total. There has been a general lowering of the Brinell readings and an increase in the appearance of the porosity on the machined face. The extra machining on the chilled bars made nothing like the same decrease in the Brinell figures, nor did the appearance of the machined face present any trace of porosity. There is not the slightest doubt that the bars with metal cast at 1,100 deg. C. are the best of the two series, but the chill-cast bars where the metal has cooled most rapidly through the solidification range are the more satisfactory of the two sets.

Conclusions to be Drawn from Tests

The chill-cast bars prove that there is a greater latitude in casting temperature to ensure a serviceable casting having fine grain and sound, even structure throughout the mass, whilst giving good density and Brinell hardness for that particular alloy. The fallacy of utilising this advantage too much and casting on the high-temperature side is to induce a tendency of segregation of the delta phosphide to parts of the casting last to solidify and a danger of the burning-on of the chills or at least overheating them.

The loose open structure which is so prevalent in heavy-sectioned, sand-cast phosphor-bronze castings is particularly dangerous in heavily-loaded bearing surfaces, the delta phosphide eutectic showing in relatively large masses—often with small microscopic fissures leading off, giving looseness of the structure. Any alteration in normal running conditions, such as rise in temperature and final breaking down of the oil or stoppage of the oil supply for any reason, is ideal for this loose constituent to be plucked out and become an abrasive in action.

In normal-section castings, the practice of controlling the foundry technique such as running and gating, feeding, casting temperature, and melting generally overcomes this weakness, but in castings having abnormal general section, the above precautions are insufficient to overcome the annealing effect and the slow cooling through the solidification range; this yields low density and low Brinell readings. The use of very low casting temperatures is not a solution; they often lead to unsightly castings with trapped-gas holes on the top machined faces and, if the mould "eases" or "gives" a little, intercrystalline shrinkage cavities. The use of materials to form the mould which will conduct heat away much more rapidly than sand and so hasten the cooling through the critical range, coupled with the usual precautions, is essential if a casting sound in every respect be required. The build-up of the structure and the feeding generally must be much improved, even when the chilled area is not the major portion of the mould.

FIG. 7.—MICROSTRUCTURE OF SECTION AGAINST THE CHILL.

These tests which show that bars chill-cast or cast at a temperature usually associated with sand castings give better Brinell readings even after heavy machinings are amply borne out in practice. Soundness and a close structure—impossible by ordinary methods—are obtained.

Examples of Faults

Large castings thrown out of normal setting by machining more off one side and correspondingly less on the other will result in one face giving high and the other low Brinell readings. When using skeleton patterns or boards, there is a great temptation for moulders to work "safe," that is, under-size for the internal sizes and oversize for those outside, thus making for additional machining. Soft ramming, resulting in swollen castings, is generally regarded by the moulder as just a little more extra machining.

Slow cooling, due to large amounts of metal passing over one section and thus causing hot spots, will give the same results as will hot moulds. Even with alloys which should normally and easily satisfy the test the above faults will give failures, proving that indiscriminate hardening of bronze alloys by extra additions of tin and phosphorus is only a part solution to meeting specifications.

It should be generally realised that these increases of hardening elements only make the possibility of low density greater in bulky castings, due to the increase in the amounts of last metal to solidify and a greater difficulty of feeding "sound" the whole of the casting. After all, if by quick cooling and a cheaper alloy one can get more consistent tests and better structure it should have some consideration if only for the advantage of much easier manipulations in the foundry.

Inverse Segregation

There is not the slightest doubt that segregation (normal or inverse) of the last metal to solidify is responsible for internal and general openness of the structure. It is not always shown by tin sweat appearing at the risers and runners in large castings and at low temperatures. It is not difficult to visualise the method of crystallisation and build-up of the structure in large sections cast in sand. Due to the low conductivity of heat of the sand, the rate of cooling will be relatively slow after the first deposition of solid metal, even with very low casting temperature. The speed with which the dentrites build up into the interior of the metal thickness depends on the size of section. The slower the rate of cooling, the more will the dendrites spread into the section having still-liquid metal around them. Near the outer edge, diffusion takes place, leading to large dendritic growth and virtually isolated pools of still-liquid metal.

If gas be present in the alloy, it may be concentrating in the liquid metal until the temperature drop is sufficient for it to come out of solution. The amount of undercooling depends on the rate of temperature fall and agitation and this has some bearing on the incidence of pressure the gas can exert on the remaining liquid. Thus, quick cooling due to low casting temperature and cold mould conditions, aided by slow cooling due to mass, can lead to general porosity under the skin. The appearance of tin sweat depends on the casting temperature and general conditions.

R. Genders' work and conclusions on inverse segregation and porosity are borne out in practice, the gas theory being admitted to explain the internal pressure required to force the remaining liquid out of position. The main factors are the composition of the alloy; the rate of cooling; the pressure of dissolved gases, and the casting temperature. The rate of cooling is effected by the heat transfer from the mould materials.

Experiments in Density

The second test for density is a most important one for those connected with castings production using sand moulds, particularly in the case of alloys having long solidification ranges. A mould 30 in. long by 9 in. wide by $\frac{3}{4}$ in. deep, provided with a longitudinal runner and six ingates of 1 by $\frac{1}{4}$ in., devoid of feeding arrangements, was made. The metal used was 11 per cent. tin, 0.15 per cent. phosphorus, the remainder being copper. It was cast at 1,100 deg. C. Six inches of the bottom of the mould were chilled, 6 in. were in dry sand, 12 in. in soft-rammed green sand, finally 6 in. of green sand normally rammed. Tests were made for density (see Table II) and microscopic examinations were carried out.

Fig. 8.—Microstructure of Section against Dry Sand.

Fig. 6 shows a photograph of the casting, and indicates the position from which the test pieces were taken. The soft rammed section is 1 in. thick, the mould having "eased" about $\frac{1}{4}$ in.

Doubtlessly, high head-pressures produce sounder castings, mainly by driving the mould gases out into the atmosphere by the correct way. This involves the use of moulds sufficiently rigid to withstand the hydrostatic pressure from the time the mould commences to fill until the casting is completely solid. Phosphor bronze solidifies over a range of temperatures, depending on the composition, whilst the time is in relation to the thickness of section; as the section becomes greater so does the time lengthen, and any easing of the mould during this period is bound to upset the method of solidification.

Faults due to Mould Conditions

Attention was first given to this phenomenon by the dissimilarity between two castings made off the same pattern and cast out of the same pot of metal at the standard casting temperature whilst using the same method of running and gating. The one casting would have good density and adequate Brinell hardness, whilst the second would yield a casting low on test with a machined surface of dull appearance. On fracture such a casting would show the usual discoloration associated with improper casting temperature. As gas and segregation conditions in one of the castings were perfect, the defects could not be due to the previously mentioned faults, although anyone not knowing the circumstances could be forgiven for such an assumption. It could, of course, be due to only one cause, that is, the condition of the mould or mould material.

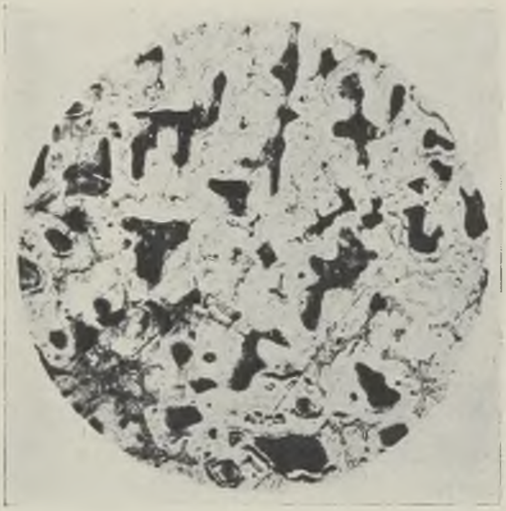


FIG. 9.—MICROSTRUCTURE OF SECTION AGAINST SOFT-RAMMED GREEN SAND.

TABLE II.—*Result of Density Tests.*

	Density.	Fracture.
Chilled	8·71	Close.
Dry sand	8·75	More open.
Soft green sand ..	8·13	Very open, showing red discoloured fracture.
Normal green sand	8·69	Similar to dry sand result.

The first indication that the mould has "given" is an excessive sink in the riser, and on measuring the casting it may be locally oversize or in extreme cases completely oversize; thus excessive metal has to be machined off. As pointed out previously, this alone is detrimental to the appearance of the casting and to the Brinell test. The explanation is that, when a mould is just cast, the portion of the mould giving way requires more metal which is drawn from adjacent areas, and, lastly, from the risers supplying the section underneath it. If these conditions persist after the metal has commenced to solidify, the position is aggravated by the liquation of the still-liquid metal to the parts requiring it and a consequent starvation in other parts, thus giving rise to intercrystalline weakness and porosity.

In this test, an attempt has been made, with some measure of success, to create a condition similar to the above, showing the deleterious effect of weak moulds on the castings made in alloys having a long solidification range. The density tests are in agreement with what was expected, as were also the fractures. Figs. 7 to 9, showing the microstructures of the various sections, are remarkable for the differences in structure. It would appear that the metal had been melted and cast under different conditions. Many castings made defective by the mould and mould material are ascribed to bad smelting and casting temperatures, particularly by those lacking personal contact with practical foundry conditions. Many castings are made in dry sand not because they cannot be made in green sand, but so that a strong mould is made having a good permeability, with a minimum gas effect on the alloys poured very near their solidification temperature.

Mould Materials

As sand suffers less from deterioration due to lower temperatures and the protection of good mould blacking mixtures, it is only necessary to use a facing mixture on the bottom face, the rest of the mould being rammed in floor sand. The facing mixture is a very open regular grained sand, drying well and withstanding very close ramming. It may advantageously consist of 30 red sand, 10 road sand (high silica), 10 horse manure or sawdust, and 50 per cent. heavy floor sand. The use of metal parts in moulds not only offers greater resistance to liquid pressures than sand, but involves the rapid expansion of the chill face when in contact with the solidifying metal which compresses into the pasty mass. This can be visualised by observing the metal in the riser; after an initial rise there follows the usual sink.

The operation of ramming "soft" in places where scabbing is expected should not be tolerated, not only on account of the danger of a swollen casting, but also because mould gases on expanding will take the easiest path, which is through this open, weakly rammed sand, into the metal. This does not always show itself by blowing up the risers, as the gas may come away in a gentle stream and not by explosive force.

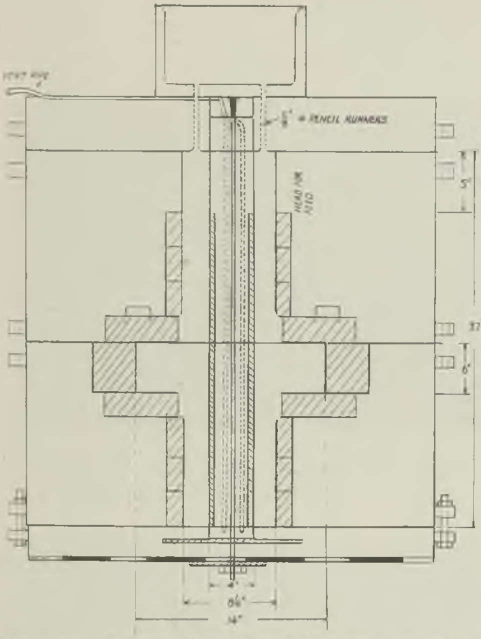


FIG. 10.—MOULD FOR WORM WHEEL AND NUT.

Progressive Solidification

Progressive solidification is so controlled by the method of running and the time that the mould takes to fill, that it is worth serious attention. The ideal condition is that the casting should commence to solidify from the bottom upwards, the risers or feeders remaining liquid to the last. This requires that the hottest metal should be in the highest portion of the mould. Thus the top running of moulds helps this to a large extent, but is not always applicable owing to design and method of moulding. When one has to resort to running in the lower parts of the mould, particular care must be paid to see that (1) the metal must enter without striking the mould or cores and at as great a number of inlet gates as possible, so as to minimise the formation of hot spots, giving localised slow cooling; and (2) the mould should fill as quickly as possible so that the difference in the temperature of the metal is as little as possible between the bottom of the mould and the top.

When the casting temperature is as low as possible, there is also the danger of cold laps. The application of hydrostatic pressures as quickly as possible, driving the gases away from the casting, is also an inducement to the rapid filling of the mould. The gating system of many large-sectioned moulds requiring an alloy of long solidification range, and therefore to be cast at as near as possible to the upper limit of that range, demands that they be run quickly and smoothly with a maximum number of controlled gates. Moreover, one must employ some method at the bush for it to be kept full of metal, so that no dross or charcoal can pass into the gating system and may be drawn by the metal into the casting.

FIG. 11.—METHOD USED FOR MAKING CHILLED CORES.

Pouring Conditions

Filter cores are not sufficiently fast for the larger and heavier castings, and any speeding up of the filter increases the danger of the collected dross, etc., entering the casting if the pourer halfway through the cast fails to keep the bush full. The use of a reservoir or pouring bush which will hold about half the metal required for the cast, and in some cases more, removes much of the personal element from the casting period. The metal is held in the reservoir by the plug and sealing system, the plug being drawn when sufficient metal has been introduced. The practice of keeping the reservoir above the risers and down gates is economical, as all the metal poured into the reservoir bush passes into the mould and is used. Moreover, it deteriorates but little and can be re-used. With due care and attention at the plug seating, it will last for weeks.

The speed with which the metal leaves the basin is governed by the size and number of ingates. These are particularly important when the reservoir basin is added after the top has been closed down. If the metal leaves the basin far in excess of the amount which the ingates can take, there is always the danger of a "burst away" where the basin sits on the down-gate entrance.

Fig. 12.—Casting for Worm Gears Weighing $6\frac{1}{4}$ cwts.

As the casting temperature is as low as possible in relation to everything else, any leakage of metal through the plug and seating will trickle into the runners and set, and so restrict the entrance of the metal when the plug is drawn, and in very bad cases may completely seal it. The deepening of the runners in the vicinity of the down runners obviates the danger of a complete blockage. The general arrangement of the mould for a worm wheel and nut is shown in Fig. 10. This arrangement does not offer any great difficulty as to moulding, but the production of this casting in a high-tin phosphor bronze requires special attention and technique. The depth of cut with $\frac{1}{4}$ in. outside and 1 in. cut for the teeth gives a total of $1\frac{1}{4}$ in. on the wheel section. The inside worm thread has a total metal removal to the bottom of the thread of $\frac{3}{4}$ in.

The difficulty of producing this casting with no visible porosity will be appreciated, as there is the slow cooling due to mass, coupled with deep machine-cuts into the metal. To overcome this slow cooling which would take place in an ordinary sand mould, the sand can be replaced with some material which has a greater conductivity of heat, which in the author's case was standard cast-iron rod. Then to regulate the cooling as much as possible, the cooling must be speeded up at the heavy section to bring it into line with the two shank parts. Therefore, the chills are a great deal heavier at that portion. The chills are not continued into the head, as this part is required to solidify last.

Fig. 13.—Heavy Sectioned Castings Typifying Subject under Consideration.

The thicknesses of the chills are 4 in. for the centre section, 2 in. for the top and bottom chills on the same section; $1\frac{1}{2}$ in. for the bottom shank; and $1\frac{1}{4}$ in. for the top. These differences were made to induce progressive solidification.

Core Details

The core was chilled by cast-iron quarter-segment chills $\frac{3}{8}$ in. thick up the casting only. In the making of the core, due care was exercised to maintain an unbroken chilled surface. If this is not observed there is a danger of a contraction crack or hot tear showing, or a porous area due to the relative slow cooling and different rates of contraction and shrinkage and liability of eutectic migration. All joints are carefully made up, two good coats of dressing being applied. Any slackness in the making of the joints of the chills will have their repercussion in the fettling shop as there will be a difficulty in removing the chills. There is a tendency for the metal to search into the weak joints in the same manner as it does in weakly rammed moulds, holding the chills into a solid mass. The running and gating was by four ⅝-in. dia. pencil runners set on the top of the head so that the metal passed down the centre of the metal section, care being taken to see that all four were perpendicular, so that the metal in dropping would not strike any of the metal parts of the mould, thereby inducing local over-heating with its attendant troubles. For the same reason the mould on assembly must be set perfectly upright. The metal was cast at 1,040 deg. C., the pouring bush being rapidly filled. Due to the open nature of the pencil runner no stopper or plug was used. The metal was first carefully skimmed while waiting for the correct casting temperature.

Fig. 14.—Pad Castings Difficult to Make.

Fig. 15.—Adjustable Wedge Casting Weighing 23 cwts.

During the casting period of any mould mixed gases are generated which may deposit moisture on the cold chills, causing a disturbance when the metal comes in contact with them. Chills hanging in the top or middle parts can with advantage be closed warm to hot, depending on their relationship to everything else, thus minimising the condensation of moisture.

Examples from Practice

Fig. 11 shows one method used for making small-diameter chill cores or for that matter any diameter where a half core-box is available. The segment chills are laid in position in the box and then rammed up in the ordinary way, provision being made for holding them in position by spring or wire through a tapered hole drilled in the chill. The use of any material to increase the adhesion of the sand to the chill which will form a large volume of gas on casting should be avoided and the chill face should be continuous in order to avoid shrinkage and structural faults.

A worm cut from the solid casting with a cored hole of 3¼ in. dia. with outside machining allowance of 3/16 in. and ⅛ in. in the bore involves difficulties in production. It should be realised that after the casting has been machined to its outside finished diameter, the worm has to be cut, which entails the removal of 1.91 in. of metal and it must show no porosity or openness of grain on inspection. The ordinary sand-cast methods, no matter how low the casting temperature, would not produce a satisfactory casting. The slow cooling of the mass and the difficulty of feeding over such a length of time would in all probability lead to open metal. The outside was chilled by segments 2 in. thick, the bore being chilled as shown previously. The head on the casting was increased to 2 in. as no quick cooling was required. The mould was rammed as hard as possible at the back of the

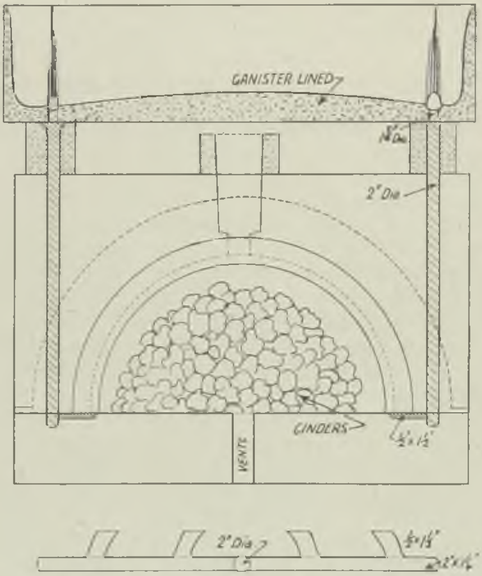


Fig. 16.—Mould for Segment Pieces.

chills with floor sand which would just hold together, and facing sand was only used on the bottom. It was top-run with four ⅝-in. dia. pencil runners, the mould completely dried and almost cold when cast, the metal being poured at 1,020 deg. C. The alloy used was 12½ to 13 per cent. tin, 0.25 to 0.3 per cent. phosphorus, the remainder being copper. Fig. 12 shows such a casting after fettling; it weighed 6¼ cwts.

Fig. 13 shows a group of castings typical of the general thickness of the castings under consideration. The total weight of those illustrated is 22 cwts. Fig. 14 shows a very simple casting which can easily lead to a good deal of trouble and expense in machining. These castings are pads which support the large cast-iron spindles in tube-boring machines, wherein the spindle weighs up to 18 tons. The machining of these pads to correct radius is by setting the full series on a machine table, the lugs being used for this purpose until they are parted off on the last operation. The riser should, if possible, be placed on this part of the casting. It was decided to chill the bottom face, as-cast, which is, of course, the bearing face, for three reasons: (1) to obtain a fine structure, giving satisfactory Brinell hardness and density; (2) to minimise the danger of any of them showing open metal due to the machine operator setting some of them so that there is a heavy cut off the bearing face, and (3) the expense and difficulty of machining odd replacements for any reason.

The chilling pads are placed on the pattern before ramming up, and then nearly dry floor sand is rammed firmly behind to maintain them in position.

Fig. 15 shows an adjustable wedge piece for a large bearing weighing when complete 23 cwts.; there are four pieces to the set, that is two segments and two wedge pieces. It is cast in phosphor bronze of 12 per cent. tin, 0.20 per cent. phosphorus, the remainder being copper. The casting must show on the bearing faces after machining a minimum of 80 Brinell. Fig. 15 shows the partially fettled casting with spray runner for distribution of molten metal and two end risers passing the end flanges so as to feed into the main body of the casting. Fig. 16 shows a sketch of a complete mould for the segment pieces, and is typical of the method employed for all half steps. The distribution of metal by sprays on both sides is used, the pouring bush being used for the heavier casting, that is those weighing over 2 cwts. Smaller castings utilise fast filter bushes. The moulds are well rammed, no soft ramming being permissible on the bearing face. The cinders are very tightly packed so as properly to support the face of the mould on casting. The chief reason for the introduction of the cinders is to ensure a quick and thorough drying of the bottom part. There are two main vents leading from the cinders to the atmosphere, and the casting temperature is of the order of 1,050 deg. C.

The author wishes to express his thanks to Mr. E. Longden (foundry manager) and to Mr. E. L. J. Howard for the help given in the preparation of this Paper, and to the directors of Craven Bros. (Manchester), Limited, for permission to publish the data disclosed.

DISCUSSION

Controlling the Charcoal Cover

The discussion was opened by Mr. J. H. King who said he was impressed by the author's reference to charcoal entering the mould. He asked whether the practice of melting under charcoal was adopted.

Mr. Hopwood replied that it was adopted in many cases. He had mentioned the matter for the simple reason that it was usual for foundrymen to use charcoal. Naturally, they liked to see the metal well stirred up, and as soon as it was so agitated, more charcoal came from the crucible sides.

Mr. King said he had raised the question because he had wanted the author's opinion as to whether or not he considered melting under charcoal to represent the ideal condition.

Mr. Hopwood replied that that depended more or less on the alloy. Although he had heard of other people experiencing trouble as the result of using charcoal, he had never encountered any. At the same time, he doubted that he would use it on such metal as manganese bronze, for instance, where there was a very considerable skin effect. He did not advocate so much putting charcoal at the bottom of the pot as keeping the metal covered with it; he liked to see the charcoal on the top just prior to the completion of the melting of the charge. He had heard references to the use of charcoal at the bottom of the pot being detrimental when melting aluminium bronze, but he had had no experience of it.

Chill Dressings

Mr. Chas. Cleaver asked whether special dressings were used on the faces of the chills.

Mr. Hopwood said his experience was that chill dressings were useless if the temperature of the chills exceeded a certain limit. The only satisfactory dressings he had found were of the refractory type, such as washes of various non-gas-producing materials, *e.g.*, blacking mixtures containing a clay wash, etc.; and he had tried silicate of soda as a binder. If the chill became over-heated, there was no thin coating of dressing that was completely satisfactory in itself. The trouble could be overcome by thick applications of refractory materials; but such applications minimised the effects of the chill.

Dry-Sand Moulding Recommended

Mr. G. C. Pierce (Past Branch-President), referring to an illustration of cores being strickled up, asked whether they were stoved and dried or whether the casting was carried out under green-sand conditions.

Mr. Hopwood said he had stressed in the Paper that the extra cost of the drying of the mould was amply repaid by reason of the production of castings of sounder general structure. It was his experience that the castings could be made in green sand; but he was always loth to use that practice because of the danger of producing unsound castings due to the gas from the green-sand mould and to the weak nature of the mould itself. There was a tendency on the part of the moulder to ease with the ram in making a green-sand mould, for the simple reason that he did not wish the sand to be any more dense than was necessary, coupled with a fear of scabs.

Casting Temperatures

Mr. Charles Cleaver, who was curious to know why the test bars referred to in the Paper were cast at the high temperatures mentioned, said that some years ago he had had experience of casting phosphor bronze, and it was found then that there was a critical temperature somewhere between 980 and 1,000 deg., according to the thickness of the job; at 980 deg. the structure produced was less heterogeneous than that produced at higher temperatures.

Mr. Hopwood said he had also emphasised that the casting temperatures of the bars mentioned in the Paper were very far in excess of the temperatures used in practice. He had used the higher temperatures to show the effect of over-heating the chills, and to ascertain whether or not he could produce a sound general structure when chill-casting at high temperatures. Casting temperatures, of course, could be reduced to within a few degrees above the temperature of solidification; a thick casting, probably weighing about 10 lbs., could be cast at a temperature very close to the solidification temperature. If, however, one were making a casting three times as large, for instance, but of the same section, which meant that there was more metal going into the mould and a greater length of time was occupied by the casting period, one must allow for that by increasing the casting temperature, or by providing far more runners in order to ensure quicker and better distribution of the metal.

Mr. Cleaver commented that the higher the temperature, of course, the greater was the length of time required for solidification. He was speaking of fairly heavy and fairly thick plates, weighing about 1½ cwts., cast in dry sand. They were run from the top, straight into the section.

Mr. Hopwood said that that was the usual practice, and one could cast at a very low temperature when the metal was run straight into such a section.

Machined Chills

Mr. E. H. Brown referred to the practice adopted some years ago of machining chills in order to obtain a deeper chilling effect on the heavier sections, and he asked whether Mr. Hopwood had adopted that practice.

Mr. Hopwood replied that he had in certain cases, but only when castings had to be produced to within very close limits. As a rule he preferred to use chills in the as-cast condition, where that was possible. If it were necessary to machine a chill, his policy was to take off as little as possible.

Dealing with the question as to whether the machining of the chill brought about a deeper chilling effect, he did not think it had much influence after the first one or two castings had been produced, because usually (and even in permanent moulds) the dressing gradually built up on the chill, thus reducing its heat conductivity. At any rate, in his experience there was no greater depth of chill effect resulting from the use of machined chills after the first one or two castings had been produced.

Casting Temperature and Running Speeds

Mr. G. C. Pierce (Past Branch-President) asked whether Mr. Hopwood was prepared to go all the way with regard to the fast running of phosphor-bronze, or whether he ever advocated slow running. In that connection he mentioned castings produced by the Ronceray system, *i.e.*, using small "pencil" runners in order to secure an equal rate of cooling throughout the mould, a system which obviously resulted in very slow running. But the castings produced thereby were very successful; he wondered whether Mr. Hopwood had used that system, and, if so, what were his results.

Mr. Pierce expressed himself as being somewhat surprised by the optimism of Mr. Hopwood in thinking that one would be able to produce decent castings at the temperatures at which he had experimented. Mr. Hopwood must have known, of course, that to cast phosphor-bronze at 1,350 deg. was asking for trouble. On the other hand, it was surprising to hear Mr. Cleaver refer to the production of perfectly good castings at 980 deg., for one would have thought that that would have resulted in trouble also. Many tons of castings in phosphor-bronze were being made at fairly high temperatures, but he personally regarded 1,120 deg. as the maximum pouring temperature. He had known castings weighing 1 cwt. in phosphor-bronze to have been subjected to very high temperatures and poured by the Ronceray system at 1,120 deg. However, he was not advocating high-temperature running.

Mr. Hopwood said he could not visualise phosphor-bronze of any appreciable phosphorus content or of high tin content withstanding exceedingly high pressures. No doubt it would be agreed that phosphor-bronze, in thick sections, had a notoriously unsound structure underneath the as-cast skin; one could not possibly produce such phosphor-bronze sand castings completely sound, to withstand very high pressures, as could be done with gunmetal. He had heard of a foundryman, operating a small foundry in Lancashire, who had adopted the practice of casting through small inlet runners, and he had learned that, due to the use of those small runners, the casting temperature was much higher than usual. He did not know the quality of the castings produced, or whether they were subjected to stringent tests.

Machining and Pressure Soundness

Mr. A. E. McRae Smith said the author had seemed to imply that the particular specification of phosphor-bronze he was using, which had a fairly high tin content, presented a great deal of difficulty from the foundry production point of view. If that were the suggestion, he would rather disagree with it, because very heavy castings were being made in phosphor-bronze to withstand very high pressures.

Mr. Hopwood replied that he had definitely experienced difficulty in meeting the specified Brinell figure of 80 on the bearing faces of phosphor-bronze castings of large sections; indeed, that was his main reason for presenting the Paper. His duty had been to find out a method of meeting that specification, and he had found two methods: either to reduce the machining (as could be done in certain cases) as far as the machine shop would allow, or so to increase the cooling rate that the crystals would build up rapidly on the chill face.

As he had stated in the Paper, the indiscriminate increase of tin and phosphorus contents to increase hardness was useless to the foundry, and he had found that he could obtain the same structure, or a better one in many cases, by quick cooling, *i.e.*, throwing the alloy further from the equilibrium.

Emphasising the bad results arising from weak moulds, he said that time and time again the machine shop had received two similar castings, one of which was perfectly good whereas the other was bad. Anyone who saw the bad casting would suggest that it had been cast at too high a temperature, or that the metal was gassy, or the like: but, knowing the conditions under which it was cast, he was aware that those reasons were not the real reasons. Therefore, he had tried to discover the real cause of the trouble, and had found that bad castings with open, porous structures could be produced through the use of weak moulds, just as such castings could be produced by casting at the wrong temperatures.

Importance of Gas Content

Mr. G. T. Callis said that in the course of his experience he had been concerned with the production of small parts in phosphor bronze, intended particularly for pressure work, and it had been a common experience to find castings having, when broken, very desirable pressure-tight skins and bad cores, showing the yellowy-brown fracture to which Mr. Hopwood had referred. The first consideration that had occurred to him was why there should be such a vast difference between the contraction of phosphor bronze and that of manganese bronze. The total contraction was practically the same, namely between 10 and 11 per cent., yet despite the similarity in total contraction, the head on a phosphor-bronze casting might show hardly any sink, and contraction troubles due to shrinkage were rare, results very different from what one met with manganese bronze. The answer was to be found in the gas content of the metal.

In the case of manganese bronze in which, due to the high partial pressure of zinc, gases were quite insoluble, contraction was not hindered by gas evolution at or near the freezing point. Phosphor bronze and gunmetals, however, readily dissolved gas, the evolution of which inhibited feeding and resulted in the voids so often mistaken for shrinkage cavities.

There were various ways of removing the gas from phosphor bronze, the most general being to maintain melting conditions oxidising at all times. The use of charcoal was considered to be bad, for it could remove such oxygen as might with advantage get to the surface of the metal.

In a recent experiment on some green-sand cast test-bars in gunmetal, which bars had given a tensile strength of approximately 17 tons per sq. in. as cast, the metal was put back into the furnace and left there for about 10 mins. with a good excess of gas; the resulting bars gave a tensile strength of about 11 tons per sq. in. Then air, the simplest and cheapest oxidising medium available to everyone, was blown in for a few moments, and the tensile strength of the bars was increased to about 20 tons per sq. in.

Commenting on the references made to the importance of the freezing range, Mr. Callis said he might be regarded as iconoclastic, but he had come to the conclusion that the freezing range had nothing whatever to do with the soundness of phosphor bronze and gunmetal castings, and that the trouble was purely and simply one of gas content. Casting temperature had but little to do with the soundness of the castings in phosphor bronze, although it influenced the tensile properties of the material as test-bars. The reason why high casting temperatures were generally regarded as being responsible for bad castings was that obviously, in order to achieve high casting temperature, the metal had to be subjected to higher temperature in the furnace, and the rate of solution of gas increased very rapidly with increase of temperature. Thus, a pot of metal heated to 1,100 deg. C. and poured at 1,080 deg. C. would produce a much sounder casting than one which had been subjected to a temperature of 1,250 deg. C. if melting conditions were bad. Mr. Callis added that those remarks applied more particularly to metal melted in oil-fired furnaces; he believed that comparatively few gas troubles were experienced in connection with metal melted in coke fires.

Solidification Ranges

Mr. Hopwood said that his theory was very much in line with that of Mr. Callis, except that he believed the solidification range had a good deal of influence on the results. Without doubt, gas was present, and he believed that was the reason that the alloys suffered from inverse segregation. His view was that concentration of gas could occur after the metal had commenced to solidify; and much depended on the amount of under-cooling and on the force with which the gas came out of solution. That explained, he believed, why heavy castings also exhibited a greater amount of inverse segregation or porosity. Without doubt, the castings suffered from under-cooling. The metal was cast into the mould at a temperature which was above that at which solidification commenced; after the first extraction of heat by the cold mould, the metal cooled relatively slowly, depending on its mass, and on that would depend the amount of under-cooling that would occur —except that vibration would upset under-cooling. It was only a theory, and he had not seen it proved, but he believed that if the metal had a shorter freezing range, there would be greater latitude in the foundry. That was why one could cast a metal containing, say, 11 per cent. tin and 0.1 per cent. phosphorus much more easily, and produce a higher percentage of perfectly sound castings, than with a metal containing 12 per cent. tin and 0.3 or 0.4 per cent. phosphorus.

Vote of Thanks

A hearty vote of thanks was accorded Mr. Hopwood for his Paper.

Mr. Hopwood, in a brief response, said the subject discussed in the Paper was partly solved, and he expressed indebtedness to Mr. Callis for his remarks concerning the solubility of gas, because that was the problem he had been trying to solve.

Scottish Branch **Paper No. 725**

Castings for Enamelling

By J. A. DONALDSON (Associate Member)

One has frequently heard the opinion expressed that cast iron as an essential commodity in world progress is quickly becoming less necessary; the extremists in this school of thought say that it is already doomed. These opinions are based on the fact that substitutes are, from time to time, being introduced which are claimed by their sponsors to be better and/or cheaper than when fashioned in cast iron. Examples of such substitutes which have been hailed as nails in the cast-iron coffin are steel castings, forgings, stampings and fabricated parts; spun concrete pipes, asbestos-cement rainwater goods, tiled fireplaces, and so on. To the casual observer such an array would seem to indicate that the outlook for cast iron was anything but bright, and indeed this would be the case if the ironfounder did not adopt measures to meet the situation. This he has done and is doing in three main directions, namely, by manufacturing castings by improved methods (*e.g.*, machine moulding and centrifugal casting); by employing iron with vastly improved physical properties (*e.g.*, high-duty and alloy irons), and by developing new outlets for iron castings.

Vitreous-enamelled cast iron is one of the outstanding examples embraced in the third category, and its importance as an outlet for iron castings is given in justification of the presentation of this Paper to a meeting of ironfounders.

Before proceeding to a discussion on castings for enamelling it might be appropriate to define the term "vitreous enamel," state its main properties and briefly outline the process.

Vitreous or porcelain enamel (the terms are synonymous) is made up of a carefully balanced mixture of mineral ingredients fused together at a high temperature to form a complex glass. When applied to cast iron it provides a finish having a large number of desirable properties. These include an infinite range of fadeless colours and shades, durability, ease of cleaning, high gloss, acid and alkali resistance, freedom from scratching and rusting, and heat-resistance.

The fundamental steps in processing cast iron call for annealing of the castings at a temperature of about 800 deg. C., shot-blasting the surfaces to be enamelled at pressures up to 80 lbs. per sq. in., and, in the wet process, spraying the castings with the enamels which have been previously milled to a fine consistency along with clay, colouring oxides and water. The water is driven off by drying in a hot chamber and the enamel is then fused on to the metal at temperatures ranging from 740 to 820 deg. C. In the dry process the finely milled enamel is dusted on to the hot casting and the enamel is fused out at temperatures in the region of 900 deg. C.

It will be realised from the preceding particulars that castings, during the process of enamelling, are subjected to unusually severe treatment which calls for special attention to their design. It is proposed to deal with some points on this subject, but before doing so it should be mentioned that the remarks apply to castings intended for wet processing, although many of the points apply equally to dry-process castings.

Fundamentals of Design

It should be the constant aim of the designer to provide castings free from sections uneven in thickness (such as heavy ribs, bosses, door catches, hinges, etc.) since in extreme cases blistering of the enamel will occur at these parts, while in less extreme cases the castings will require to be "double run" to fuse out the enamel equally. ("Double running" consists in heating the castings during the fusing operation until the enamel on the lighter parts has almost fused out, withdrawing the castings from the muffle partially to cool off, and returning the load to the muffle to fuse out the enamel on the heavier sections. Just as the thinner part of the casting reaches the fusing temperature sooner than the thicker part, so will the former cool more quickly when withdrawn. When the casting is returned to the muffle a second time the heavy section will be at a higher temperature and, provided the fuser's judgment is not at fault, the whole casting will arrive at the fusing temperature of the enamel simultaneously.) Such a procedure is costly since about 50 per cent. more time is required to fuse the article. A further objection to castings of unequal thickness is that, due to the inherent casting strains, they are liable to spring during the annealing, blasting or fusing stages.

Fig. 1A illustrates the type of boss which causes blistering due to open structure of the iron. Should the boss be intended to take a screw shank the defect can be largely eliminated by casting it in, as it will then act as a densener. Even so, unless the boss is very light, double running will still have to be employed. Methods designed to overcome the difficulty are shown in Figs. 1B and 1C. Either method will make it possible to avoid a double run.

DIAGRAM NO. 1A

DIAGRAM NO. 1B

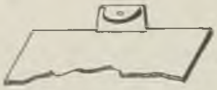


DIAGRAM NO. 1C

Design of Ribs

Heavy ribs on the underside of a casting, as well as tending to cause blistering, will frequently bring about the condition of " hairlining " of the enamel. Hairlining is due to unequal heating of the casting, which has the effect of causing the unfused biscuit of enamel to crack over the heavy area. When the enamel fuses, depressions form at the cracks, which give the enamel surface a corrugated appearance. The remedy here is to reduce the weight of the ribs or, if they are present merely to strengthen the casting, to have two or more smaller ribs in place of the single large one (see Figs. 2A and 2B). Door catches and hinges should be cored out to give these parts the same thickness as the rest of the casting.

DIAGRAM NO. 2A

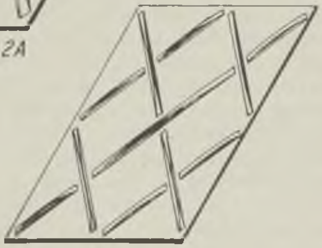


DIAGRAM NO. 2B

Deformation of Flat Castings

It is a well-known fact that the blasting of a flat casting inclines to make the blasted face convex, due to the peening effect of the abrasive. Where this occurs the cure lies in thickening the casting, or, where this cannot be done, to make the casting slightly concave on the face to be enamelled (Fig. 3). It might be mentioned here that the general tendency to reduce the weight of light castings to the absolute minimum has led to extra cost in enamelling, due to excessive warping and breakage, greatly in excess of the saving in metal.

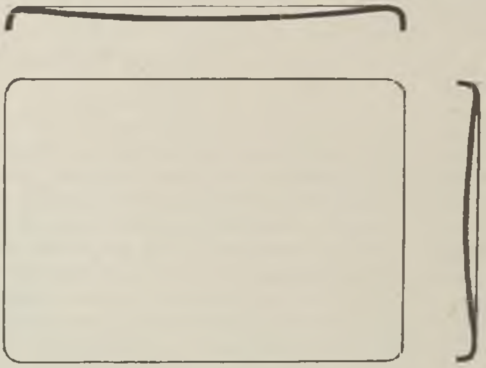


DIAGRAM NO. 3

Before dealing further with design it is necessary to explain a point in connection with wet-process enamelling practice. In this process two methods of application are used. In one the true enamel is applied over a matt ground-coat and in the other the enamel is applied direct to the blasted casting. The matt ground-coat is sprayed on to the blasted casting, dried, and fired on at a temperature of about 820 deg. C. The true enamel is then sprayed on the cold ground-coated casting and, when dried, fired on at about 720 to 740 deg. C. In the direct method the enamel is sprayed, dried and fired around 740 to 760 deg. C. Because of the fact that the enamel applied direct to the metal has a far better adhesion than the best matt ground-coat enamel, the former is always applied if the casting design and, to a lesser degree, the colour required make this possible. Should a

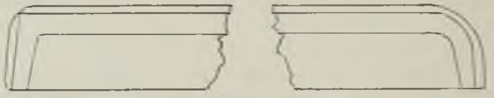


DIAGRAM NO. 4A

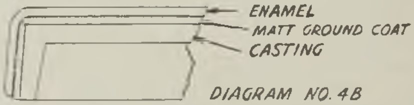


DIAGRAM NO. 4B

casting be of such a design that it warps appreciably in blasting, it will require to be ground-coated in order to allow of its being fired at the matt ground-coat heat (820 deg. C.) and thus attain a temperature at which it can be straightened with the least chance of breaking.

Edges and Fillets

Another feature in design which determines whether a direct enamel can be applied is the state of edges and fillets. Should they be sharp the direct enamel will flow away from these edges, when fused, leaving a line of almost bare metal (Fig. 4A). This is not so apparent when a matt ground-coat is applied, since this coat is only partially fused, when properly fired, and so cannot flow away from the edges to the same extent. Further, the fired matt ground-coat has a surface similar to fine sandpaper, and this has the effect of holding the true enamel in place when it is fused on (Fig. 4B). It should not be assumed from what has just been said that sharp edges are permissible on castings to be ground-coat enamelled, since the edges of an enamelled casting are more liable to chip with rough handling, and the sharper the edges the less will be their resistance to chipping. Whether castings are intended for direct or ground-coat enamelling, the edges and fillets should have minimum radii of ⅛ in.

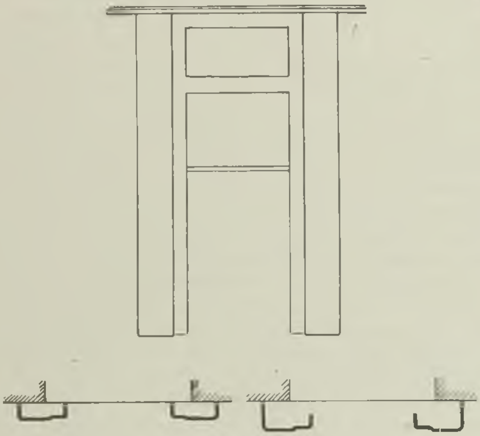


DIAGRAM NO. 5A DIAGRAM NO.5B

Every endeavour should be made to see that castings with projections on the underside will have these of the same depth. Castings which are not designed with this in mind will require special packing on the firing supports to avoid distortion during annealing and fusing, leading to considerable loss of muffle output. Figs. 5A and 5B typify good and bad design in this respect.

METAL COMPOSITION

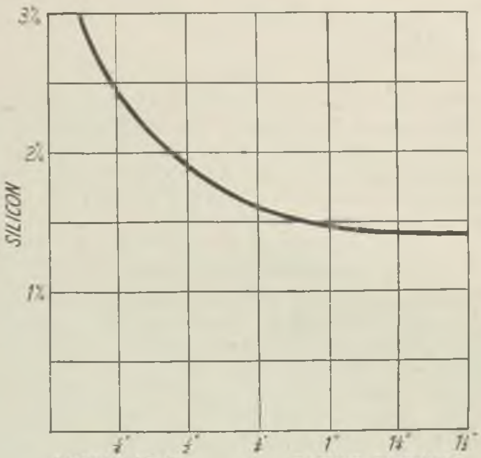


DIAGRAM NO. 6

It has been claimed that cast-iron pieces ranging in fracture from white to coarse grey have been successfully enamelled. There is no reason for doubting that this has been done in isolated cases, but even those who demonstrated that this is possible would admit that to attempt to enamel such castings on a production basis would be nothing short of madness. The fact is that the fracture—and therefore the metal composition, since this almost wholly governs fracture—is of paramount importance in cast-iron enamelling. Indeed, it can be said that the regularity of composition of castings being processed in a given enamelling works has a very definite bearing on the results achieved.

Castings best suited for enamelling requirements should have a close-grained grey fracture, high density and good mechanical strength. Close control of these factors can only be

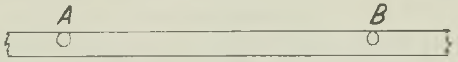


DIAGRAM NO. 7A

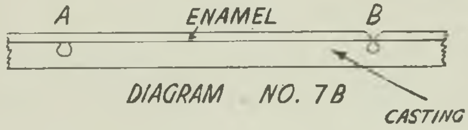
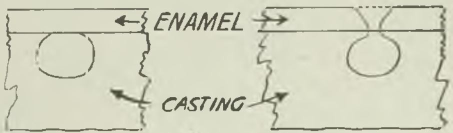


DIAGRAM NO. 7B



ENLARGEMENT OF 'A' ENLARGEMENT OF 'B'

obtained if the chemical composition is given full attention.

Silicon

The silicon content is the chief factor in controlling grain size and in determining the relative proportions of combined and graphitic carbon in the casting. Castings having a suitable grain size will contain from 0.40 to 0.60 per cent. combined carbon as cast.

Manganese and Sulphur

Manganese aids in densening the structure and has a stabilising action on the combined carbon, and since the main purpose of annealing castings is to break down the carbides it should not be present in large quantity. On the other hand, sufficient ought to be present to ensure that all the sulphur is combined with it to form manganese sulphide, as otherwise the sulphur will retard carbide dissociation. It is considered that if the manganese present is in excess of 1.7 times the sulphur content plus 0.3 per cent., all the sulphur will exist as manganese sulphide, in which form it has no apparent influence on enamelling results in rational quantities. Due regard should be given to the fact, however, that manganese sulphide is present in molten cast iron in minute globules, and since it is considerably lighter than iron it is reasonable to assume that, under certain conditions (for example, castings of heavy section, poured hot) the globules will segregate at the upper surfaces of the mould. Such surfaces when blasted will be pitted at the points where the brittle manganese sulphide has been removed. The obvious remedy is to keep the sulphur down to as low a percentage as possible.

Phosphorus

Phosphorus should be limited to that quantity necessary to impart sufficient fluidity for casting. Any amount in excess of this will merely increase the breakage loss, not only in the enamelling shop, but also in the dressing and fitting shops and in transit.

Having given due regard to the amount of the other constituents mentioned, the variations in the graphitic carbon of iron from a normally operated cupola will have no influence on the enamelling results.

Many compositions have been quoted as being best suited for enamelling castings, and it is not intended to add another to the list. The aim should be to arrive at a composition which gives the best all-round results and then maintain such an analysis as closely as possible. One point calling for mention in connection with these ideal analyses is that the silicon content is generally given as around 2.5 per cent. Since castings ranging in thicknesses of from $\frac{1}{8}$ in. to well over 1 in. are being enamelled and, as already stated, silicon is the main determining factor in grain size, the silicon content should be controlled accordingly. Fig. 6 gives the silicon: thickness ratio, which should provide the best structure for the mean thickness of a given enamelling casting if the other constituents are within normal limits.

Foundry Practice

Some adjustments in orthodox foundry procedure are called for in order to obtain high-quality enamel finishes. Castings should be sound internally and free from sand and slag inclusions. Special care should also be taken to ensure that the castings are perfectly smooth on the surface. The Scottish moulder has long been famed for the pleasing smooth blue finish he produces on light castings. This surface is entirely suitable for enamelling purposes provided the casting is sound below the skin, but the methods adopted to procure this finish are apt to lead to the presence of small gas-holes, which may be broken into when the casting is shot-blasted. Fig. 7A illustrates a section showing this defect. Where the gas-hole is well exposed, as at A, the void can be filled with a special clay, but where the wall of the hole is just punctured (B) it is not readily seen by the clayer. This results in a dent in the enamel surface due to some of the fused enamel finding its way into the hole beneath (see Fig. 7B). The remedy here lies in being sparing with the coal-dust and blacking. The best enamelling results will be obtained from a casting which comes away from the mould with a film of facing sand adhering. Owing to the demand for finishes in pastel shades, it is essential that the casting be sound and have a perfect surface. The well-known mottle finish effectively masks small defects on the enamelled surface which would be very obvious if the casting was pastel-enamelled.

Running and Gating

Gates should be located on the edge of the casting, and should the casting be of unequal section the gate should be set at the thinner part since this arrangement will lessen the tendency for the casting to warp. Runners should be broad and their thickness tapered to as thin a section as possible at points where they meet the casting, so that any dirt from the gate may be trapped. Flat and "pop" gates should not be used, if at all possible, because of the lined surface which generally results from this practice. The face to be enamelled should always be cast down, and in cases where the casting is to be enamelled on both sides the less conspicuous face, when fitted, should be cast up.

It is a good practice to melt the metal hot so that any slag, etc., may have time to come to the top of the ladle before pouring commences. Botted iron should not be used, since such metal is likely to be hypereutectic, and some of the excess carbon may be precipitated on the casting face, leaving a poor enamelling surface when shot-blasted. The castings should be removed from the moulds hot and stowed well away from wet sand. Should this not be done, and rusting of the casting occurs, trouble in the enamelling process is very likely to arise.

Mention was made at the beginning of this Paper that vitreous enamelling afforded an important outlet for iron castings. It is to be expected that production will diminish somewhat during the war, but there is no doubt that the demand will revive and steadily increase when conditions return to normal. The extent of the increase will depend on the cost of the article, and if these notes have, even in the smallest degree, contributed to that end, the time given to preparing them will be considered well spent. The ironfounder will have some justification for wondering where a reduction in cost of the enamelled article comes in in view of the obviously increased cost of producing castings along the lines suggested here. He can rest assured, however, that the added cost of production in the moulding shop will be saved many times over in the enamelling shop, and that it will also result in increased durability and attractiveness of the enamel finish. Increase in demand is then sure to follow.

The writer wishes to express his thanks to Mr. George Pate, O.B.E., J.P., manager for Carron Company, for permission to present this Paper and for facilities afforded him in its preparation.

DISCUSSION

Mr. D. Sharpe, in opening the discussion, said that he had no intention of offering any detailed criticism of the Paper ; the subject was so specialised that only an expert could deal with it. He would, however, like Mr. Donaldson to develop the theory of the formation of the hole under the enamel. He himself was more inclined to think it was caused by a blowout of the hole rather than a suction taking the enamel into the hole. He thought further information might help in accounting for any pinpoints found on enamelled surfaces. He agreed that design was a matter of importance and that the enameller was frequently asked to enamel castings of a wrong design ; in fact, the enameller was often asked to do more than was reasonable in maintaining the shape of the complicated and ill-designed articles.

Mr. Donaldson agreed there might be an evolution of gas from the surface holes as the enamel reached the fusion point. He had shown on the screen the type of defect referred to and a section cut through the hole. The type of hole giving most trouble was that just below the surface, and it was difficult to realise that the enamel could go through so small an aperture. It was probable that the oxide on the surface of the metal became assimilated in the enamel and caused an evolution of gas.

Commenting on the graphitic carbon in the iron, which, a member suggested, was largely the cause of defects in the enamel surface, Mr. Donaldson pointed out that this question has long been a subject of discussion. Some authorities maintained that if the graphite could be eliminated no troubles would arise; others said that graphite had no effect on the enamel. He himself thought that graphite as such had no effect, but voids around the graphitic flakes had.

A Specialised Production

Mr. T. Tyrie suggested that the real difficulties arose with foundries which did not regularly make castings for enamelling. Those foundries making engineering castings did not get a sufficiently clean surface to permit the enamel to adhere properly. The type of sand used was usually coarser, so they went to extremes in putting on a heavy coating of plumbago in an effort to obtain a smooth surface on the casting. No amount of shot-blasting would produce a sufficiently clean skin for enamelling purposes. Referring to the holes under the surface, he was inclined to think there might be pressure in the hole so that the enamel was blown up, and on cooling suction occurred.

There were a great many views on the graphitic carbon. He felt that the graphite itself was not the cause, but the void around the flake or that which might be formed by the burning of the graphite flake. Another aspect was the formation of a micro-chill largely composed of carbides, which in the enamelling decomposed with the formation of a very active form of carbon, which produced carbon monoxide and carbon dioxide gases.

Mr. Donaldson agreed that graphite as such was not the cause of the troubles, but rather gases formed by action of oxides which tended to cause the enamel to lift if the surface were such that complete adherence did not take place. It was essential that the surface be clean and free from plumbago or blacking, as this would tend to peel and separate the coating.

The Chairman (Mr. Erskine), proposing a vote of thanks to the author, said that many difficult problems faced the enameller, especially in the case of very thin light castings, and the Paper had been of considerable interest.

A Preliminary Study of Gases in Cast Iron

By WM. Y. BUCHANAN (Associate Member)

PART I.—SURVEY OF EXISTING KNOWLEDGE

The work of the Committee of the Heterogeneity of Steel Ingots includes, besides its own findings, an excellent bibliography, of which the following are some extracts. Although the results cannot be directly applied to cast iron made under foundry conditions, many useful pointers can be taken for lines of research in the matter, although the author's own work was carried out before reference was made to these reports, and the extracts are included here as a basis for discussion and reference.

OXYGEN BIBLIOGRAPHY (EXTRACTS)

A. Wüster and E. Piwowarsky, 1927

An apparatus for measuring the quantity of gases in molten metals, especially steel, and for analysing the gases. It consists in the main of a steel container, capable of containing 2.2 kg. of liquid steel, into which samples can be drawn by suction direct from the furnace bath. The container is first evacuated by a high-vacuum pump; when the container is full the vacuum causes the gases to evolve, and these are removed by a mercury pump to a gas collector and analyser.

R. Kjerrman and L. Jordan, 1928

The authors refer to oxygen in cast iron (solid) from 0.01 to 0.04 per cent.

NITROGEN IN IRON AND STEEL

Harbord and Twynam, 1896

Nitrogen exists in two conditions in steel:—(*a*) in the free state, being mechanically occluded in the metal, and (*b*) as fixed nitrogen, in combination with some other element. The amount of nitrogen was not connected in any way with the good or bad qualities of the steel.

Braune, 1905

Braune found nitrides Fe_4N and Fe_3N in studies on the blast furnace.

Brittleness in steel has been attributed by many workers to nitrogen.

J. H. Andrew, 1912

Iron and iron-carbon alloys absorb small amounts of nitrogen when melted under a high pressure of the gas. The absorption of 0.3 per cent. of nitrogen entirely suppresses the critical changes in pure iron, and prolonged heating *in vacuo* is required to denitrogenise the metal. The absorption of 0.25 per cent. of nitrogen by a 0.6 per cent. carbon steel lowers the Ar_1 point to a marked degree. Nitrogen tends to retain carbide in solution in iron.

N. Tschischewsky and N. Blinow, 1914

Experiments show that vanadium and titanium do not eliminate nitrogen in iron. Nitrides of vanadium and titanium being soluble in iron, the presence of these elements may even tend to increase the percentage of nitrogen in iron.

N. Tschischewsky, 1915

The results of an exhaustive investigation on the influence of nitrogen on steel are reported. These include experiments made to ascertain the conditions under which nitrogen passes into steel during manufacture; the influence of carbon on the combination of nitrogen with iron; the influence of manganese on the absorption of nitrogen by iron; the influence of silicon and of aluminium on the combination of nitrogen; the metallography of iron nitride and the influence on the mechanical properties of steel, which, according to the author, is *wholly injurious.*

S. W. Miller, 1919

The brittleness of electric welds is attributed to the presence of iron nitride. Oxy-acetylene welds made with low carbon materials have much greater ductility and resistance to shock.

F. Wüst, 1922

The results of Wüst's work show that the nature of the raw materials has no particular influence on the nitrogen content of basic-Bessemer steel, that the quantity of nitrogen taken up increases with the temperature of the bath, and that a high blast pressure probably promotes the taking up of nitrogen. The nitrogen content can be lowered by cooling the bath with scrap additions.

N. Parravano and A. Scortecci, 1924

In ferro-vanadium, the gaseous and combined nitrogen is lowered by melting, but in ferro-manganese the total nitrogen remains unchanged. In other ferro-alloys the combined nitrogen is increased from five- to nine-fold on melting.

J. Kent Smith, 1925

The low-temperature reduction of iron in the blast furnace is advocated as a precaution against the absorption of nitrogen.

F. Adcock, 1926

Nitrogen is rapidly absorbed by chromium in the liquid state, and alloys containing up to 3.9 per cent. nitrogen can readily be obtained. Alloys of iron and chromium, both in the liquid and solid states, take up nitrogen at high temperatures and in general the quantity of nitrogen taken up increases with the chromium content. Penetration of the metal by nitrogen appears to be especially rapid in the vicinity of the crystal grain boundaries.

L. W. Schuster, 1932

In a chromium steel containing 0.75 per cent. of manganese but free from carbon, nitride needles are not inhibited when the chromium content is 0.83 per cent., but are inhibited when that element is raised to 1.01 per cent. With a reduced manganese more chromium is required.

L. Barduc-Muller, 1914

The gases were extracted from a cast of 550 kg. in weight by the vacuum method (hot-extraction) and 1,159.8 litres of gas was obtained, of which 147.7 litres consisted of nitrogen and 604.3 litres were hydrogen. The remainder was mainly carbon dioxide and monoxide. The effect of the gases on the properties of the steel was not studied.

" Gases in Iron and Steel," by T. Swinden and W. W. Stevenson, 1935

Summary of Observations

(1) In the absence of carbon above, say, 0.02 per cent., oxide of iron does not cause unsoundness.

(2) In the presence of carbon, violent reactions occur in oxidised iron.

(3) Passing gas through deoxidised iron and mild steel has the following effects:—(*a*) Hydrogen—unsoundness; (*b*) nitrogen—no unsoundness; (*c*) hydrogen followed by nitrogen—no unsoundness.

(4) Passing gas through oxidised iron and mild steel has the following effects:—(*a*) Hydrogen—unsoundness often showing large holes internally; (*b*) nitrogen—no effect; (*c*) hydrogen followed by nitrogen—no unsoundness where the carbon is low, but in "rimming steel" type unsoundness persists; (*d*) carbon monoxide—slight unsoundness; (*e*) carbon dioxide—no effects.

Brief Discussion of the Results

The foregoing observations may be regarded as indicating that:—

(1) The solid solubility of nitrogen and carbon dioxide is not seriously lower than the liquid solubility, and these gases are apparently inert under experimental conditions recorded.

(2) The solid solubility of hydrogen is considerably less and that of carbon monoxide slightly less than the liquid solubility. The authors, however, recognise that the evidence presented by them is not entirely conclusive on this point in that there are no means of differentiating between unsoundness due to reaction and unsoundness due to gas coming out of solution. This work to be supplemented by work of a different character carried out in the vacuum fusion apparatus.

(3) In addition to the oxide/carbon reaction there is evidence of oxide/hydrogen reaction producing blowholes.

(4) In *killed* steel the effect of hydrogen can be removed by a subsequent passage of nitrogen, and an otherwise risen and blown ingot converted into a solid piping ingot.

(5) In *unkilled* steel the effect of passing nitrogen subsequently to hydrogen has not been to promote greater soundness under experimental conditions recorded. This may possibly be due to acceleration of the oxide/carbon reaction. Note that in the case of electrolytic iron melt (3*i*), nitrogen subsequent to hydrogen gave an almost solid ingot.

The authors think it will be conceded that the results are of interest and in several directions novel. They have shown, apart from the well-known iron-oxide/carbon reaction producing blowholes by the formation of carbon monoxide gas, that passing hydrogen, and to a lesser extent carbon monoxide gas, causes unsoundness, whilst nitrogen and carbon dioxide are inert; moreover, that the effect of hydrogen can be eliminated, presumably by the removal of hydrogen, by subsequent passing of an inert gas like nitrogen, at least under certain conditions.

That hydrogen is present in the gases evolved when solid steel is heated as well as in the blowholes of blown steel has been proved according to the evidence of previous workers, and it is generally conceded that during manufacture the steel has ample opportunity of absorbing hydrogen from the furnace gases.

It is not so clear how the content of hydrogen can be controlled in normal steelmaking practice, and the authors have yet to determine the effect of nitrogen treatment on the physical properties of steel.

" Formation of Graphite in Grey Iron," by Alfred Boyles, A.F.A., 1938

(*Annotated Abstract*)

" 17. It was observed that certain grey iron alloys freeze white when melted in hydrogen and slowly cooled. The resulting white iron is restored to its original condition by melting in air, or rendered still softer by melting under reduced pressure. Such changes are attributed to an absorption of hydrogen by the iron, the extent of which is governed by the amount of hydrogen in contact with the molten metal, by the pressure in the furnace and by the temperature, inasmuch as *the solubility* of hydrogen increases as the temperature is raised.

" 34. The behaviour of hydrogen during freezing can only be surmised from what is known of its action on pure iron. According to Sieverts, the solubility of hydrogen in iron changes with temperature as in Fig. 29 [not reproduced here]. An abrupt change occurs at the melting point. Therefore, hydrogen would be expected to segregate during freezing in the same manner as sulphur because its solubility in the solid is less than in the liquid state."

Note. This is typical of the state of knowledge on the subject—continual quoting and requoting on the subject.

" 37. Sulphur and hydrogen were found to work in the same way though not quite equivalent, *i.e.*, low sulphur and high hydrogen did not produce quite the same effect on the carbide as high sulphur and low hydrogen. Hydrogen in absence of sulphur did not have any great effect on iron-carbon-silicon alloy but sulphur is effective in absence of hydrogen.

" 72. In hypoeutectic grey irons, the graphite flakes form during freezing of the eutectic and grow radially from the crystallisation centres of the eutectic liquid. With a given rate of cooling, the size of the graphite flakes is determined by the rate of graphitisation along the solid-liquid interface. Sulphur and hydrogen in solution in the eutectic liquid decrease the rate of graphitisation, and the segregation of these elements produces composition gradients around each crystallisation centre."

H. A. SCHWARTZ asked in the discussion whether hydrogen content had been determined, and MR. BOYLES replied that he did not know, but it would be very difficult to determine. He also said that he believed that the amount in solution at the time of freezing was the significant thing.

Note. This is about the best available individual attempt on cast iron so far found, but is confined to the effect of gas on the microstructure.

" Silicon and Manganese as Deoxidisers in Cast Iron," by A. H. Dierker, A.F.A., 1934

(Annotated Abstract)

" 9. Just how much oxygen may be present in molten cast iron is not known. However, it is probable that any cast iron melted by ordinary commercial methods will contain oxygen in sufficient amount to affect the physical properties of the material when solidified. Assuming that some FeO is present in superheated molten metal it is possible to visualise the reactions that take place as the temperature drops."

No attempt was made to find how much oxygen was present, and it will be noted that this work is carried out by deduction and the application of steelmaking theory.

" Formation of Flaky Graphite in Cast Iron," by K. Mityashita, 1937

" Metals and Alloys " Abstract

In those irons in which N is below 0.0015 per cent. the eutectic arrest appeared always at a constant temperature, and very fine, uniformly distributed graphite was obtained ; when N content in the Fe is above 0.0020 per cent. the eutectic arrest occurs in steps, and flaky graphite colonies surrounded by fine graphite and free cementite were obtained.

In the B.C.I.R.A. Index to Research Reports and Translations, 1924-1932, no record appears concerning any work on gas in cast iron.

The treatment of liquid cast iron by bubbling gas through for refining the graphite has been carried on, but this is a different matter altogether.

Other Abstracts

W. West and C. C. Hodgson (Proc. I.B.F., Vol. XXXII, 1939, p. 421) point out that the study of gas in liquid cast iron is essential and suggest that perhaps a certain amount of gas may be beneficial in reducing shrinkage. This, however, would have to be proved by suitable research on the matter because others have suggested that interdendritic porosity is caused or exaggerated by gas at solidification temperature.

Norbury (*B.C.I.R.A.*), in the same discussion, expressed the opinion that blowholes were caused by hydrogen, *e.g.*, by steam passing through the metal in the first place, but did not refer to any particular investigation on the point.

Faulkner (" Foundry Trade Journal," *August* 11, 1938).—This article might be quoted in full, but take one short reference in particular: " Every foundry metallurgist who is familiar with researches on the influence of hydrogen on iron and steel would like to have the experiments repeated with cast iron as the liquid to be treated. . . ."

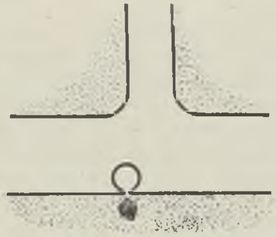
H. C. Hall (Proc. I.B.F., Vol. XXX, 1937, p. 283).—Pinholes or cavities are formed in sand castings during change of state by disengagement of hydrogen, carbides of hydrogen, and carbon monoxide.

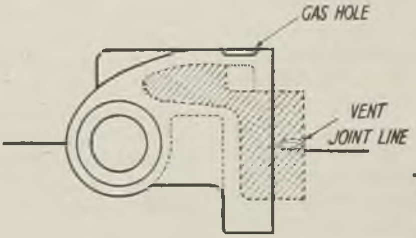
PART II.—EXPERIMENTAL WORK AND DEDUCTIONS

General Causes of Gas Holes

The formation of gas holes in cast iron is dependent on a large number of factors. These defects become more or less serious, depending on whether the casting is for an important purpose, and whether filling is allowed. In some branches of the industry, such as machine-tool manufacture, they are looked upon with extreme disfavour, and consequently even a small solitary hole in a large expanse of close-grained machined surface may cause the rejection of the casting, the excellent quality of the metal notwithstanding.

Gas holes are known to be formed by gases from the mould surface, *i.e.*, the excessive evolution of gas immediately after contact of the metal with the mould coating and the surface layers. If the permeability of the mould be low and this gas evolution rapid, conditions are favourable to the formation of gas holes in the top surface of a casting.





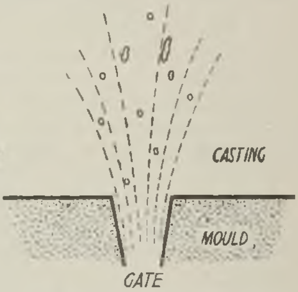


Fig. 1.—(Left) Gas Hole Formation From Coal Particles or Similar Material Near Mould Face Fig. 2.—(Centre) Difficult Type of Core to Vent Properly Where Metal Traps Air in the Top Edge. Fig. 3.—(Right) Gas Holes in the Stream of Metal.

The same applies to relatively large particles of material, such as coal or limestone or even wood chips being close to the mould face. These warm up and give off gas later on when the metal is setting, and the gas so formed has no chance to separate from the pasty metal. These particles of foreign material form isolated holes in any part of the casting to which the particle happens to be adjacent, as is shown in Fig. 1.

Cores are often a source of gas holes owing to their shape, and this may be exaggerated by too rapid filling of the mould. This defect, shown in Fig. 2, may be corrected by turning the core in such a way that the metal in passing over the surface tends to drive the gases towards the proper vent, instead of from the vent towards some extremity.

There are also cases of excessive ramming, which lowers the permeability of the core, and gas holes from this source are readily recognised by their shape and close proximity to the defective core. In addition to this, the use of partly-baked cores or excessively bonded sand produces gas holes due to gas coming off in the mould when it should have been driven off completely in the drying stove.

Gas holes may also be caused by the positioning of the system of gates so that air may be entrained in the stream of metal during filling of the mould (Fig. 3). This usually produces a stream of small holes leading away from the gate in the line of flow of the metal.

In green-sand work, the excessive use of the swab on joint lines, especially in rough plate work, when the patterns are drawn by hand, is a common source of gas holes. In addition to these, excessive bubbling may be caused by wet green sand used in making up bushes or head-boxes. These defects are, of course, rare with skilled moulders, but may occur during the training period of boys or unskilled labour. Gas holes may also be caused by the coating on chaplets, if this be of inferior grade.

When using "chills" or external denseners the metal may "flutter," causing gas holes close to the surface. This may be due to having put a cold "chill" into a warm mould, thus causing the condensation of moisture on the metallic surface, or to the type of coating used. No doubt many strange liquids have been tried on chills, such as boiled linseed oil, alone or with sand; red lead—wet and dried; tar: creosote; black-wash; plumbago water; aluminium paint; sodium-silicate mixtures, etc., most or all of which give off gas in large quantities when in contact with hot metal.

Dissolved Gases

The object of this Paper is to consider the gas which is brought to the mould dissolved in the cast iron itself, and is likely to come out of solution during solidification. The gas remaining in solution after solidification does not materially affect the foundry, as the chief interest is in the production of a sound casting.

That there is such a thing as "gassy" metal is well known, but nothing seems to be definitely understood, and most of the old-timers attributed gas in molten cast iron to oxidation in a vague way. Much has been blamed upon the rapid driving of the hot-blast furnace as compared with the slow-running cold-blast furnace, and cold-blast pig-iron was said to be superior to the hot-blast variety.

There were also certain fixed ideas about cupola melting, which prompted these old-timers steadfastly to avoid light scrap and steel as potential sources of dissolved gas, or oxidation as they called it. In this they were at that time quite justified, but this point of view ruled out a large volume of raw material so far as cupola practice was concerned, and has often caused unnecessary market upheavals at regular intervals due to uneven supply and demand. In the present war conditions, the conservation of national resources for so important an industry as iron founding is essential, but it should not require a European war to emphasise the fact.

Since one of the main objections to these cheap scrap materials is that of gas, the study of this subject in connection with melting conditions is of considerable importance, and is evidently new.

The writer's interest in the subject of gas in metals began a number of years ago in Parkhead Forge, where as a research assistant under Mr. T. Service he was given the job of collecting and analysing gases evolved during solidification* of steel at the time when the committee on the Heterogeneity of Steel Ingots was very active. At this time also the Metallurgical Club of the college held many excellent meetings, at which metallurgists met to carry on discussions following lectures by such authorities as Dr. Desch, Prof. Andrews, Mr. Service, Dr. McCance, Mr. Austin, Prof. Hay, Dr. Donaldson, and many others well known in the metallurgical world.

Slag inclusions in steel and the conditions bringing these about were constantly under discussion, whilst the importance of gas had long been recognised in steelmaking, and its study had been extensive and painstaking.

The fact that the matter has not been given more attention in cast iron is rather strange, and may, in fact, be due to the fact that replacements in cast iron are relatively cheap and that in small foundries facilities for carrying out any investigation are usually entirely lacking.

Experiments on Cast Iron

The work detailed in this Paper was carried out before a search was made of the published literature, and while it was not influenced by the published material, it is interesting to consider the experiments made on cast iron in the light of these records, annotated extracts from which form Part I of this Paper.

Owing to the possibility of disturbing factors entering into the collection of gas from molten cast iron, it was thought necessary to find some method which could be *readily repeated under foundry conditions* so that ample verification of any work could be made, and the method decided on was to use a cast-iron bell (Fig. 4) which could be readily replaced and to draw off the gas from a standard foundry ladle.

Volumes might be calculated per unit area, but this also brings in the question of depth of metal, and it is uncertain whether the gas collected will rise from the bottom in a vertical direction, although it does not appear to rise in bubbles but steadily and uniformly from the surface, as in slow evaporation of water, except in excessive gas evolution. The bell readily melted away under the surface of the liquid metal and had to be renewed for each test.

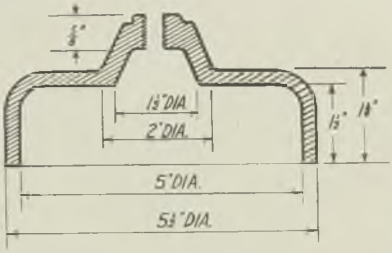


FIG. 4.—DIMENSIONS OF CAST IRON BELL USED IN TESTS.

In order to make the bell withstand liquid metal erosion, a refractory was tried out, and the bell remained intact, and a great deal of work was done until it was found that this wash coating gave off CO_2 as well as combined water, and the work had to be discarded. Other cements were tried, but they also gave off CO_2, to the following extent:—Pyruma (commercial), 0.42; Alundum cement. 0.42, and bentonite, 0.52 per cent., when tested in stream of O_2.

No further attempt was made to preserve the bell, and the present method is to bore and tap the bell without using oil and then sand-blast the inside carefully, using a new bell for each experiment. It was also found necessary to clamp the bell so that no movement occurred during the sampling, as this would obviously affect the volume of gas delivered momentarily.

A suitable wooden stand was constructed, as shown in Fig. 5, to hold the ladle on one side,

---

* See letter to the Editor in the "Foundry Trade Journal," August 25, 1938.

and the glass apparatus on the other side of a protecting partition which held the clamp. The level of the liquid metal was fixed by marking the ladle before filling.

The ladle or shank was always filled with metal and allowed to stand, then the metal was poured out prior to the actual test in order to burn off any blackwash and thoroughly dry off the lining. This was done at least once and often three times. Then the ladle was filled to the correct level with the metal to be tested, placed on the stand carefully and the bell lowered into position on a *clean* surface of metal.

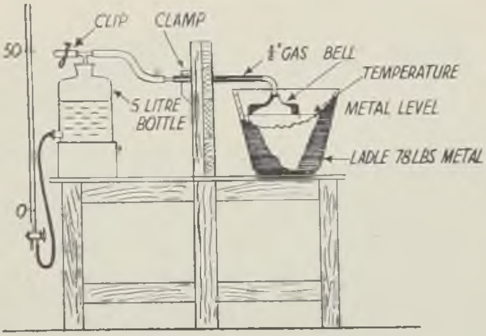


Fig. 5.—Arrangement For Measuring Gas Volume in Cast Iron.

The tube was connected to the exhausting tube, as shown in Fig. 6, and all air and some gas drawn off. When the required amount was taken off, the sampling tube was switched into the circuit and the sample taken at atmospheric pressure, *i.e., under no suction.* Gas forming gas holes in a casting would come off first of all at atmospheric pressure, and later under a head of metal, but never under suction in normal conditions. That there is a large quantity of gas was clearly demonstrated when the exit end from the tube of the bell was kept closed.

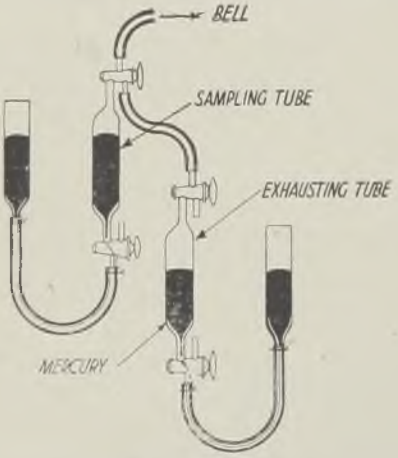


Fig. 6.—Method to Secure Samples Free From Air.

The surface of the liquid metal rose above its normal level by $\frac{3}{8}$ in., as shown in Fig. 7, and when the tube was opened, this fell with the escape of gas. This happens even when no sign of gas can be seen, and when gas is actually seen to escape from the metal surface, the volume of dissolved gases must be excessive. The same may be demonstrated if the bell is connected to a large bottle which has a water connection to a vertical glass tube. The water displaced by the gas will be seen rising rapidly in the tube.

From the point of view of its immediate application to practice, the volume of gas evolved is probably more important, since it may be assumed that a small volume would tend to produce a smaller gas-hole content than would a large volume.

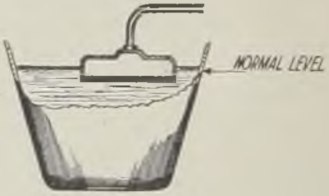


Fig. 7.—Gas Displacing Metal From Bell.

Several possible methods of measuring the volume were tried, and it was obviously best to collect over a range of temperature between reasonable pouring temperature and that of solidification or between pouring and a normal temperature in the runner basins, *i.e.,* allowing for a temperature decrease normally found in filling the mould of a medium machine-tool casting.

The method found to be best is that indicated in Fig. 4. The bell is lowered and clamped in the surface of the liquid metal, then with the clip (Fig. 5) open, the burette is placed alongside the large bottle and moved up and down till the levels are in line at zero, and the reading on the burette is noted.

The clip is closed and as the water is displaced into the burette, it is lowered to keep the water levels in line, thus keeping the mixture of gases in the large bottle at atmospheric pressure, as this saves a considerable amount of calculation or correction where gas is collected under suction and has to be converted to N.T.P. The method has the advantage of considerable accuracy of measurement, and if the two-way stop-cock is used to run quantities of water out of the burette, the volume measurement may be carried on indefinitely.

It was found convenient to take readings of volume and temperature every 15 seconds and to make from these the time/temperature and temperature/rate of evolution graphs. The reason for plotting these graphs was to find whether there were ranges of accelerated evolution (such as during graphite separation) which may be useful as an indication of possible methods of treatment of the metal. The temperatures were taken by a Cambridge optical pyrometer and no corrections applied, as this instrument has been used for years daily on the measurement of tapping and pouring temperature.

Discussion of Results

Although a special study could be made of the reaction of gas analysis of the metal to melting conditions, it seems that the gases exist in cast iron in no fixed proportions but merely in those proportions in which they happen to be available finally. It also seems likely that they may combine on coming out of solution.

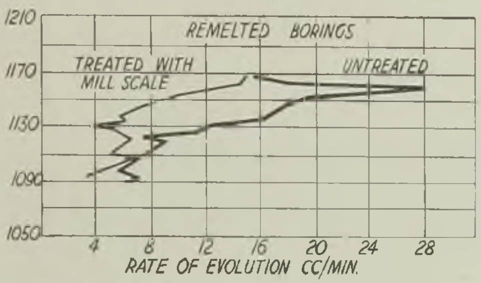


Fig. 8.—Effect of Scale Treatment on Rate of Evolution of Gas.

Oxygen as such does not exist, and this fact is not difficult to accept, considering the large quantities of carbon, silicon, manganese, sulphur and iron at high temperature available for reaction. Some of the results obtained in the course of these experiments are set out in Tables I and II.

Carbon dioxide, too, is unlikely to exist in quantity owing to the well-known $CO_2 + C = CO$ reaction at high temperatures.

Hydrogen appears to exist in large quantities in the free state associated with carbon monoxide. These could be formed from the action of steam and carbon: $C + H_2O = CO + H_2$.

The presence of nitrogen would, of course, be accounted for by the large residual volume in the furnace gases after combustion was complete. The presence of CH_4 or methane is erratic, and no explanation is offered at the moment, but this is affected by oxidation as shown producing CO and H_2 from CH_4.

It is obvious that a systematic study of the composition of gas in cast iron related to melting conditions, *i.e.*, to air supply, patching conditions, slag volume and constitution, nature and size of charge and furnace gases is necessary and would make a welcome addition to the metallurgy of cast iron.

From the examples given it can be shown that 35 to 90 per cent. of the gases are subject to oxidation treatment, and for the purpose of removal some straightforward solid oxide treatment is indicated.

In any experiments on gas oxidation, however, the volume measurement becomes essential, as apparently the oxidation process does not oxidise and remove the combustible gases only but removes nitrogen by agitation or a sort of washing process.

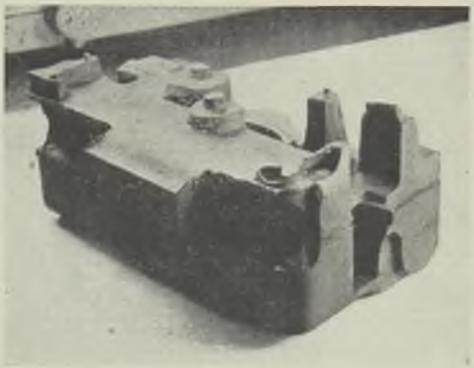


Fig. 9.—Gas Hole or Pocket Caused by Dissolved Gas Coming Out of Solution in the Mould.

Then, since the gas analysis sample and the volume test were not done simultaneously, there may have been a difference in the gas compositions of the ladles used, whereas for direct comparison of the effect of treatment they should have been the same. These differences can only be counteracted by generous duplication of the tests.

Rust Treatment

The first gas oxidation tests were carried out using 1 oz. of ground rust (probably hydrated) to the shank containing 78 lbs. of metal, and this gave a vigorous reaction. Then 2 ozs. of aluminium-alloy scrap was added to take up excess of oxide, and this appeared to absorb the oxide film, but was very difficult to skim, and would probably lead to trouble in pouring. The result of this experiment showed a decided

TABLE I.—*Influence of Various Treatments on the Composition of Gas Evolved from Cast Iron.*

	Furnace.	Treatment.	Gas analysis. Per cent.						Cast-iron analysis.				
			CO_2	O_2	CO	H_2	CH_4	N	T.C.	Si.	Mn.	P.	S.
Hard	54-in. balanced blast	None	1.22	0.7	11.67	Nil	42.6	43.8	3.19	1.18	0.74	0.42	0.114
Hard	,, ,,	None	0.76	Nil	12.9	37.4	0.83	48.1	3.22	1.28	0.87	0.48	0.120
Soft..	,, ,,	None	0.43	0.43	23.9	36.5	27.25	11.47	3.46	1.78	0.96	0.40	0.091
Remelted borings	32-in. balanced blast	None	Nil	Nil	9.05	35.3	Nil	55.6	3.00	2.38	0.72	0.54	0.116
All pig	18-in. cupola ..	None	1.93	Nil	29.27	11.47	2.2	55.3	3.48	3.35	0.83	0.28	0.066
Hard	54-in. balanced blast	2 oz. scale, 6 oz. Al	3.8	Nil	46.0	37.0	8.0	5.1	3.37	1.52	0.76	0.43	0.108
Soft..	,, ,,	3 oz. scale only	Nil	0.3	12.14	38.1	2.2	47.2	3.20	2.26	0.99	0.59	0.106
Soft..	,, ,,	6 oz. scale only	0.48	Nil	14.1	63.9	17.2	4.22	3.53	1.92	0.94	0.47	0.094
Soft..	,, ,,	Soda ash ..	1.06	0.24	13.15	Nil	49.28	36.27	3.25	2.10	0.88	0.56	0.062
Soft (wet ladle) ..	,, ,,	Soda ash+scale ..	0.86	Nil	13.31	11.87	7.2	66.76	No sample taken.				

TABLE II.—*Quantity of Gas Evolved from Various Types of Cast Iron through a Temperature Range.*

	Furnace.	Treatment.	Total vol. c.c.s.	Range of temperature. Deg. C.	Average rate of evolution. c.c./min.	Cast-iron analysis. per cent.				
						T.C.	Si.	Mn.	S.	P.
Soft iron ..	54-in. balanced blast	None	19.4	1,140—1,070	6.5	3.26	2.18	0.73	0.103	0.55
		None	25.5	1,200—1,090	7.1	3.18	1.81	1.08	0.099	0.54
		None	40.6	1,160—1,090	9.6	3.28	2.43	0.90	0.105	0.55
		Rust	51.5	1,160—1,080	14.7	3.40	2.21	0.83	0.104	0.60
		Soda ash	36.7	1,110—1,030	13.4	3.14	2.23	0.82	0.072	0.63
		Soda ash	61.5	1,220—1,060	20.5	3.15	2.23	0.85	0.065	0.68
		6 oz. scale	44.2	1,180—1,080	11.8	3.15	2.58	0.91	0.108	0.56
		Scale and Al ..	34	1,220—1,060	9.7	3.21	2.18	0.93	0.107	0.61
		Soda ash and scale	17.5	1,160—1,090	8.8	3.10	1.66	0.83	0.083	0.50
		Soda ash and scale (wet ladle)	44	1,100—1,040	25.2	No sample taken.				
Hard iron ..	54-in. balanced blast	None	38.3	1,170—1,080	10.2	3.30	0.99	0.805	0.118	0.43
		None	39.1	1,180—1,060	11.2	3.17	1.28	1.00	0.111	0.48
		None	39.9	1,180—1,050	10.0	No sample taken.				
		2 oz. scale ..	28.0	1,140—1,075	12.4	3.55	1.03	0.715	0.124	0.43
		3 oz. scale ..	25.9	1,160—1,040	8.0	3.36	1.22	0.76	0.119	0.40
Remelted borings	—	None	44.5	1,170—1,090	13.7	3.16	1.99	0.815	0.130	0.54
		6 oz. scale ..	21.6	1,170—1,090	7.2	2.99	1.74	0.84	0.118	0.48
All pig ..	18-in. cupola	None	88	1,240—1,130	27.1	3.48	3.35	1.03	0.066	0.28
72 per cent. pig and 28 per cent. scrap		None	39.8	1,140—1,080	15.9	3.27	2.68	0.75	0.100	0.58

increase in gas content due to the treatment. The volume was, in fact, doubled, and it was decided that any oxides such as brown or red hematite would be unsuitable. Mill scale, which is usually plentiful, was found very suitable, as it is easily granulated and graded and is, of course, non-hygroscopic.

Mill Scale Additions

Systematic tests on the use of powdered scale show that very heavy scale additions can be used without causing any reduction of the total carbon, and that this reduction of percentage of carbon does not take place in the presence of even low silicon, *e.g.*, 14 lbs. of scale added to 5 cwts. of liquid cast iron produced a copious gas evolution, but the analysis of the metal was 3.10 per cent. T.C and 0.84 per cent. Si before treatment, and 3.05 per cent. T.C and 0.43 per cent. Si after treatment, these figures showing no real change in the carbon content. It seems germane to stress that, in any scale treatment, the quantity added should be kept to the minimum, and all reaction must be completed some time at least before casting.

Mill scale gave the best gas reduction; a rapid reaction took place, which was complete in a very short time after the ladle was filled, and appeared to cause no decrease in temperature—probably due to the exothermic reaction or thermit effect. The resultant slag was apparently a silicate of iron, as the composition was 43.24 per cent. Fe and 33.98 per cent. SiO_2. It rose readily and formed a light, but solid, crust which was very easily skimmed; in fact, it did not require skimming, as it would not flow and tended to collect to itself any other oxide films.

One interesting point in the treatment of cast iron with scale is that it appears to reduce the sulphur slightly; for instance, an untreated metal showing 0.103 per cent. sulphur, when treated with 0.6 per cent. scale, gave 0.098 per cent. sulphur, that is, a 5 per cent. reduction.

The effect on volume of gas is illustrated in Fig. 8. The total volume has been reduced to about half that in the untreated sample. This shows the gas evolution from remelted borings melted in the loose form, a charge of 73 per cent. loose borings and 27 per cent. pig-iron. It is interesting to note that gas evolution is small in spite of the extreme fineness of the material charged to the cupola:—

	Total vol.	Range. Deg. C.	Rate.
			cc. per min.
Untreated ..	44·5	1,170—1,090	13·7
Treated with 6-oz. scale ..	21·6	1,170—1,090	7·2

Soda Ash

It should be stated here that all metal melted and referred to in these notes, except that melted in the small 18-in. cupola, had regular additions of soda ash to the charges to keep the slag in good condition, and this will undoubtedly have a beneficial effect on the metal in the ladle, but the use of granular soda in the ladle itself has been used as a method of degasifying metal. The intention is to remove the gas by a sort of washing process due to CO_2 liberated from the soda ash and rising in large bubbles through the metal.

The test carried out showed the usual violent reaction on pouring metal on the soda ash. The bell was placed in position after the usual interval of time and the gas collected from the metal and slag. The cooling effect of the soda ash was responsible for the freezing process being more advanced than usual at the end of the test, but temperatures could not be taken through the slag. Gas escaped freely through the centre of the bell where the slag remained fluid.

Gas ..	CO_2	O_2	CO	H_2	CH_4	N_2
Per cent.	11·5	0·19	1·35	Nil	40·43	46·55

Comparing this analysis with others when the soda slag is kept out of the small ladle used for tests, it is seen that CO_2 comes off the slag, but in coming through the metal it is converted to CO, and this is in itself an oxidation process.

The volume of gas found in iron treated with soda ash is greater than in the untreated metal.

The addition of scale to soda ash appears to effect the desired degasification with a reduction of the heat loss, and probably more efficient purification.

Effect of Wet Ladle

An improperly-dried ladle may cause a considerable increase in the gas content, even though the evolution of gas is quite impossible to detect by signs of bubbling in the metal. The volume may be increased from 17 to 44 c.c. total volume, and the rate of evolution from 8 c.c. per minute to, say, 25 c.c. per minute, to quote figures from an example in which no gas evolution was showing in the surface of the ladle. When actual boiling is evident, the increase of gas content will be much greater.

Type of Furnace

It was found that the gas content in the metal from the balanced-blast cupola was uniformly low in both high- and low-silicon cast irons. In general, the use of light scrap, which causes gassy metal in the ordinary cupola, makes no difference when using the balanced-blast cupola.

To test an extreme case of this kind, measurement was made of the gas content of loose cast-iron borings (most of which was rather fine) melted in a 32-in. balanced-blast cupola. This was dead quiet in the ladle, and only gave 44 c.c. total volume, associated with a gas evolution of 13.7 c.c. per min. between 1,170 and 1,090 deg. C.

For comparison a small 18-in. bore ordinary cupola was tested. This has a blast supply in excess of that required, and it cannot be evenly distributed owing to the small diameter. When melting an all-pig charge this gave a gas content of 88 c.c. during the cooling range at an average rate of 27 c.c. per min. This furnace would be generally classed as giving " good hot metal."

The same furnace melting 28 per cent. light scrap and 72 per cent. foundry pig gave an evolution of 15.9 c.c. per min. between 1,140 and 1,080 deg. C. The metal, however, showed a distinct boil above the tested ranges when the gas content must have been very high indeed.

Examples from Practice

It can be quite generally stated that melting high percentages of scrap or by remelting several times and maintaining low total carbons, the percentage of gas-hole defects is much higher than in mixtures containing high percentages of pig-iron. However, it is rather difficult to furnish concrete examples which can solely be attributed to dissolved gas.

A gas pocket which seems typical carries a perfect outside shell, and the cavity is only detected by hammering, sometimes very heavily.

Fig. 9 shows such a defect in an apron for a lathe. This had a cut gate on the parting, four risers, and two ¼-in. whistlers on each of the corner projections, which are only about ½ in. broad at the top. This defect was persistent even with all these precautions, and produced six " wasters " in a batch of 18. The moulds were made on a roll-over machine, and oil sand was used for core making. The scale and soda-ash treatment was applied, and this produced sound castings, whereas on a repeat untreated test, three defectives were had from a batch of six castings. This seems to support the line of investigation carried out for these notes.

CONCLUSIONS

(1) Sparking is said to indicate oxidation, *i.e.*, gassy metal. This appears to be incorrect, as sparking occurs at high temperature and low silicon range, whereas the gas volume may be much greater in high-silicon iron.

(2) Fluidity and life must play an important part in the ultimate importance of the quantity of gas present, as, for example, good castings can be had from high-phosphorus or high-carbon, high-silicon, medium-phosphorus iron even with excessive gas content, but the element of risk will always be present, of course.

(3) Moisture is the cause of most gas formation in cast iron.

(4) Gas escaping rapidly through metal may to a certain extent delay freezing locally.

(5) In high-duty irons the presence of gas is more serious than in low-grade irons, owing to the tendency to low fluidity and life in these irons.

(6) Apart from the many causes of gas holes, dissolved gas must always be an additional contributing factor.

(7) Some research on the matter should establish the permissible volume of gas in molten cast iron. Examples of good and bad gas content are given in these notes.

The author puts forward these notes as a contribution to the practical metallurgy of cast iron rather than as a recommended procedure to be adopted in the industry in general. This comment is made lest the wholesale and ill-advised use of oxidation causes more trouble than it cures.

In conclusion, the author wishes to thank John Lang & Sons, Limited, for their kind permission to put these notes before the Institute.

Sand Testing with Special Reference to Deformation

By WM. Y. BUCHANAN (Associate Member)

The author's last Paper on this subject, given to the Scottish Branch of the Institute of British Foundrymen, was presented in January, 1932, and the work for it was carried out in 1930 and 1931. At that time the British Cast Iron Research Association had completed a good deal of experimental work, leading to some definite conclusions which were slowly having effect on foundrymen in this country. The Paper referred to was one of the first to draw attention to the verification of the main conclusions drawn by the B.C.I.R.A. as to the value of milling on a practical scale, and this particular time saw the beginning of a period of intensive study of sands and testing, followed by an equally intensive reconditioning of foundry plant to improve foundry conditions. Sand handling and reconditioning plant played a very important part in the revival of the foundry from the trade depression conditions and the value of milling was clearly recognised in the best composite sand handling plants.

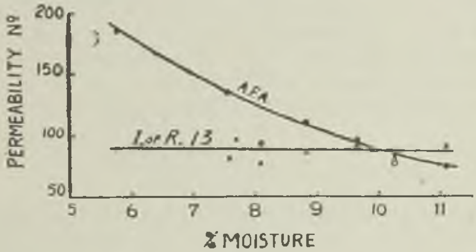


Fig. 1.—Effect of Moisture on Permeability of Rock Sand as Measured by A.F.A. and Double Compression at Index of Ramming 13.

There is no need to modify the conclusion reached in the earlier Paper that the two-roller type of mill is the most important part of any sand-preparing plant dealing with clay-bonded sands.

Technologists have continually argued amongst themselves in the committees set up to decide on the best methods of testing and procedure, but this is not surprising when it is considered that sand testing is amongst the most difficult forms of mechanical testing to perform with the degree of precision one associates with mechanical testing of metals, for example. This statement will be the more readily acknowledged the more one learns about the subject. The subject is not one which can be tackled by mere deduction and argument. It must be studied by extensive systematic experiment.

The vast amount of work done and on record both in America and other countries, as well as in Britain, should inspire considerable respect for the subject in the mind of the beginner. It should be stressed that it is not wise for anyone to begin sand testing and immediately adopt an uncompromising attitude, such as one occasionally finds, namely, that the foreman or underforeman is always wrong if he does not agree with one's test results, because he may not know how the A.F.A. permeability number is determined. If he does not agree, then he is entitled to a reasonable explanation of the new point of view, and if that is unconvincing to him, it is possible there is something wrong.

Sand testing is by no means above ambiguity, as the author has shown in several Papers to the Institute, and it is none the worse for the support of practical trials and the criticism of trained moulders who have risen to executive position. More success is likely to result where the older foundryman follows the proposed change with enthusiasm and the feeling that he has contributed to that success. The criticism of the more conservative foundrymen is always valuable, even if its only merit is to restrain the would-be headlong progress which may lack balance. The Institute serves a very useful function in the author's opinion by the facilities it gives for criticism of new ideas. With reference to the Paper of 1932, one or two points might be recapitulated.

Preparation of Sand Sample

It was stressed that the treatment prior to testing had an influence on the test results and these remarks still hold good. The sand to be tested should be sieved and kept in an air-tight tin and placed in a mixing drum during testing. By this means no loss of moisture will occur even in a well-heated room. When testing sand with varying moisture contents it seems to be common practice to mill the sample to disperse the moisture, but if this be done it should be remembered that the effect of milling alone is very important, and care should be taken to assess the value of these variables separately.

Rate of Loading the Test-Piece in Compression

As then found, the rate of loading does not seem to have much effect on the compression strength on the 1⅛-in. test-piece, but working with the A.F.A. test-piece and measuring deformation it is better to avoid variations in the rate of loading.

Mould Hardness

The principle of testing mould hardness as a means of producing a test-piece representative of foundry practice is still quite sound, but the attempt to measure moisture by mechanical test, like many others with the same object, has not been fruitful. However, the penetration method of measuring ramming density has been shown to be much more reliable than the skin hardness test.

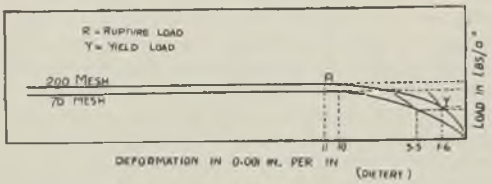


FIG. 2.—EXAMPLE OF DEFORMATION AND YIELD POINT MEASUREMENT (DIETERT).

The Test-Piece Controversy

In a Paper to the Birmingham Branch the 2-in. by 2-in. test-piece and the 1⅛-in. dia. by 2¼-in. test-piece were studied, and it was shown that the test-piece with its length twice the diameter was the correct shape, the A.F.A. 2-in. by 2-in. test-piece being too short in proportion. The many defects in the A.F.A. test-piece were tabulated and discussed, and these should be kept in mind. However, since the A.F.A. test-piece is most commonly used by those in the committees dealing with the matter it must be accepted as the standard, for general use.

The distribution of ramming force in the A.F.A. test-piece by the standard drop-weight method is not too satisfactory, as the layers may vary from 20 to 3 hardness ratio. The same test-piece by double compression has hardness practically equal throughout, that is a ratio of 3 to 2 hardness.

By ramming the A.F.A. test-piece whilst allowing the tube to move with the last blow, the distribution of hardness is improved very materially, and a ratio 35 to 20 is given, although it has a hard layer on top. This improved method is used for this Paper as the standard A.F.A. test, since it can be compared with the test-pieces made by double compression to index of ramming 13. The 1⅛-in. dia. by 2¼-in. test-piece is now being used for high-temperature work in preference to the 2-in. diameter because it is admitted to be a better test-piece. It is rammed by double compression, or so-called double end ramming, using a special A.F.A. rammer.

The double compression mould and plungers for making the 1⅛-in. by 2¼-in. test-piece being supplied are still of inadequate design and insufficient accuracy. The mould or tube should be of steel, highly finished in the bore, and should retain the flange at one end as it is more convenient. The plungers should be case-hardened and ground to a minimum of clearance giving an almost air-tight fit. The tube should be 8.256 in. long with one plunger 6.000 in. long and one 1.000 in. long, and the bore of the tube 1.128 in. The distance pieces should be horseshoe-shaped, of 1/16 in. mild steel, as shown in the original illustration. Finally the test-piece should be made by simple pressure and not by blows of a mallet; this is important. The same remarks apply to making the 2-in. by 2-in. A.F.A. test-piece by double compression.

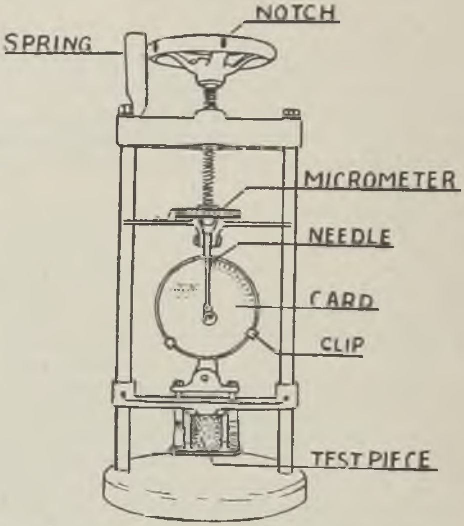


FIG. 3.—ARRANGEMENT FOR GRAPHING DEFORMATION UNDER COMPRESSION LOAD.

The question of what a standard ramming is has been raised at various times since 1932 in committee, it being said that the A.F.A. method gives a standard ramming, and that this represents normal foundry practice. There is a tendency to introduce different shades of meaning into the words "standard ramming" when discussing this aspect of sand testing.

To clarify this the A.F.A. procedure may be referred to as a test-piece made by a standard ramming machine, where the machine only is standard, the degree of ramming varying with all conditions. The index of ramming method, on the other hand, aims at controlling the degree of ramming.

The question as to which is more rational or representative of foundry practice resolves itself into a question of whether moulding is controlled by the energy expended in ramming to the exclusion of variations in the resulting mould or by trying to control the *results* by varying the ramming energy when necessary. The author contends that moulders work to the latter method. For example, if a sand is heavy and tends to ram too hard with the normal number of blows on a jolter, the number of blows would be reduced in order to secure a reasonable hardness.

Index of Ramming

The index of ramming is a number denoting the ratio of the porous rammed sand to the true density of the sand materials. It is a method of expressing the degree of ramming which is quite different from the idea underlying the A.F.A. method. It is defined as—

$$\text{Index of ramming} = \frac{\text{Dry apparent density}}{\text{True density}} \times 100 - 42.$$

Making test-pieces of varying dry apparent density, it will be seen that at between 1.1 and 1.2 the zero of ramming is reached and the fraction $\frac{\text{Dry apparent density}}{\text{True density}}$ then equals 42

This is not an arbitrary figure but one found by careful experiment. By deducting 42 a figure is obtained which the author has called the index of ramming. The range of ramming is thus 0 to 20, and the average for foundry practice found by trial is 13 index of ramming. The A.F.A. test-piece rammed by drop weight is subject to variations of ramming due to flowability, resulting from changes of water, clay, grain size and grain distribution.

Using the A.F.A. test-piece made by drop weight and the A.F.A. test by index of ramming, the true effect of flowability can be separated. In addition the effect of degree of ramming can be studied. Examples of this were given in the Birmingham Paper. Water does not close up the air spaces in the sand as is supposed, but goes to increase the plasticity of the clay, which causes the sand to ram harder under the A.F.A. rammer. When this variable is eliminated the true effect of the water will be seen to be nil, as shown by the graph (Fig. 1) at the index of ramming 13.

Whether or not this method becomes generally used does not matter very much, but it is useful for research on the effect of variables. It gives an explanation of many obscure points connected with testing, and apart from this it has a considerable educational value which should be beneficial to those taking an interest in the subject.

Modification of Tests in General Use

Green Strength.—In the old type of B.C.I.R.A. compression apparatus, the pan of the balance moves sideways. It was re-designed after Parkes showed the cause of slightly low readings. In the new B.C.I.R.A. machine a tension spring balance is used instead of the compression type, and agreement can now be had when using either pendulum or hydraulic machines for testing green strength.

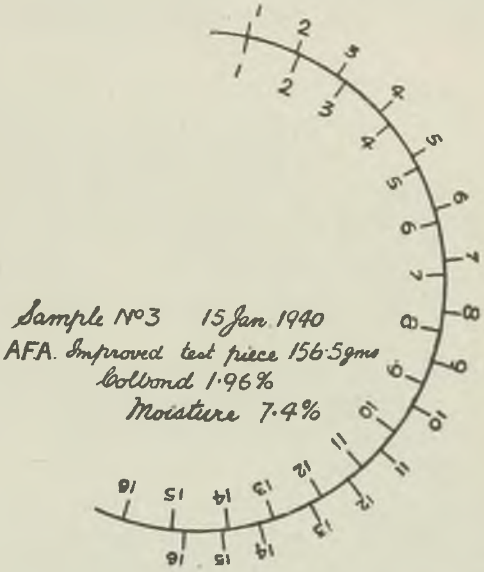


FIG. 4.—SPECIMEN CARD FOR DEFORMATION TEST.

Permeability.—The B.C.I.R.A. permeability apparatus is quite good, but the distance of the mercury seal from the manometer should not be too great, or a false reading may be registered, due to friction in the air tube.

Dry Strength.—The drying oven illustrated in a previous Paper does not require a fan, as it gives the necessary changes of air, and does not cool on opening the door. It reaches the temperature in 9 min., and can be regulated to any fixed temperature from 80 deg. up to 300 deg. C. and higher. The hydraulic testing machine for dry sand and oil sand up to 7,000 lbs. is very successful, and the principle was used by several others after it was proved successful.

Moisture.—Dietert's Moisture Teller is used by the author, as he believes it to be more accurate and quicker than other types of moisture meter he has tried, although it is, strictly speaking, not portable.

Sieve Test.—There is little new in this line. and it is still difficult to get agreement between different workers. In any case, however, clay should first be washed out.

Flowability.—There is as yet no standard method in America. Dr. Ries of Cornell University in a recent Report emphasised the necessity for study of this property. The method used for this Paper is to make a 2¼-in. by 1⅛-in. test-piece of the same density as the A.F.A. test-piece by single compression, *i.e.*, filling the tube and squeezing it in one direction only. This test-piece is then tested, top and bottom, for hardness (skin hardness), and the bottom hardness expressed as a percentage of the top hardness. Thus, if the top and bottom were equal the flowability would be 100 per cent. A distinct relation is shown between this flowability test figure and the deformation test. This is brought forward for consideration of the Institute.

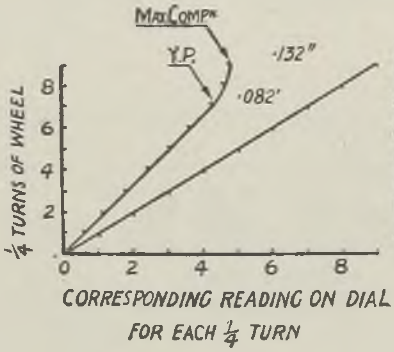


Fig. 5.—Deformation Graph for Oil Sand.

Mould Hardness and Ramming Density.—The Dietert skin hardness tester measures an impression made in the sand in thousandths of an inch, whilst the penetration tester measures the degree of ramming more faithfully than the other, the penetration being reported in millimetres.

Tensile and Transverse Tests.—These are not much used as they do not seem to have added to knowledge of sands. They are not required as an addition to the compression test.

Deformation, Yield Point and Plasticity.—The deformation and yield point test was put forward in the Birmingham Paper, and the method was described there. Although the B.C.I.R.A. machine is changed to a tension balance, the method of working remains the same.

Deformation

Deformation has been said to be that property which plays an important part in the stripping of moulds where inaccuracies of draft are present. It also prevents "drops" as the moulding box distorts in lifting. The deformation gives flexibility to sand on parting the mould, to take up inaccuracy of the mould at the parting, and also in being able to deform sufficiently to receive considerable core print pressure without failure. These will be readily endorsed by experienced operatives. Moreover, deformation plays an unfavourable part in that it allows molten metal to swell the mould. It also has the tendency to open up the mould at the parting during filling.

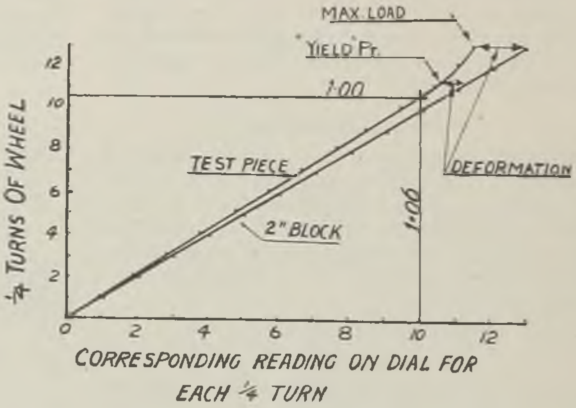


Fig. 6.—Deformation Graph for Green Sand.

This requires some qualification as sand in the mould is usually reinforced and this will offset deformation to some extent, whereas A.F.A. test-pieces during compression are not reinforced. To illustrate this a green-sand test-piece was tested for deformation and compression strength, and it was found to have a deformation of 53 thousandths when loaded with a maximum of 27 lbs.

Another test-piece was left in the ramming apparatus and loaded with a further 50 lbs., *i.e.*, 50 lbs. plus the weight of the rod and rammer. This additional load on the test-piece, in the tube only, produced a deformation of 2 thousandths of an inch, which, strangely enough, disappeared on removing the load as though the test-piece had a minute amount of elasticity. This may confirm the view expressed by Pearce in the discussion on the Paper given in Birmingham.

In moulding, it is seldom that the sand under pressure would be so well supported as this but much more seldom would be the case of sand loaded by liquid metal only on the end and entirely unsupported on the sides. This experiment serves, however, to illustrate the difference which may exist between test and mould conditions, and this applies to all sand testing. Swelling in green-sand moulds is encouraged by lack of ramming, and the degree of ramming is quite separate from considerations of plasticity or deformation testing.

Assessing Moulding Quality of Sands

The green compression strength test has on close study appeared to be unsatisfactory as the figure obtained could be misleading. For example, a dry powdery sand could give a good compression strength but be unfit for moulding, whereas certain strongly-bonded plastic sands give a low compression strength and at the same time are ideal for moulding and patching. The measurement of deformation during fracture has been introduced in America as a measure of this plasticity and, when considered together, the maximum compression strength and deformation give a clear idea of the moulding quality of the sand.

This is analogous to the tensile and elongation measurement in metal testing. Copper and cast iron may have nearly the same tensile strength and without the elongation figures would give an impression of similarity which does not exist. The deformation test is therefore highly desirable and none the less so because it may appear difficult to carry out.

The yield point was also measured and this was claimed in America to be very important as the load at which swelling occurred in green sand. This again is analogous to the elastic limit in metal testing, or at least is thought to be so, but as will be shown later, no elasticity exists in sand under compression *testing.* (This is not intended to contradict the previous statement.) The example (Fig. 2) taken from Dietert's Paper shows the graphs curving steadily from zero and the marking of the exact yield point must be treated with reserve for the time being.

The micrometer fitted to the B.C.I.R.A. type of compression frame was first constructed about 6 years ago to measure moisture by deformation, and when the frame was redesigned by the B.C.I.R.A. the deformation test measurement was revived. The deformation and yield-point test were suggested as a normal procedure for the consideration of the committee, and they evidently gave the matter their attention, comparing the results obtained by the suggested method on the B.C.I.R.A. apparatus and apparatus of American manufacture or design. Many or all of the workers who tried the measurement of deformation gave it up or at least shelved the matter indefinitely.

The author is informed by Mr. Parkes, of the B.C.I.R.A., that four laboratories, using different machines, returned figures on the same two sands as follows:—

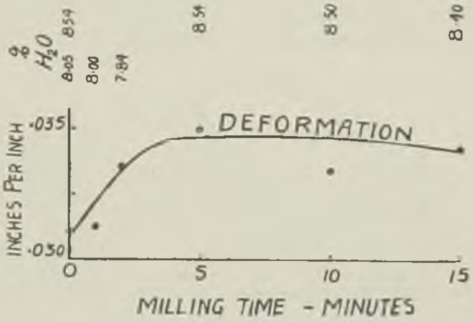


FIG. 7.—EFFECT OF MILLING TIME ON DEFORMATION.

1st Laboratory	0.034	0.056
2nd ,,	0.027	0.034
3rd ,,	0.140	0.100
4th ,,	0.040	0.046

With figures so divergent as these, the general recommendation of the test is, of course, impossible in its present state. Nevertheless, the test was thought to be so important as to justify further study, and the following work was carried out to find the possible causes of these differences and to eliminate the errors by improving the technique.

In order to understand the manner in which the deformation takes place under varying conditions, it was thought desirable to get some continuous measurement of this deformation during the compression test, and as at one time it was thought that this method might be applicable to general testing, considerable trouble was taken to simplify the method of operation. Several methods were tried, but the simplest form is illustrated in Fig. 3.

In order to get the deformation, two readings are required simultaneously, and as this is rather difficult, if not impossible, one was made by sound, leaving the operator free to keep his eyes steadily on the other.

A spring was fixed on the top of the frame, and the hand wheel was nicked at each quarter turn equal to 31 thousandths vertical movement. The usual pointer on the spring balance was removed and one carrying a suitable needle inserted in its place. A card, cut to the shape of the brass dial, was slipped behind the pointer. Then, using a 2-in. block as the test-piece, the hand wheel was turned steadily for the purpose of depressing the needle at every click, *i.e.*, every quarter turn. This gave the set of points in which the travel of the hand wheel was reproduced on the card shown in Fig. 4. . The same procedure, using the sand test-piece, gave a set of points lagging behind by the actual amount of deformation. Intervals of a quarter-turn of the hand wheel were found to be convenient, but smaller divisions could have been selected. The zero might come between two quarter-turns, this causing a slight deformation reading at the beginning which really does not exist, and so the wheel was turned till the zero came after the first quarter-turn position.

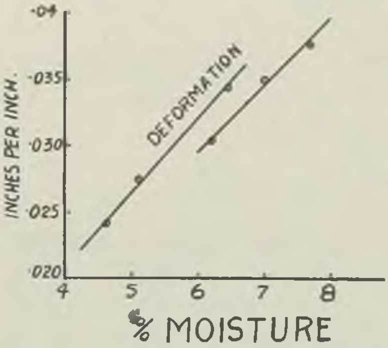


Fig. 8.—Variation of Deformation With Moisture in Rock Sand.

The maximum compression always occurs a little after the last point marked, so that the graph does not give the exact figure. It is, however, not very far away and the graph itself gives all the information required. If a loose pointer be used, of course, the end point can be marked quite easily. The rate of loading is easily kept uniform throughout the test and from one test to another.

Plotting the points for the sand test-piece and the 2-in. wood block on the same paper, the deformation graph is seen to start deviating from the lowest possible loads in all three types of sand.

In oil sand and some strongly-bonded sands like Scottish rock sand, the yield point is, as is shown in Fig. 5, considerably lower than the maximum compression strength, but in green sand (Fig. 6) it is usually equal to or very slightly below this maximum. The so-called "yield point" is actually the beginning of fracture, but strictly speaking the yield begins at zero load in all sands tested in the green state.

From this it is obvious that the yield point as a test can be neglected as it serves no useful purpose. Swelling as such would begin just above no pressure and be proportional to the load and could only be offset by the degree of ramming and suitable reinforcement. Several methods of interpreting the graphs were tried, as shown in Fig. 6.

(*A*) *Deformation at Yield Point.*—This was got by drawing the straight line through the points from zero and noting the point at which the graph left the straight line. This was expressed in thousandths of an inch deformation Another method was to express the yield point and maximum compression strength in lbs. per sq. in. and take the ratio of the difference between these to the maximum compression as the degree of plasticity.

i.e., $\frac{\text{M.S.} - \text{Y.P.}}{\text{M.S.}} = \text{degree of plasticity.}$

(*B*) *Deformation at the Maximum Compression Strength.*—The yield point seemed more accurate than the maximum compression strength owing to the uncertain end point.

(*C*) *Deformation from the Gradient of the Graph.*—This gave a simple ratio of, for example, 1.06 where no deformation would read 1.00. This graphic method was tried out extensively on the effect of moisture, ramming, bentonite and Colbond additions, and grain size mixing, but was found unsatisfactory when carried out in single tests. As a routine testing method, it seems too long and its lack of success seems due to the necessity for duplicating. This duplicating is essential in all sand testing, but the plotting of numerous graphs does not make the test very attractive.

However, it does show clearly that the deformation is always proportional up to the yield point, and for all practical purposes the maximum load is quite suitable for the measurement of deformation. This method has been described to give a clear idea of the way in which deformation occurs, and at the same time the record of the method may save someone else raising the same proposition later on It was therefore decided to return to the method recommended in previous Papers and remove any possible errors.

Manipulative Difficulties

The first fact which becomes painfully obvious to anyone trying to measure deformation is that one thousandth of an inch is a very short distance, and this is more particularly obvious when measuring pieces of rammed sand. The sand test-piece and wood block are always considerably different in length, and must be measured each time a test is done. A loose pointer was fitted to the balance, and both the pointers ground to a fine point to facilitate accurate reading, as the smallest division on the brass dial is equal to 4 ozs., which in turn is equal to four thousandths of an inch in the length of the test-piece.

In order to read the length of a test-piece accurately, the reading should be taken with a load of 1 lb. to make sure that all the backlash is taken up. The test-piece must be quite smooth and square on the ends, and this requires good accurate dimensions in the test-piece mould, stripping posts, etc. There should be no loose particles of sand on the ends, as these will cause differences in length of about ten thousandths of an inch.

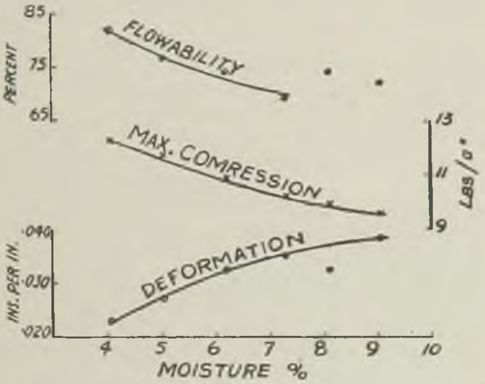


FIG. 9.—EFFECT OF MOISTURE ON FLOWABILITY, MAXIMUM STRENGTH AND DEFORMATION, WHEN USING THE A.F.A. TESTING METHOD.

The rate of loading in this method is inclined to be faster than the card plotting method, and it might be better to recommend a definite rate of loading for the guidance of users of the apparatus—for example, 2.5 lbs. per sec. using a 56-lb. balance.

The measurement of the A.F.A. test-piece is of course, essential, because even with the greatest care and under the best conditions considerable variation in length is encountered. For example, in test-pieces made one after the other from the same sand, the following differences in micrometer readings were recorded:—

Sand No. 1 ..	116	107	122	118
Difference ..	9	0	15	11
Sand No. 2 ..	107	105	85	100
Difference ..	22	20	0	15

In the first example the readings showed a maximum difference of 15 thousandths in the duplicates, and in the second example a maximum difference of 22 thousandths of an inch

In the index of ramming method using the A.F.A. test-piece made by double compression, where the test-pieces are made a definite length. the accuracy of duplicates is much better. The following records the differences in micrometer readings of two samples, A and B:—

Sand A ..	101	99½	101	102
Difference ..	1½	0	1½	2½
Sand B	100½	98½	97½	100
Difference ..	3	1	0	2½

Accuracy of Duplicates

In the measurement of the wood block, the readings taken one after the other (108, 108, 108, 109, 107.5) were obtained, which means that the accuracy of measurement of fixed distances by this apparatus is very good indeed. The following figures were reported using repeat tests by two operators, X and Y.

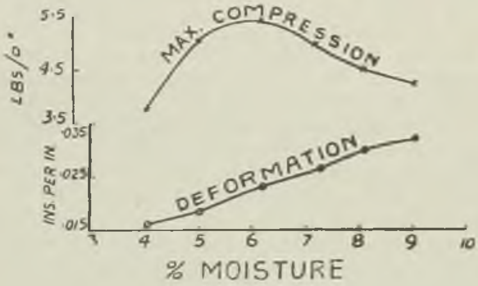


FIG. 10.—EFFECT OF MOISTURE ON DEFORMATION AND MAXIMUM STRENGTH TESTED AT INDEX OF RAMMING 13.

X's figures				
Max. compression, lbs. per sq. in.	25⅜	25⅝	26	25⅞
Deformation (thous.)	49	53	50	49
Y's figures				
Max. compression ,, ,,	23	23		
Deformation (thous.)	52	51		

Thus, the agreement between operators is very good, and the duplicates for one operator are also satisfactory. It is also evident that the use of four readings per test will produce a good average. This is quite usual in sand testing, and where one of the duplicates is obviously out, it can be neglected as is the usual practice. The readings may be considerably improved after a day's practice, *e.g.*, 62½, 60½, 60½, deformation on 2 in. in thousandths.

This means reading to the half thousandth, which may be derided but which is not so far-fetched as it sounds, because the divisions on the micrometer scale are equal to about ⅛ in. and are easily subdivided.

Most of the work done for this Paper on deformation has been confined to the actual details of the methods, its accuracy, etc., but it was thought advisable to include some examples of its application to common variables such as moisture variation, variation of clay content, etc.

Effect of Milling on Rock Sand (Two-Roller Mill)

A large quantity of Scottish rock sand was well turned-over, heaped and levelled to ensure uniformity in moisture and constant temperature; batches were taken from this for the milling experiments. The same weight was taken for each batch and the milling time was varied. After completing the milling time, a sample was taken and the batch discarded, a fresh lot being taken for the next batch. The samples were sieved and returned to the air-tight tin.

The graph (Fig. 7) shows an increase in plasticity or deformation to a maximum in about 3 minutes and indicates no further increase beyond that. The green strength continues increasing from 8.2 lbs. per sq. in. as received to 13.6 lbs. per sq. in. with 15 minutes milling. This may indicate that the lack of aeration of the samples after milling allows the excessive packing to be transmitted to the test-piece. The deformation test is probably a better method of judging the efficiency of the milling operation, and this particular example denotes very efficient mixing.

Effect of Moisture on Rock Sand

A batch of rock sand was first milled to develop the maximum plasticity at the particular moisture content, and then additions of water were made, followed by further milling. This was repeated on another batch of very low moisture content. The results as shown by Fig. 8 in each case record a sharp increase in deformation with rise in moisture content. This is easily explained as moisture would be expected to increase the plasticity of a clay-bonded sand. As shown, 1 per cent. moisture increase raises the deformation by 0.005 in. per in.

This was repeated using new batches instead of adding more water to the same batch for further milling. The results recorded in Fig. 9 using the A.F.A. improved drop weight ramming show the same rapid increase in deformation with a corresponding decrease in compression strength. It is interesting to note that the flowability has dropped as the deformation rises. This suggests that the A.F.A. test-piece rammed by drop weight alters considerably with the flowability of the sand, as stated in a previous Paper.

The tests on these samples were repeated using the double compression on the A.F.A. test-piece at index of ramming 13 (Fig. 10), and it will be observed that the deformation curve is the same but the maximum compression strength is quite different, showing an increase in strength up to 6 per cent. moisture and above that a decrease. There is a considerable difference in the weights or degree of ramming by the two methods, but the A.F.A. test, when used upon this type of sand, gives a test-piece which seems too hard for good moulding.

Effect of Colbond Additions to Green Sand

Here again a large quantity of green sand of the Erith type was mixed, heaped and levelled to make it quite uniform; then batches were taken and milled with varying quantities of Colbond from 0 to 4 per cent. Care was taken to keep the moisture the same and to mill in each case for exactly two minutes. The tests detailed in Fig. 11 were carried out on the improved A.F.A. test-piece. Over-all, the maximum compression strength is raised about 2 lbs. per sq. in., while the deformation is not decisively raised. It will be noted, however, that the flowability again follows the exact opposite trend to the deformation, as though the curves had just been reversed.

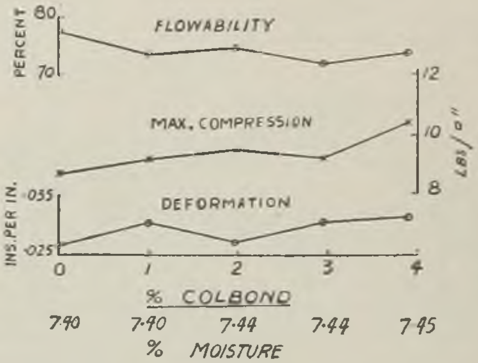


Fig. 11.—Effect of Additions of Clay to Green Sand Tested by A.F.A. Method.

Conclusions

(1) Deformation is definitely related to the percentage flowability as expressed by the methods put forward.

(2) Deformation should be used as a method of judging mixing efficiency.

(3) The deformation test is useful and a good figure for normal practice should be easily established, *e.g.*, 0.025 in. per in. for Scottish rock sand.

(4) The A.F.A. compression test is affected by flowability, and this should be taken into account when assessing the value of such variables as moisture, milling, grain size, grain distribution and bond.

West Riding of Yorkshire Branch **Paper No. 728**

Practical Application of Monolithic Linings in Cupolas

By F. OLDERSHAW (Associate Member)

In recent years monolithic cupola linings have been tried with varying degrees of success, due no doubt to the fact that it has been difficult to procure any one material which can be relied upon to stand up to the varied severe conditions which are encountered in present-day practice. Most of the failures have been due not so much to the material used as to the application and the initial treatment of the lining before putting the cupola into commission.

The choice of a cupola lining is restricted to either a brick or a rammed lining, and the merits or demerits of the former are well known to most foundrymen. The producers of firebricks have attained very good results and have recently given to the industry bricks with performances which leave nothing to be desired—except that the price in some instances is prohibitive for ordinary cupola work. However, firebricks cannot be fitted into the cupola without joints, which have always been a source of trouble, especially if the bricks have been badly set or jointed with unsuitable material. It is well known that if two or more pure substances are heated together to an elevated temperature, mutual solubility will occur. This action, taking place at the joints, lowers the average melting points of the refractories and this, in conjunction with pressure, weight and the action of the slag, considerably reduces the efficiency of the lining.

It is hard to find two cupolas where the conditions and working performances are alike, and what may be considered good results in one case may not satisfy others. The question of size, melting rate and length of blow enters largely into what can be called efficient and economical practice; but in the long run foundrymen are most concerned with production of good hot metal at the spout at a low cost per ton. The cost of repairs to the lining must also be carefully considered, and it is a fact that the money spent on patching material and bricks for repairs—apart from the time spent in bringing back the lining to its proper size—may exceed many times the original cost of the lining in the course of a working lifetime.

It was with the foregoing facts in mind and also to compare results and costs, that the possibility of using monolithic linings for lengthy blowing periods, under severe conditions, was investigated.

Cupola Details

The cupola used for the first experiment was a solid-bottomed one approximately 6 ft. 6 in. diameter inside the shell. It was stripped of the old brick lining with the exception of the outside course of bricks measuring 4½ in., which were left in their original position. A circular former 43 in. in diameter was then placed in position, allowing for an equal thickness of 13 in. of rammed lining to be installed. The material used was a proprietary monolithic lining material supplied by a well-known firm specialising in refractories, and was received ready-mixed, matured and tempered. Here it is important to emphasise that the condition of the material before ramming has a direct bearing on the ultimate life and efficiency of the lining. To be in a good condition the material, especially the clayey part, should have been allowed to weather in the open air to develop maximum plasticity. The siliceous part of the mixture should be good ganister. True ganister when mined is a very hard rock, composed of small angular grains of silica with interlocking characteristics. It is found in North Derbyshire and the Sheffield district. The rock should be ground in a mill to the size of large peas prior to mixing with the correct proportion of bonding clay, sand, etc.

The actual ramming in respect of the experiment under review was carried out by means of a pneumatic rammer, fitted with a rubber foot. The moisture content was controlled at approximately 6 per cent. and for building up a 4-in. layer was initially used, being well rammed to the utmost density. The surface of the layer was then roughened to prevent the formation of a joint, and subsequent layers were rammed in up to approximately 9 in. deep. The template should be from 12 to 18 in. deep. The process was repeated up to a height of about 6 ft. from the bottom bed of the well of the furnace. At this height—well above the melting zone—three or four courses of circular firebricks could be usefully built above the rammed lining. From this point up to the top of the charging door cast-iron blocks were used to resist the abrasive action of the descending charges.

Drying the Lining

The next procedure was that of drying out, which should be performed with the utmost care. It is essential that it should be done very slowly, and for the first two or three days a current of air should be allowed to pass through the cupola to allow the lining to set. A small fire can then be placed in the bottom of the cupola to induce a flow of warm air; but the fire should on no account be allowed to come into contact with the lining itself until it has all become thoroughly warmed up and most of the free moisture evaporated. The next step was to stand a row of whole bricks on end in a circle inside the lining, and inside this protective ring a good coke fire about 9 in. deep was lighted and fed with coke as it burned away until a temperature of between 150 and 200 deg. C. was reached. This was maintained until the lining was perfectly dry. Then, and only then, should the temperature be increased. The fire could now be made up to the melting zone and the temperature increased to about 1,200 deg. C., and then all air inlets at the bottom of the shaft—including tuyeres—made up with bricks, loam, etc., and the whole allowed to soak for as long a period as possible.

The fire should be allowed to cool down before the bottom is opened out, and, when cool, the ashes can be raked out and the cupola is now ready for the first blow. If the operations have been carried out properly, the lining will be hard, firm and free from cracks and spalls, and have the appearance of a lightly-burned firebrick.

Operating Details

The cupola in this experiment was put to work on June 25, 1936, and the weight of metal melted during the first blow was 59 tons 13 cwts. and the melting rate approximately 9 tons per hour. The effect of the blow from measurements taken was:—Well, *nil, id est,* 43 in.; tuyere level, 44 in.; 6 in. above the tuyeres, 45 in.; 12 in. above the tuyeres, 47 in.; and higher up, 43 in. Taking into consideration that this was the first blow in a new lining, the above figures can be regarded as very fair. On examination, it was found that the lining face was solid, sound, and well vitrified.

Novel Patching Procedure

After a thousand tons of metal had been melted it was found on examination after each blow that while the bricks used for patching had dissolved or melted away due to heat and slag action, the plastic patching—which was of the same composition as the lining—stood out in ridges between the remains of the bricks. It was realised that if the bricks could be dispensed with, the melting away could be reduced, and if one composite substance were used the mutual solubility would be less pronounced.

Every furnaceman knows the futility of applying thick patches of wet refractory, and it is usual to find that where this has been done the patching cracks badly on drying and steam generated behind the wet mass forms large blisters or cavities, and even before the blast is put on, the patches are often loose, when fluid slag finds its way behind, with disastrous results. The first attempts to overcome this difficulty were to ball up the plastic and patching material into solid lumps about the size of an orange. These were allowed to air-dry to avoid cracking and were then placed on the core-stove floor to dry. They were then used in place of bricks and inserted in the patching where a thick patch was required. The dry lumps absorb the excess moisture and the resultant patch does not blister or crack off; moreover all the materials used and the lining have similar characteristics.

The next step in the evolution of the method was to use an air-dried unburnt block made of the same material as the patching and lining, and for this purpose a cast-iron die was made and fitted to a machine in the form of a press. The die is filled and pressure applied, and the plastic block is pushed out of the die from the bottom by means of a foot pedal. The blocks are allowed to air-dry in a warm place and are then ready for use. They are really unburned bricks and the slots in the sides and ends are to provide a grip when fixing. They can be produced very cheaply, and compared with the price of bricks, show that a distinct saving is effected.

Overcoming a Weakness

Since these methods were adopted, further developments have taken place and are the outcome of experience gained while using monolithic linings. It has been found that the weakness of monolithic linings occurs at a point between 5 and 7 in. from the face of the lining and is due not to the quality of the material or the application, but to expansion brought about partly by structural conversion or vitrification in the first few inches, and to the fact that the unvitrified portion beyond this loses its mechanical strength due to movement caused by sudden changes in temperature.

This can be overcome by double lining, and this procedure was tried as an experiment in a cupola with a rammed lining which had been used for a considerable time. By using only a small amount of patching after each blow, the diameter of the lining was allowed to become larger to a mean extent of about 4 to 5 in. greater radially than the original 43 in. diameter. This served two purposes: (1) The unconverted part, or backing where rupture had occurred, became strong again owing to vitrification, and (2) formed a strong foundation for the new lining which was rammed inside the old one. This gave, after a few blows, a much stronger lining than had been obtained in the first instance, and much less material was used. By using this double lining method the material was vitrified from back to front, so forming a lining with the strength of firebrick but without the undesirable joints.

Improving Slag Notches

A further problem which has been investigated is the slag hole. On prolonged blows with an open slag hole it will be appreciated that with slag action there is considerable erosion at this particular place, and previous to adopting the current practice it was usual to find after a few hours' melting that the slag hole had become so large that it was necessary to stop blowing in order to carry out temporary repairs. The method of dealing with this was to make a round core-box, 8 in. in diameter, and corresponding in length to the thickness of the lining. Inside this was placed a round peg to form the actual slag hole and a form of core was made, using ramming material similar to the lining. A number of these refractory cores were made and allowed to air-dry and were then placed in the bottom of the core stove until thoroughly dry. They were inserted quite easily and would last for a number of blows with practically no further attention except for the cutting away of cold slag after each blow.

Damage to Cupola Linings

More damage is done by careless charging, when first filling up the cupola, than during the rest of the blow. In fact, very little damage, if any at all, is done to the lining above the melting zone during the blow. In front of the charging doors the author has a shute which slopes at an angle of 45 deg. In filling up, the pig-iron and scrap charges are placed on this shute and slide gently down into the cupola. When the cupola is full the charges are, of course, thrown in the usual way. If ordinary care is taken to prevent bumping the sides of the cupola with the iron, there is no reason why a rammed lining should not last a very long time, as the scouring effect of the charges passing down the cupola is only slight.

For patching no firebricks are now used in this job. The only bricks used are those needed for supporting the sleeve made of plastic material forming the slag hole. Very little patching is required in the well of the furnace, and after the slag has been chipped off only a thin layer is actually needed. Very rarely are blocks needed in this part of the furnace. More material for patching is required between the tuyeres than in any other part of the cupola; in fact, it has been noted that the melting zone has withstood two and three heavy blows before requiring attention, whereas in the neighbourhood of the tuyeres the material has burned back 3 in. or so. When this has taken place it is necessary to cut away part of the material so as to get a solid foundation and then build up again with plastic material and blocks.

Life of Linings

On the question of longevity, most foundrymen will agree that the life of a cupola lining, whether monolithic or firebrick, depends on the usage. Apart from the damage which may be done by careless charging, there are other factors which can cause equal if not more damage. To work a cupola so that the best all-round results may be obtained is to ensure that when the blast is put on, it is maintained at the correct pressure and volume throughout the whole blow. A fluctuating blast, or alternating blow—that is, stopping and starting every hour or so—does more damage to the lining than is generally realised. It has been noted that the patching material required is far less after a uniform continuous blow, say of 60 tons, than after an intermittent blow, say of 40 tons, involving a stoppage of two or more hours. This is attributed to the cooling down of the furnace and then, after a period, quickly raising the temperature to melting point. This has the effect of cracking or spalling the patching, especially in the neighbourhood of the tuyeres.

Influence of Coke Size

Another bad effect on the lining is caused by use of unsuitable coke for the bed. Only large coke should be used for this purpose—the larger the better. If this be done, the blast will flow quite easily between the interstices of the coke, thus penetrating evenly into the cupola, whereas if small coke be used, it presents an almost solid front to the blast, which is thus diverted to the sides of the furnace, causing an oxidising and cutting effect detrimental to the lining. Nearly all wagons of coke contain some "smalls," but if the latter be used for the last three or four charges, no harm will be done.

It is much better to have a few large tuyeres than several small ones, for the easier the air can enter the cupola the better. Tuyeres of small area are more readily choked. Small tuyere openings not only have the effect of increasing the velocity of the air, but divert it to the sides of the cupola. The lining of a cupola does not burn back uniformly all the way round. It will be found in nearly all cases that a cupola will require more material and patching in some places than in others, thus showing that some irregularity is taking place. One of the causes of this is irregular charging—that is, charging down one side of the furnace.

To obtain consistent results from a cupola, the following advice may be helpful:—Avoid small coke for the bed; keep the tuyeres clear; use large-size tuyeres rather than small ones; keep blast and temperature regular throughout the blow. By applying these precautions, the best possible results will be obtained from the lining.

DISCUSSION

Retaining Rings

Mr. Oldershaw's observations were amplified by tables and diagrams on the blackboard, to which a good deal of reference was made in the course of questions and discussion.

Mr. H. Forrest inquired whether Mr. Oldershaw used anything in the way of a retaining ring beneath the firebricks and the iron blocks in the higher parts of the cupola, with the idea of taking the weight from the lower monolithic lining material. He also asked for details of the limestone addition per ton and whether Mr. Oldershaw had much sand or siliceous matter in his scrap. Had he to use any different bricks from those formerly used? Did he make any provision for venting at the back of the monolithic lining near to the cupola casing?

Mr. Oldershaw replied that he did not have a specially adapted cupola for the experiment. It was done with existing cupolas, which had been in use at least 30 years. He was perhaps fortunate in having eight big cupolas with which he had some scope for experimenting. He stripped the original cupola to one course of bricks up to the casing, and this course would be supported on the separate rings at intervals, the lining supporting itself. The bricks stood partly on the monolithic lining and partly behind it. There was not a great deal of weight and they were largely self-supporting. He used the usual quantity of limestone, that is, 40 lbs. per ton.

There was the usual sand on the pig. He melted a quantity of economiser scrap. If cheap and dirty scrap were used there was the scouring to overcome, so that when using economiser material it reduced the limestone accordingly. There was no venting whatever. The lining must dry properly; it must not be accelerated. He actually left one three weeks for this purpose. It was essential that the lining be thoroughly dry before beginning to blow. He realised that it was not possible to wait a long time in all cases, but it was a matter of getting away the steam, which was essential.

Mr. Forrest asked whether the refractory was a very close material.

Mr. Oldershaw said that it was rammed to the utmost density. That was why it was allowed to stand and set. There was approximately eight tons of material per lining, depending of course upon its thickness.

Moisture Control Methods

In answer to Mr. H. Drewitt, who asked whether there was a reliable method of ascertaining when the material was thoroughly dried, Mr. Oldershaw said it could be done by boring a hole in the lining with a cleaner or sharp-pointed tool, and pushing a glass tube or rod into the hole. If not thoroughly dried there would be moisture on it when withdrawn.

A Member asked what was the overall thickness. Could the lecturer give any figures for cupolas of smaller diameter?

Mr. Oldershaw replied that it was not necessary to have the 13 in. of rammed lining that he had mentioned in his own experiment. Six inches would be suitable for smaller sizes. There must be sufficient monolithic lining to be stable. A couple of inches would be useless, and operation would remove it. The casing of the cupola would determine what could be put into it. In a general way he would consider that six inches would meet the need in many cupolas, but it must obviously have sufficient body to carry its own weight.

Conditions for Smaller Cupolas

Mr. S. W. Wise (hon. secretary) pointed out that the author's experience had included a number of cupolas, but he was dealing with quantities beyond the capacity of many members. Would he recommend monolithic linings for the medium-sized foundry?

Mr. Oldershaw pointed out that advantage would have to be taken of holiday times when the lining could be left long enough to become thoroughly dry. It must not be lost sight of that the temperature inside the furnace was at least 1,500 deg. C. in the melting zone. He allowed three weeks' drying, but it was not essential, as good results could be obtained from ten days' drying.

Control and Brick Linings

The Branch-President (Mr. Carter) suggested that if foundrymen took as much care with the brick lining as the author had with monolithic ones, similar good results would be obtained.

Mr. Oldershaw pointed out that brick linings had always been a personal bugbear. With a brick lining was associated the natural solubility between the individual bricks which had certain physical characteristics, but different chemical analyses. The result was that the lining began to perish at the joints, and the monolithic lining suggested itself. He was not decrying bricks, and agreed that good results could be obtained thereby.

Mr. G. W. Thornton asked how far above the melting zone the monolithic lining might reasonably be taken. He personally had found that good firebricks lasted as long as iron blocks. Mr. Thornton referred to the difficulty of having to patch up very early so that the cupola would be ready to blow at about 2 p.m.

In answer to **Mr. Forrest**, who expressed the fear that he, personally, had little chance of trying the monolithic lining because he could not afford to stop three or four days to dry out, **Mr. Oldershaw** said plastic blocks would be helpful, as they could be made quite thin. If they were used for patching, it would be found that before one completed the circle it would be almost sufficiently dry to allow of immediate firing.

Mr. Oldershaw was heartily thanked tor his Paper, on the motion of Mr. Squires, seconded by Mr. Thornton.

Some Jobbing Problems*

By F. G. JACKSON (Associate Member)

Shrinkage, Porosity and Segregation

The graphitising effect of silicon in cast iron is well known. Present in normal amounts in ordinary irons, it exercises a coarsening effect on the carbon structure, and at the same time assists in throwing out of solution varying amounts of carbon which would, if the silicon was lowered, be more in the combined form. In a low-carbon iron of 2.6 to 2.7 T.C, two per cent. silicon would impart good machining qualities to the iron, which would probably be unmachinable if only 1.0 per cent. was used.

Phosphorus, too, is to some extent a graphitiser. It exists in iron in a very different state from the silicon. While silicon becomes part of the ferritic structure, phosphorus forms a separate network around the crystal structure. Its low melting point causes the metal to remain in the fluid state for a much longer period, if it is present in fairly large percentages. It remains fluid after the iron has frozen, and sometimes feeds down from higher to lower sections and causes tears in some castings, especially in the bores. The fact that it prolongs fluid life will in itself bring about a coarser structure.

Fig. 1.—Shrinkage Cavities in Broken Turbine Casings Bought for Scrap.

On precipitation, a certain expansion takes place which helps to prevent shrinkage cavities, but which at the same time produces an open-grained metal. In low-carbon, low-phosphorus irons, quick cooling takes place and segregation, porosity and internal shrinkage are rarely seen.

External shrinkage in the form of piping is more in evidence, and this can generally be overcome by large risers or feeder heads. If a fairly large daily tonnage of low-carbon iron has to be melted, shrinkage and segregation troubles can be avoided. Otherwise trouble can be expected. Even so, it is mostly with badly designed castings that these troubles become apparent. It can be truthfully said that if a casting could be poured hot and every part of the casting could be cooled quickly and at the same time, a perfect casting would result, but that casting has yet to be made.

In black castings, the trouble will be present, but will not be discovered until the casting is broken up. Fig. 1 shows such a case where shrinkage cavities and precipitation are evident, probably due to the fact that these particular parts were the last to freeze and could not be fed from above, they themselves having fed the part of the casting below.

Trouble due to the junction of thick and thin sections on the wheel shown in Fig. 2 was overcome by employing low-carbon irons, casting hot and using substantial risers for feeding. It will probably be noticed by the practical man that this casting is rather a difficult one to run in a satisfactory manner. It can only be run from

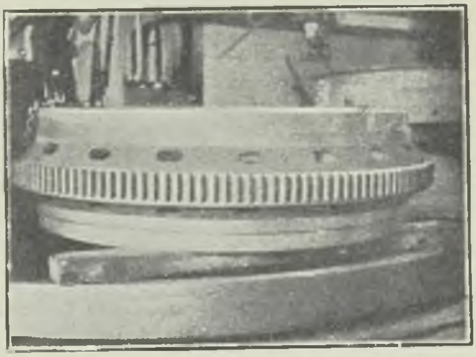


Fig. 2—A Casting Liable to Give Trouble at Junctions of Thin and Thick Sections.

---

* The Author was awarded a Diploma for this Paper.

the bottom, and this causes the dullest metal to be in the top. This, with low-carbon irons, tends to produce gas holes if cast at too low a temperature. The gases are trapped under the rapidly-freezing upper surface and the casting when machined discloses the holes under the top skin. Hence there is the necessity of casting at not less than 1,300 deg. C. It will be appreciated that, when a casting is machined, the denser metal is removed and the deeper one cuts the more open becomes the structure. In this case, in order not to leave a facing which will entrap dirt, the casting is made with a thick straight section. Fig. 3 illustrates the varying sections, whilst Fig. 2 shows how much metal is cut away. In this type of casting there is a general sort of trouble, but one which can be overcome by good iron and good feeding.

What of smaller castings in everyday work, which give local porosity or segregation? Many large castings give local troubles, but in most cases it is due to lack of uniformity in section thickness, in other cases due to the junction of many sections, and in some castings fundamentally bad design. In the last category enter spur wheel blanks having very heavy rims and bosses and spidery arms. The foundryman has to consider the thinnest section—the arms—when he is deciding the type of iron to use. He will probably use an iron in the hematite class, which will give softness, elasticity and toughness, but is this metal suitable for the rim, when heavy teeth have to be cut? He is bound to get an open-grained metal. Such a case calls for alteration of design if possible.

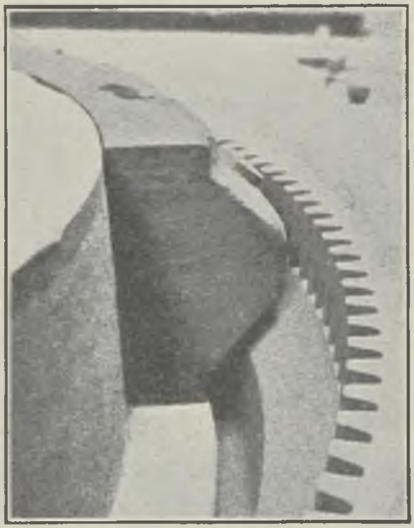


Fig. 3.—Showing the Variation in Section Thickness of the Casting shown in Fig. 2.

Austenitic Cast Iron

Two or three years ago a little experience on small pump castings in austenitic irons conveyed to the author the many remarkable properties of nickel-alloy irons, but during the past six months his foundry has tackled this material in screw pump work (Figs. 4 and 5) in a bigger way. Eight screw pumps and sixteen steam-jacketed screw-pump bearing covers, along with glands and valve covers, were required in "Ni-Resist." Crucible melting was out of the question with such a job, which meant cupola melting with heavier oxidation losses and increased impurity pick-up. Personal experience, though short, led to the belief that trouble might be expected even with new metal, and further trouble when returns had to be used, especially when the intricate nature of the work was taken into consideration. Therefore, several precautions were taken, and on the first melt a pig with a carbon content of 3.5 per cent. was used. The castings shown in Fig. 6 were quite good.

On the second melt 25 per cent. returns were used, the balance being N.C.C. pig and "iron." This iron consisted of 50 per cent. 3.5 carbon material and 50 per cent. hematite with 4.0 per cent. carbon; the latter was used to raise the carbon. It must be realised that in the first place 20 per cent. of carbon-free metal is used and the carbon has to be around 3.00 per cent. to give good machinability. Carbon pick-up in the cupola was assisted by using extra coke on the charges. To keep oxidation losses low, a soft blast pressure of 5 ozs. associated with a tuyere ratio of 1 : 4 was used. Soda ash was used on each charge in addition to limestone, to keep the slag as lively and fluid as possible. This assists materially in keeping the sulphur low.

The metal when tapped was quite hot and undoubtedly superior to the crucible-melted product in this respect. The metal was poured instantly. The feeder heads, shown in Fig. 7, were set in the cope and the runner above the cope, so that the runner drains away into the mould and saves metal. When the metal had entered the feeder heads, pouring was stopped and feeder heads filled directly from the ladle.

The opinion, both as regards this particular metal and any other, has been formed that it does not pay, if it can be avoided, to have the runners at the bottom only. Bottom running means hot metal at the bottom and cooler metal at the top. The bottom of the casting must, therefore, be left to feed itself, as it will still be liquid while the top has frozen, and the feeder heads are useless. It is well known that this metal is non-magnetic, and thus all these castings were non-magnetic.

An Experiment in Magnetism

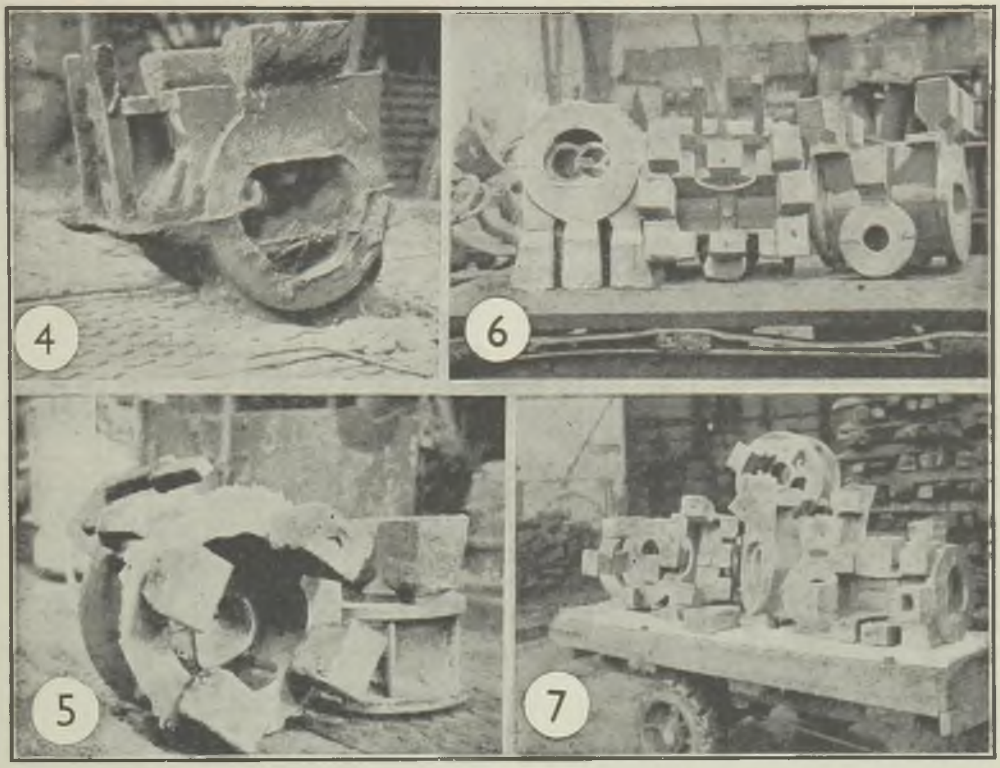
The author went over to the machine shops to see the feeder heads removed, the object being really to point out to the operator that he should be careful not to get a splinter in his eyes as the magnet would be useless on non-magnetic material. When trying the magnet on the borings it was noticed that they were slightly magnetic. While not yielding to magnetism like steel or iron, the turnings would definitely pick up. The tool was tried and found to be magnetic, and it was thought that was the answer. Later, not feeling satisfied, the author tried other tools after other operations. These tools were non-magnetic and the borings were magnetic. A test-bar was then placed on a magnetic chuck, and it could be rolled about the chuck without being attracted at all. The turnings from the test-bar were placed on and they moved to the magnets immediately.

The author has since learned that this is due to the breakdown of the molecular structure.

One other remarkable feature about the metal is the surface hardening. In the first place an effort was made to remove the feeder heads by hacksaw. Good-quality saws were ruined after being passed over half a dozen times, yet machinability was good. When the outer skin was removed it was quite easily sawn. Initially the author expected considerable trouble with the metal, and it was successfully avoided. Whether the precautions were justified or whether the metal is easy to work can be left to those best qualified to judge. Incidentally, in a jacketed cover, studs must be used to secure the core. In this case studs made of the same material, Ni-Resist, were turned out of the runners of the previous castings. Steel studs would have a very short life with certain types of acid, and the expense of making Ni-Resist studs will undoubtedly be justified by longer service.

Hydraulic Cylinders and Rams

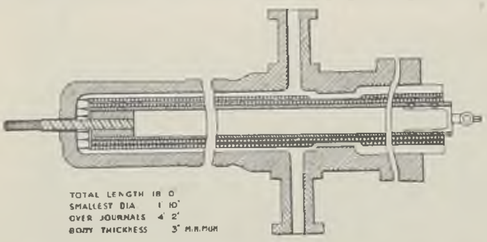
One of the first problems in hydraulic work is to decide how the cylinder or ram is to be cast—whether on the flat, banked or vertically. Many cylinders are cast on the flat or banked, but they are generally of small size. This en-

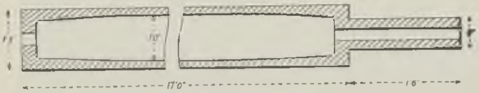


Figs. 4 and 5.—Screw Pumps in Austenitic Cast Iron, as cast. Fig. 6.—Batch of Austenitic Screw-Pump Castings. Fig. 7.—Another Batch, showing Feeder Heads.

ables them to be run sharply, and they can be cast without the employment of chaplets to hold down the core.

Large cylinders made on the flat or banked require the core to be held down in one or more places. This is not the only objection. A heavy hydraulic cylinder is a bulky casting which is never poured at white heat. Therefore, it must take a reasonably long time to pour. Metal climbing slowly up a wall between mould and core must not only be oxidising rapidly, but at the same time must be enclosing gases generated from the mould and core. The combination of these actions results in a seam of drossy metal along the top of the casting, which will probably sweat badly under pressure. A cylinder cast on a steep bank will not show these defects to the same extent.





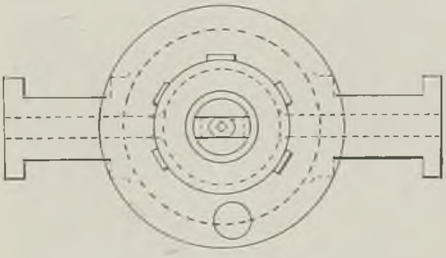


FIG. 8 (TOP).—HYDRAULIC CYLINDER OF GOOD DESIGN.

FIG. 9 (CENTRE).—LESS SATISFACTORY DESIGN.

FIG. 10 (BOTTOM).—POSITION OF RUNNERS AND RISERS.

Cylinders cast horizontally are known to have opened right along the top centre under water pressure. This sort of thing is unusual, of course, but there is no doubt that the method of casting leaves something to be desired.

Hydraulic cylinders and rams can be divided into two classes; types which can be machine-moulded and types which cannot. In the case of a cylinder with trunnions and several diameters, it would hardly pay to put a cylinder of this nature on a machine even if boxes were available. The most economical way of moulding such work is horizontally, whilst the best way of casting it is vertically.

In the production of this class of work, there are seven main considerations:—

(1) A good loam sand is advisable on the bottom of the cylinder, for a distance of 3 to 4 in. up.

(2) A good quality loam, made up of sharp sand free from lime, and ball clay and manure, should be used. It should be crisp, hard and open. The straw rope should never be wound tight in one winding. The best method is to wind with a gap between the coils and tie up. Loam should be daubled on the rope and barrel and another rope pressed down between the coils of the first rope. This gives a bridging effect, causing each rope to be entirely covered by loam. Half an inch of loam should be applied and the core dried. The barrel should always be of largest possible diameter. A small core-bar with wind after wind of straw rope is not good practice. On the last coil a double $\frac{1}{2}$ in. coating of loam is required.

On very long heavy cylinders, a few irons, $2\frac{1}{2}$ ft. long, placed 3 in. apart at the bottom of the cylinder and wired in position, on the last layer of loam previous to the finishing coat, will be effective in preventing any swelling or distortion of the core. On this type of cylinder only $\frac{3}{8}$ in. clearance is given between ram and cylinder wall. Any scab or swell has to be machined off. This means on a cylinder of this length, a very long boring bar, and it is both a costly and tedious job.

(3) Suitable design, meaning uniformity of section, without too many heavy pads and ribs, contributes to the production of good-quality work. Fig. 8 shows a cylinder of good design, illustrating the design of core bar and method of winding the core. Prints for the trunnion cores are in the main core to eliminate a feather edge on the inside. Fig. 9 shows a ram of awkward design. The section thickness is good, but the foundry has not been considered. Casting risks are increased by the very small holes allowed at each end. A better and completely safe job is to make the long narrow neck a separate casting, and screw and pin in position afterwards. This allows the full diameter of the core to come through the casting and suitable head metal can be added.

(4) The runners should always be nearer the mould than the core (Fig. 10), and the mould should be absolutely perpendicular, so that runners will not foul the core or mould. Incidentally, when considering runners, it is as well to err on the right side, keeping the runner

choked off and releasing the chokes, if metal is on the dull side. Prints can always be juggled with to allow the runners to be filed out of the core prints. This is always the cheapest and cleanest method.

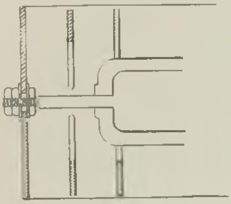


FIG. 11.—METHOD OF ANCHORING CORE FIRMLY.

(5) Cores may be anchored with the least trouble and with the maximum of safety by having a screwed journal and a lock nut above and below the bottom bar of the box. This is shown in Fig. 11.

(6) Many hints have been published as to how much head is required on hydraulic cylinders, but experience teaches far more than books, and it pays to be generous with heads. The practical man knows that they perform three main functions—cleaning, inducing pressure and lifting up the shrinkage patches. The author's notions are illustrated in Fig. 12.

(7) The author has always maintained that immense latitude is allowed with regard to metal. Many years ago foundrymen used to rely upon hematite. If a casting was in any way different or intricate, hematite was used. It has been a personal practice to eliminate hematites from pressure work, unless part of the charge was steel, when, of course, the hematite with its 4.0 per cent. carbon loses its identity, as hematite, and becomes low-carbon iron. Low-carbon iron with its close structure is ideal for pressure work.

For cylinders, a casting temperature of about 1,220 to 1,240 deg. C. and for rams from 1,250 to 1,280 deg. has been found to be suitable. Rams can be produced quite clean and free from gas holes at this temperature.

Sometimes lack of head room and crane facilities causes difficulty in upending cylinder and ram moulds and boxes. On a long cylinder, if four chains are used, and the bottom handles are slung at the top and the top handles at the bottom, the box will pick up at 45 deg. and can be laid on a bank in the pit and turned up quite easily. When turned up, the box should be well propped or it may topple during casting.

Hydraulic Brake Cylinders

With regard to problems where design cannot be altered and where the troubles are local, much good work can be done by external densening. In the first place, it is necessary to appreciate one inevitable action in a casting in which thick and thin sections join, or a number of sections meet. The thin sections, freezing first, draw metal from the still liquid thick sections and thus feed themselves. If the design be such that a feeding rod cannot be applied, shrinkage ensues. The denseners have, therefore, the action of equalising the freezing times of thick and thin sections. Fig. 13 shows a twin steam-jacketed, hydraulic-brake cylinder. The core for this casting is shown in Fig. 14. The casting thickness is $\frac{5}{8}$ in. round the bores and $\frac{5}{8}$ in. round the steam jacket, while under and over the ports there is 3 in. of metal. There are many heavy pads on the cylinder, which aggravate the trouble.

FIG. 12.—LOAM PATTERN OF HYDRAULIC CYLINDER WITH TRUNNIONS, BEING TRIED IN BOX. TRUNNIONS ARE HELD IN POSITION BY STRETCHER. NOTE DEPTH OF HEAD.

In the first place, it is necessary to get the gases away from the jacket and four ports as quickly as possible, and to facilitate this, the

FIG. 13.—TWIN STEAM-JACKETED HYDRAULIC BRAKE CYLINDER.

job has to be cast slowly. Casting slowly will produce bad leakage around the studs, if low carbon iron be used. Therefore, one must use an iron of greater fluidity, obtained by increasing the carbon and silicon, for increasing the phosphorus is objectionable. While the mixture is quite good around the bores and jacket, it is open grained above and below the port cores. Using feeding heads caused the open grain to be more pronounced; therefore, every heavy section was densened, including the tops and bottoms of all four bores, and additionally a small densener was used on each of the heavy lugs, as is shown in Fig. 15.

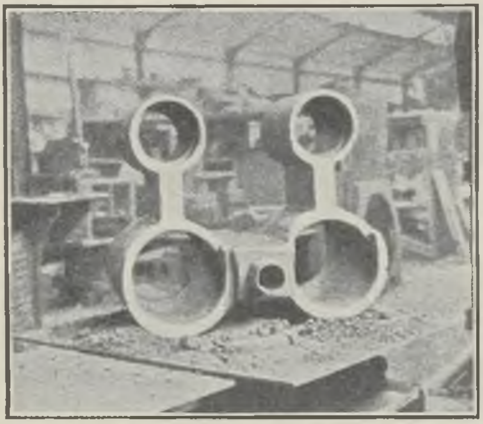


FIG. 14.—TWIN STEAM-JACKETED HYDRAULIC BRAKE CYLINDER CORE.

Rotary and Screw Pump Castings

In a simple steam-jacketed rotary pump, the thin jacket joins the heavy bore, and porosity results at the junction. A densener placed on the top surface of the bore, where the jacket joins one of the ports (Figs. 16 and 17), equalises freezing rates and produces a sound casting.

Fig. 18 shows an example of a screw pump in which a number of sections meet behind the valve face. In the centre of the valve face is a thick bar of metal, which aggravates the trouble. Only in this one section, underneath the valve face, does any trouble arise, and Fig. 19 shows how and where the denseners were applied.

Fig. 20 shows a cone capable of giving rise to much trouble. In this instance the cone pattern was solid, and when the groove was cut, porous metal was revealed. Even when cast with cores, this cone is not too satisfactory, because of the heavy body of metal in the interior. Iron cores were used on this casting and gave really splendid results. The hard bright groove is easily seen in Fig. 21.

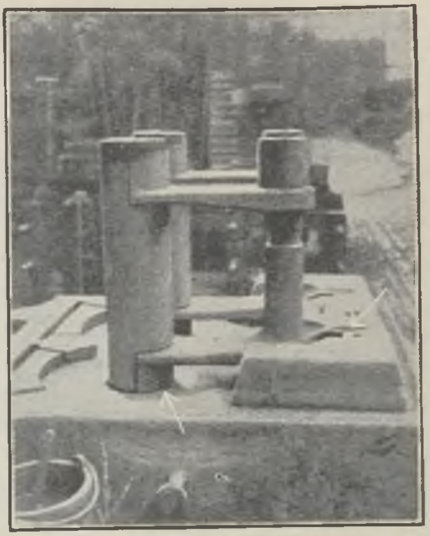
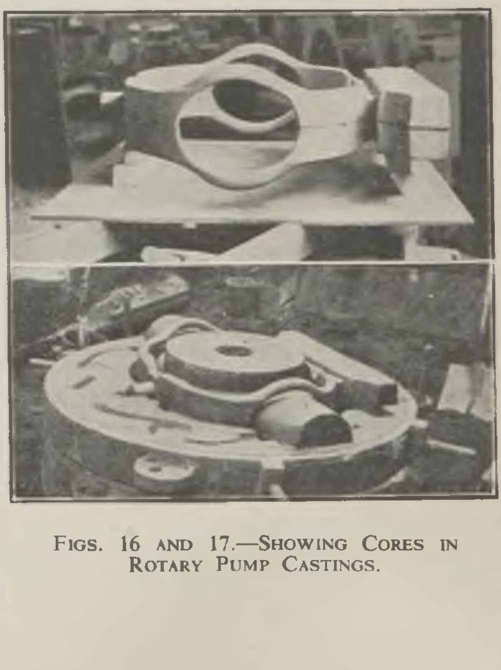


FIG. 15.—SHOWING THE DENSENERS USED FOR MAKING THE CASTING ILLUSTRATED IN FIG. 13. NOTE DENSENERS UNDER MAIN BORES AND ON LUGS.

Sometimes, in pressure work, small intricate castings can give rise to trouble, and Fig. 22 is a typical case where the junction of many sections again resulted in a porous patch and trouble was experienced in the fitting shop. The use of an iron core cured the leaking.



FIGS. 16 AND 17.—SHOWING CORES IN ROTARY PUMP CASTINGS.

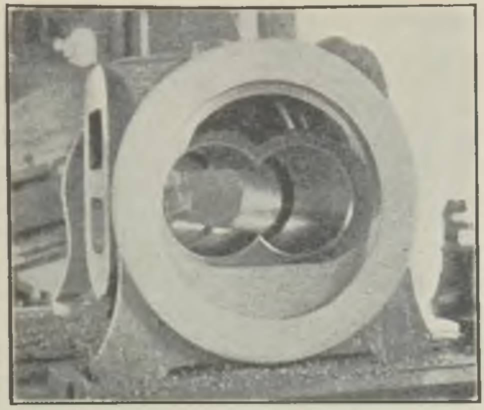


FIG. 18.—SCREW PUMP CASTING.

It is not suggested that densening is a cure for all foundry ills. Neither is it a simple matter of applying a piece of iron to a casting and producing a satisfactory result. A definite technique has to be developed. On dry-sand work, the densener can be rammed in position. When it comes out of the stove it will probably be rusty. Thus it is necessary to clean off the rust, and coat the surface with oil and blacking.

For use in green-sand work prints should be used, with denseners of definite shape. The denseners should be dried, coated and put in the mould and cast as soon as possible, that is before steam condenses on the densener. Probably the most important point of all is not to run the casting directly on the densener, or a burning on action will take place.

This densening process can be applied to the bottoms of heavy bosses, on brake wheels, couplings, pump covers and a large number of other castings. Prolonged feeding times can be saved and the foreman need not rely on feeding to the same extent. That the value of densening is

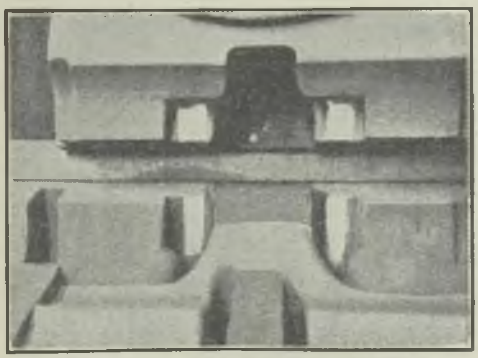


FIG. 19.—METHOD OF APPLYING DENSENERS IN THE CASTING SHOWN IN FIG. 18.

FIG. 20.—A CONE CASTING LIABLE TO CAUSE TROUBLES.

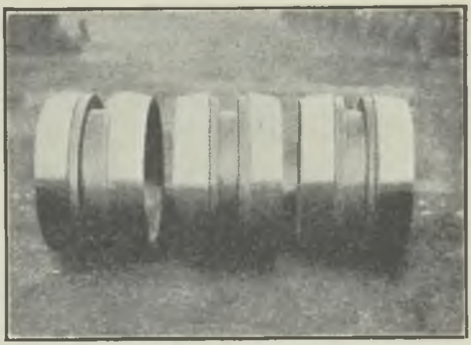


FIG. 21.—FINISHED CONE CASTINGS SHOWING GROOVES.

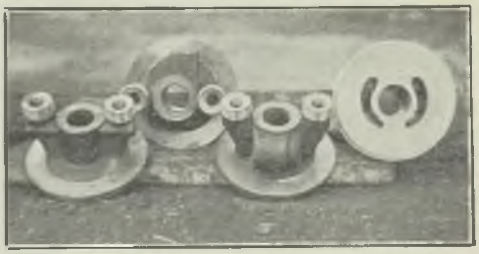


FIG. 22.—LIGHT CASTINGS WHICH ARE CAPABLE OF CAUSING TROUBLE IN THE FOUNDRY.

appreciated in America is shown by Fig. 23, taken from "The Foundry." It shows a wheel which has been heavily densened on the rim to counteract shrinkage and porosity. If the methods are justified by results, which are the main object, why not indulge in them? After all, the founder is only taking advantage of elements in the iron which lend themselves so readily in densening, and is not production from densened moulds similar to chilled work? The only difference is in the iron itself.

Small Rolls

Reference to chilling brings up another problem to the foundryman. To the experienced chilled-roll founder, with air furnaces at his disposal, the ordinary little rolls would be treated with contempt. In the small foundry, and with cupola-melted metal, much trouble can be encountered with these small rolls, especially when they have to be cast together with everyday work. Before and behind the chill iron charges are irons of entirely different structure, and extreme precautions have to be taken to ensure the correct tapping of the charges. One difficulty with the brake chills is that the inside has to be perfectly machinable, and the outside, of course, must be diamond-hard.

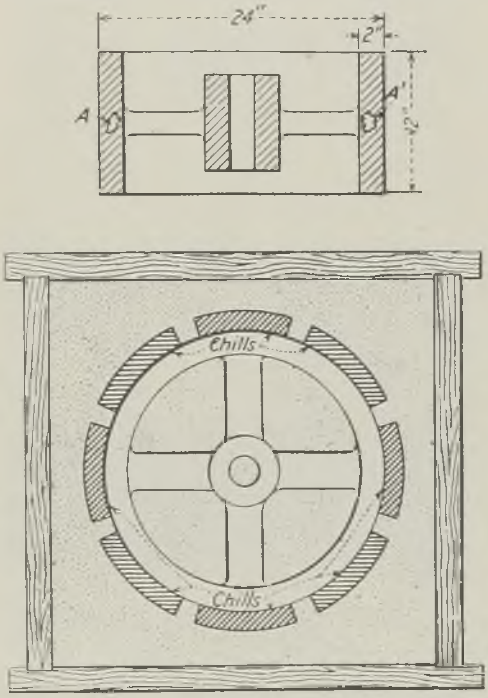


Fig. 23.—Losses from Shrink Holes in Gear Castings can be Greatly Reduced by the Use of Chills, as shown in the Lower Drawing. [From "The Foundry."]

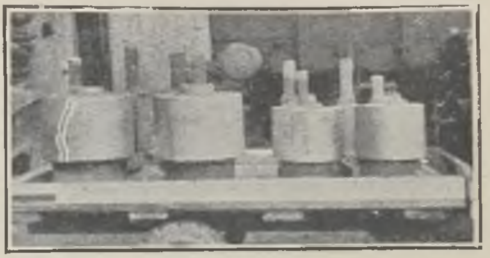


Fig. 24.—Small Brake Chill Castings.

During one cast, illustrated in Fig. 24, a peculiar result was achieved which could not be understood at the time. The four chills were poured from the same ladle of metal. The first, third and fourth were sound, but the second shown in Fig. 25 cracked. Chilled-roll makers would probably have known instantly the cause. It was afterwards found that the chill block was very much hotter in the case of the cracked chill, due to the fact that it had been loaded in a higher position in the stove. This was tried again later, and the same cracked casting resulted. This, it was reasoned, was due to the fact that the hot chill block would remain in contact with the casting for a much longer period and a more severe chilling action would result. On the other hand, the cooler blocks would expand away from the casting much

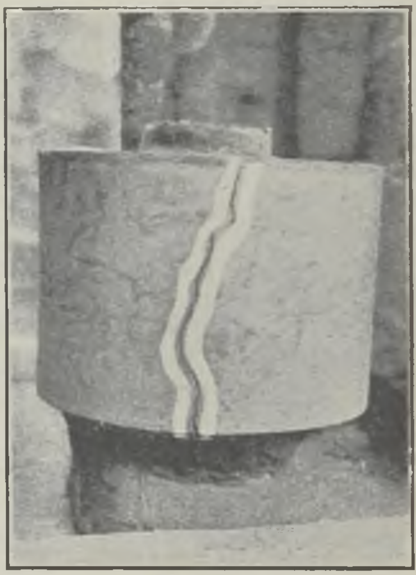
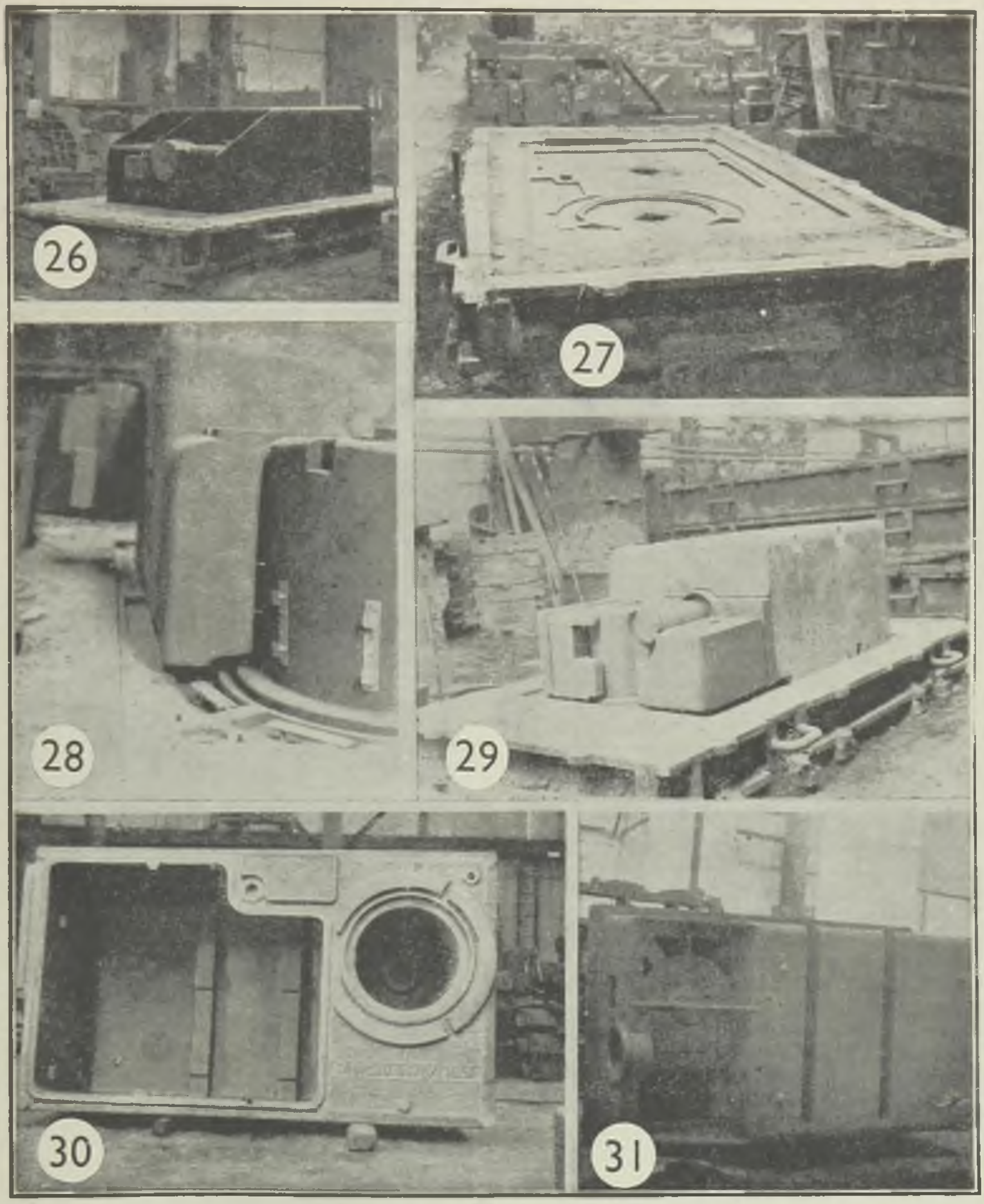


Fig. 25.—Showing a Cracked Casting Difficult to Diagnose.

earlier, and give a less deep chill but a sound casting.

Capstan Boxes

A capstan box with worm box cast on is an interesting type of casting. The general thickness is $\frac{9}{16}$ in.; the size is 7 ft. 6 in. by 4 ft. by 3 ft. 2 in. deep at the deep end, whilst the shallow end is 1 ft. 6 in. deep. At that end are two prints. The pattern for this was freshly made, but before the job was started in the foundry an order was received for a casting



Figs. 26 to 31.—Stages in the Manufacture of Capstan Boxes.

exactly like this one, but 4 in. shallower, and the same pattern had to be used.

Now this is a problem which is difficult to surmount if it is the first time it has arisen in a casting of this nature. Many suggestions were made and rejected before the correct method was found. The final methods of manufacture are illustrated in Figs. 26 to 31.

The first thing to do is to find the thickness of the lower middle part. This was 12 in.; therefore, a line was drawn 12 in. above the bottom joint. The prints were sawn in two, 4 in. above this line, and the lower half dropped 4 in. This left a 4 in. gap, the bottom of the gap being level with the top of the lower middle part. The lower middle was gaggered and rammed up, a joint was made here and a 4-in. wooden middle part placed on and rammed up with floor sand. The upper middle part was then gaggered and rammed up, as was the top part. The top part was lifted off and then the complete middle part. The upper middle was lifted off, the wooden frame removed, and the upper middle part placed on the lower, and the joint dressed off. The prints then formed a whole again and the mould was 4 in. shallower.

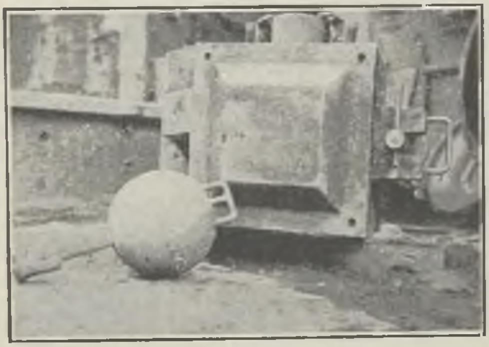


Fig. 32.—Casting Made in the Metal Mould (shown closed in background).

The core boxes were reduced by putting 4-in. blocks in the bottom.

Iron Moulds

Some time ago a Paper on "Iron Moulds" dealt with the production of air turbine rotors in iron moulds. The rotor was cylindrical in shape, with a fairly large hole through the centre. No top part was used, and a cast-iron mould formed the outside and a high-carbon steel mandril was used for the core.

The method of casting was to allow the metal to cool to a certain temperature and then pour directly and as quickly as possible into the mould. When set, the iron mould was tipped on its trunnions and the casting allowed to fall out. The steel centre was knocked out.

The value of this method as a labour-saver can easily be appreciated; moreover, the fact that cooling is greatly accelerated and a hard dense structure produced, means that inferior irons can be used and still be as strong as high-quality iron cast in sand. Another important factor was that rod-feeding was eliminated. The author of the Paper claimed for this method a higher percentage of good castings.

This idea is fundamentally an extension of the densening system. Instead of local densening there is a general densening. Being impressed by the possibilities of the system, the author sought for any job lending itself to production in iron moulds. There was one job, shown in Figs. 32 and 33, free from machining, but which had to fall within ± 3 lbs., the gross weight being 84 lbs.; therefore, it had to be within 81 and 87 lbs. The diameter was important, having to pass through a ring gauge 8.6 in. dia. The most important feature was a steel eye which could actually be fitted in four different positions. The depth of the eye portion outside the casting had to be to gauge. These jobs with 300 to 400 off were a nuisance. If rammed soft, they were too big; then the eye would be put in the print the wrong way. The depth of the eye in the sand print would vary. The worst feature was that the plummets had to be fed, and even if cast with dull iron, kept open quite a while. The iron mould system was therefore applied. The trouble was to decide how to run it; it would not answer to run on iron, as the runner would freeze and not allow the casting to be fed, either with or without a rod. Therefore, a small core was fitted in the top.

Fig. 33.—Metal Mould (Open) and Two Castings Produced Therefrom.

In the first place, the bushes or runner basins were weighted down, but as this was rather cumbersome, two bolts were fitted with springs and clips. Initially a coating of plumbago and oil was used, but it caused gasholes at the top of the castings. Blacking applied by spray gun was next tried, and found to be highly satisfactory. A very interesting thing occurring on these iron moulds in that after the mould has been cast about 1½ min., the metal begins to flow up the runner and freeze until the top of the runner is almost hemispherical. This is probably due to two causes: the rapid contraction of the outside of the casting forcing the metal up through the runner, and the expansion of the carbon when separating out as graphite on reaching a point between liquid and solid.

In one experiment, when the metal had commenced to come through the runner, a small weight was put on it, which chilled it. After about one minute there was a slight explosion, and the runner bush and head were lifted about ⅛ in. and the metal spurted out underneath the bush.

The dust is brushed out; the mould sprayed, closed and cottered The runner core is put in position with the bush on top and the clips are fitted, when the mould is ready for pouring.

As in the other case, the metal is poured as fast as possible at about 1,200 deg. C. The time between pouring and knocking out is approximately five minutes, if the metal has an analysis of C 3.4, Si 1.8 to 2.0 and P 0.60 per cent. With lower carbon, phosphorus and silicon, quicker cooling takes place. This particular mould has had over 1,300 castings poured in it and they were not fed after the first few times. This mould was still in use together with other iron moulds of the same type.

One of the most important points is the accuracy of the eye. This cannot now be fitted wrongly and is always in exactly the same place. The cores do not cost more than a penny. Closing can be done by a labourer or apprentice, and the cost is negligible.

Columns

In Fig. 34 is shown a water column or water crane, used on the railways for filling engine boilers. It is interesting because of its length, which attains 22 ft. The methods of casting, drying and securing the core all present features of interest. Fig. 34 shows a 15 ft. column alongside a 22 ft. one. The large base, 4 ft. by 3 ft. 6 in., is noteworthy. Fig. 35 shows one of the columns in casting position on a bank. This is done to bring each end of the casting to a level mark. This mould was rammed up in green sand, skin dried by a modern mould-drier in 1¼ to 1½ hours, the coke consumption being under 1 cwt. The same type of core bar as illustrated in connection with hydraulic work was used on this job, only both ends were open. Only 1¼ in. of straw and loam was allowed at the small end. The core was secured by three ¾-in. steel stems, which passed through the thickness of core to rest on the core bar (see Figs. 36 and 37).

The casting was poured from the centre and also from the foot, two ladles being used. Pouring was started in the foot with very dull metal, and when the metal reached the body, pouring was commenced in the centre from the main ladle with hot metal.

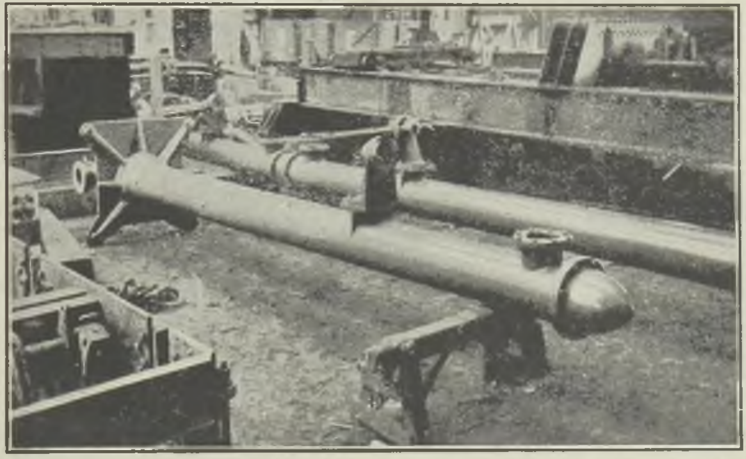


FIG. 34.—A 15-FT. COLUMN AND PART OF 22-FT. COLUMN.

DISCUSSION

Mr. R. J. Richardson asked whether trouble was experienced with the steam-jacketed pumps due to the jacket core breaking across the narrow neck over the ports, or whether there was blowing or bubbling in the mouth.

Mr. Jackson replied that on the particular type there was no such trouble, but types which had a shrouded jacket core did at times show defects. The pumps were cast hot and fairly slowly to allow the gases to escape freely. Fast pouring caused the gas to generate so quickly that pressure was set up in the vents, and the gases took the line of least resistance, breaking the cores.

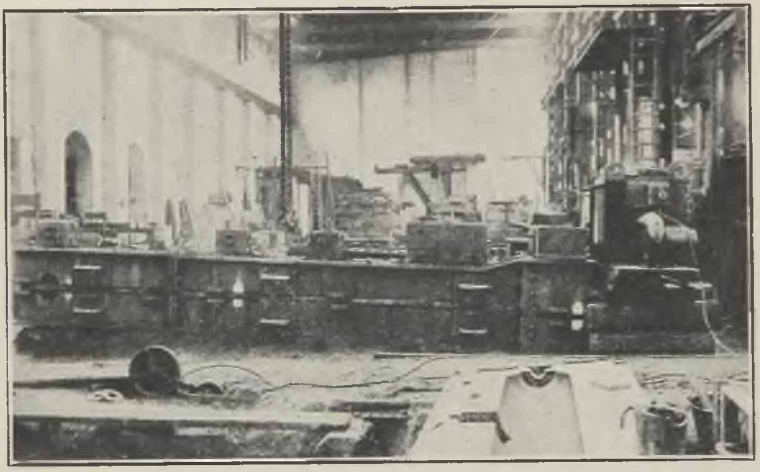


Fig. 35.—Column Mould on Bank, with Drier in Position.

Fig. 36.

Fig. 37.
Method of Securing Core.

Mr. Richardson said his foundry cast the pumps in steel at 1,650 deg. C. and at a fairly fast rate.

Ni-Resist Castings

Mr. John Williams, jun., asked whether the finish of Ni-Resist castings was inclined to be rough.

Mr. Jackson thought that there was a tendency to roughness on iron castings alloyed with fairly high percentages of nickel, probably due to the fact that the metal was inclined to drag and follow the tool. The metal was tapped and taken straight to the mould and poured; he did not think the metal could be poured too hot. Crucible-melted metal seemed to have a much shorter freezing range than that from the cupola, probably because the carbon was lower. Carbon must be kept fairly high to give good machinability and flexibility, and by using extra coke in the charges sufficient pick-up was obtained. Ni-Resist gave 1,300 lbs. on a transverse bar $\frac{7}{8}$ in. in diameter set at 12-in. centres.

Mr. Richardson asked what metal was used for the dies for receiving iron.

Mr. Jackson said he used a cold-blast iron with a silicon content of 1.4 per cent. After 50 or 60 castings had been made, there was a certain amount of crazing. Hematite was a very good iron for this class of work, and usually the blocks used for chill castings were made from it. The departure from ordinary hematite to cold-blast iron was made as an experiment, and the results seemed to be in favour of the latter. The life of a die or block of this nature seemed to depend upon its early treatment. If it was well warmed up and a good coat of blacking put on before casting started, it would certainly last longer than if the metal was poured in a cold, unprepared mould.

The Properties of Grey Cast Iron, with Special Reference to the New B.S. Specifications

DISCUSSION ON SPECIAL REPORT No. 1.

The Report of the Cast-Iron Sub-Committee of the Institute of British Foundrymen on " The Properties of Grey Cast Iron," was presented for discussion to nine Branches of the Institute by various members of the Sub-Committee, and the points raised in the discussion have been summarised under the various headings given below.

Methods of Running Test-Bars

Many members sought information as to the method of running test-bars, particularly when cast independently from the casting, and stressed the importance of standardised methods. Expressions of opinion as to the best methods were invited, and five members stated that they favoured vertical running. Of these, Mr. J. E. Greenwood (Birmingham, Coventry and West Midlands Branch) and Mr. R. C. Tucker (Sheffield Branch) did not indicate whether the bars were top or bottom run, but Mr. H. Forrest (West Riding of Yorkshire Branch) advocated bottom running. Mr. H. Foster (Middlesbrough Branch) and Mr. J. Roxburgh (Sheffield Branch) preferred top running, the latter stating that the head was cut off and that the moulds were circular with three inches of sand round the test-bar. Mr. R. C. Tucker (Sheffield Branch) stated that he had carried out tests which showed that vertically-cast test-bars were superior to horizontally—or inclined—cast bars. He used split moulds turned up on end to cast.

Mr. J. E. Mercer (Middlesbrough Branch) and Mr. G. O. Stanley (Middlesbrough Branch) stated that they cast transverse bars horizontally. Mr. Mercer mentioned that he cast tensile bars vertically.

Mr. J. G. Gould (Middlesbrough Branch) stated that test-bars should be run as quickly and at as high a temperature as was possible, whilst Mr. H. Forrest (West Riding of Yorkshire Branch) asked for information on pouring temperature.

Mr. E. W. Wynn (Birmingham, Coventry and West Midlands Branch) drew attention to the influence of mould temperature and type of sand on test-bar strength and Mr. F. Whitehouse (Sheffield Branch) stated that all his test-bars were cast in green sand.

Cast-On Test-Bars

Mr. C. W. Brown (Birmingham, Coventry and West Midlands Branch) and several other speakers asked that the Sub-Committee should recommend whether test-bars should be separately cast or cast-on, while Mr. J. G. Pearce (Birmingham, Coventry and West Midlands Branch) and Mr. J. Roxburgh (Sheffield Branch) drew attention to the bad metallurgical conditions under which cast-on bars were made. These two speakers laid particular emphasis on the fact that the cooling rate of a cast-on bar was altered —with a consequent coarsening of the grain by the comparatively large mass of hot metal in the adjoining casting. Mr. Pearce added that the Admiralty was aware of this metallurgical difficulty, and in the event of an inspector not being present to ascertain that the casting and bar were of the same metal, a silicon and phosphorus determination on this casting and the bar was accepted.

Mr. Roxburgh (Sheffield Branch) and Mr. J. E. Greenwood (Birmingham Branch) both stated that their cast-on bars were cast vertically, and Mr. Roxburgh mentioned in addition that such bars were bottom run.

Do Test-Bars Represent Castings?

Mr. A. J. Shore (Birmingham Branch) emphasised the necessity of using the correct grade of metal for various types and designs of castings and thought it advisable for some such specification to be drawn up.

Dr. A. B. Everest (London Branch), Mr. J. Roxburgh (Sheffield Branch) and Mr. F. Whitehouse (Sheffield Branch) were in agreement that test-bar results as a rule bore but little relationship to the test results which could be expected from castings made of identical metal, and Mr. Roxburgh mentioned in particular that the metal for a good casting was too low in silicon to give a strong bar.

Mr. R. C. Tucker (Sheffield Branch) was of the opinion that round bars were not representative of castings.

Section of Castings Represented by Test-Bars

Mr. L. W. Bolton (Birmingham Branch) was disappointed to find that the number of bars

---

* Special Report No. 1. was circulated to members of the Institute of British Foundrymen in September 1938.

listed in the specification had been increased from three to five, but on the other hand several speakers expressed the view that even with a greater number of bar sizes, it was difficult to decide which bar was representative of a particular casting, especially where large sectional variation occurred. For instance, Mr. G. R. Shotton (Birmingham Branch) doubted the advisability of the 0.60-in. bar for a $\frac{3}{8}$-in. section, whilst Mr. J. L. Francis (East Anglian Section) enquired whether the average, maximum or minimum section of the casting should be taken as the basis for determining the appropriate bar size. Mr. G. Elston (Newcastle Branch) was pleased to learn that the number of bar sizes had been increased so that a nearer approximation to a casting's section was obtainable.

Methods of Producing Iron to Meet 786

Several speakers drew attention to the importance of exercising great care in the production of high-duty cast-iron in order to meet the specification, and in this connection Mr. Kain (East Anglian Section) emphasised the necessity of using good pig-iron and a high coke ratio.

Mr. A. S. Worcester (West Riding of Yorkshire Branch) inquired whether the use of steel or hematite with, say, Northants pig-iron for the same charge would be advocated, and whether it was practicable to obtain a No. 2 Grade without the addition of steel. The impossibility of using a local high-phosphorus iron was pointed out by Mr. J. Lucas (East Midlands Branch).

Heat-Treatment

In connection with high-duty irons, Mr. G. B. Taylor (Middlesbrough Branch) inquired if the Cast Iron Sub-Committee were prepared to make any recommendations for heat-treatment. A London Branch member also inquired whether any comparison between heat-treated bars and as cast-on bars had been made, and whether wide difference on such results were obtained.

Machining of Bars and Bar Sizes

Mr. S. E. Dawson (East Midlands Branch) stated that in his experience the 1.2-in. bar was the most consistent and that if one worked on the 1.2-in. bar and used the same metal a bigger proportion of consistent results was obtainable than in the case of the 0.875-in. or 1.6.-in. bar.

Mr. W. H. Smith (East Midlands Branch) asked whether, in the Sub-Committee's work, any of the large bars, say, 2.1-in. diameter, had been machined down to smaller bars. He further inquired whether the results obtained on such machined bars were comparable with those on the original un-machined ones, and whether it was possible, for specification calling for thick sections, to machine bars down to standard sizes

Mr. A. Logan (London Branch), dealing with the reference to the tensile requirements of the various sizes of bar, said that the decrease in strength with the increasing size of bar was a very important factor, and he asked for a reassurance that the figures were really reliable. In Table III of the Report the tensile requirements for high-duty cast iron, Grade 1, were given as 15 tons with an 0.875-in. bar, 14 tons with a 1.2-in. bar, 13 tons with a 1.6-in. bar and 12.5 tons with a 2.1-in. bar. For Grade 3 the tensile requirements for the same bars were 28, 20, 19 and 18 tons respectively. He drew the Sub-Committee's attention to the fact that the figures showed a slight difference in the rates of reduction of strength.

Chemical Analysis

Many speakers discussed the merits and demerits of including chemical analysis in the specifications, but the general opinion was that the omission of such analysis marked an important step forward, and it was generally agreed that the metallurgical structure was far more important. In the course of the discussion, however, it was mentioned that many customers ask for chemical analysis to be supplied. Mr. C. Lashly (Newcastle Branch) was of the opinion that testing, and tensile testing in particular, was useless and that a chemical analysis of the material would serve the same purpose just as efficiently.

In support of the omission of chemical analysis, Mr. R. B. Templeton (London Branch) mentioned that a specification to which he had to work, namely:—TC, 2.8 to 3.85; Si, 1.5 to 2.5; Mn, 0.5 to 1.2; S, 0.2; and P, 0.2 per cent., allowed so much latitude that he could produce fine grades of cast iron, varying in tensile strength from 16 to 27 tons. On the other hand, Mr. Chas. Cleaver (London Branch) expressed regret that the chemical analysis of the test-bars mentioned in the report had not been mentioned in the report. Mr. F. Whitehouse (Sheffield Branch) agreed that the omission of chemical analysis was a progressive step, and particularly advocated that a series of micro-structures should be prepared showing the typical structure which should be obtained with different classes of castings.

Mr. R. C. Tucker (Sheffield Branch) was also of the same opinion, but stressed the value of chemical analysis as a day-to-day check, and pointed out how customers could utilise it as a ready means of confirming the quality of the iron.

Deflection

Although he was unable to advance any data in support of his contention, Mr. J. G. Gould (Middlesbrough Branch) was of the opinion that results of deflection testing were influenced by the temperature of testing.

Mr. H. H. Shepherd (East Anglian Section) said that in his experience, even with the latest type of deflection testing machine, considerable difficulty was experienced recording the deflections accurately. He suggested that the Sub-Committee should append a note recommending a standard method of recording the value.

Mr. C. Gresty (Newcastle Branch) found deflection testing to be somewhat unsatisfactory, and suggested that to take the deflection value at a definite proportion of the load was the only satisfactory way. With regard to using a corrected test, he said that if a test-bar nominally 1.2 in. dia. was taken, one would probably register the rupture strength and not the breaking load.

Compression Strength

Mr. C. H. Kain (East Anglian Section) asked if the Sub-Committee were able to explain why, in the new specifications, a considerable increase in the tensile strength of cast iron had been shown, but the compression strength of the material had not increased proportionately. He asked for further information generally on the compression strength of cast iron, and particularly with regard to the relationship strength and the modulus of elasticity.

Mr. A. E. Peace (East Midlands Branch) said the higher compression strength of cast iron has long been recognised as one of its most important qualities, and he thought, therefore, that it was to be regretted that information had not been included to show the variation between compression strength and size of bar. He thought that the Report seemed to indicate that in heavier sections the compression strength fell away in the same way as did the tensile strength, and he drew attention to the lower curves of Fig. 1 of the report, and pointed out that a tensile strength of 15 tons was shown on the 0.875-in. bar and that in Table VII that tensile was related to 54 tons compression. It would be assumed, therefore, that such metal in a 2.1-in. dia. bar, giving 11½ tons as shown in Fig. 1, would have a compression strength of 41 tons. Whilst he had no data to support his view, he did not think the compression strength would diminish to that figure in the larger section.

Modulus of Elasticity

Discussing Table VIII of the Report showing the approximate values of modulus of elasticity for each grade of cast iron, **Mr. A. Logan (London Branch)** said that a lower order of testing than was specified was rarely required, but he pointed out that the modulus of elasticity given for Grade C was from 10 to 14 million lbs. per sq. in., and said that he had never experienced an iron with a modulus of elasticity lower than 13 million lbs. per sq. in.

Mr. A. E. Peace (East Midlands Branch), speaking with regard to the determination of the modulus of elasticity, said he appreciated that when a material had a low modulus, the necessary rigidity could only be obtained by increasing the section. He mentioned that a second method of increasing this property had been disclosed by Pearce. He assumed that the first method consisted of dividing unit deflection into unit stress at the recommended 25 per cent. of the ultimate tensile strength, but he asked to have confirmation of this point.

Mr. R. C. Tucker (Sheffield Branch) drew attention to the various methods of estimating Young's modulus of elasticity, and particularly the American method, which gave the ultimate modulus and which depended on taking the total deflection on fracture. It was possible, he said, to obtain Young's modulus by the direct examination of the tensile test-bars, and he emphasised the difference between Young's modulus in compression and in tension.

TABLE A.—*Fatigue Strength of Cast Iron and Steel.*

Material.	Tensile Strength. Tons per sq. in.	Fatigue strength. Tons per sq. in.	
		Plain.	Notched.
Mild steel*	34·3	17·2	11·4
Nickel steel	51·5	22·5	13·5
Cast iron*	15·8	8·9	8·9
Cast iron	29·6	15·7	15·7

* Cornelius and Bollenrath, "Die Giesserei," Vol. 23, No. 10.

Mr. G. Elston (Newcastle Branch) asked for an explanation of the term modulus of elasticity.

Fatigue

Mr. R. C. Tucker (Sheffield Branch) said that he had heard that grey cast iron had a high fatigue value compared with steel, but he wished to point out that this was not in fact true. Ordinary engineering iron, he said, had a fatigue value of about 0.46 of the tensile strength, and this was not very different from a structural steel which would have a higher tensile strength.

Mr. A. E. Peace (East Midlands Branch) was interested in the information concerning fatigue strength, and said that the statement that cast iron was less sensitive to grooves and notches than steel was of great importance. The wording could, he thought, be enlarged to cover, in addition to "grooves and notches," toughness of surface and expanded parts.

Presenting the data shown in Table A, Mr. Peace said it could be seen that the two cast irons showed no reduction in fatigue strength when notched, but the steels showed a loss of 25 to 40 per cent. It was interesting to note that the ratios of fatigue to tensile strength ratios for cast irons were 0.53 and 0.60, which figures were within the limits given in the Sub-Committee's report.

Mentioning that castings occasionally failed due to fatigue, Mr. C. H. Kain (East Anglian Branch) asked that the Sub-Committee should give further information on the fatigue strength of cast iron and on fatigue failure.

Impact Value

Several members asked for more information on the impact testing of cast iron, and on the value of the test.

Brinell Hardness

Mr. E. Noble (Birmingham, Coventry and East Midlands Branch) drew attention to the development on high-duty cast irons, and mentioned their resistance to wear and abrasion. He did not wish to suggest that there was any direct relationship between abrasion resistance and hardness, but he did think that the Brinell number was a help in determining the suitability of an iron where resistance to abrasion was required. In his opinion, it would have been useful had the B.S. Specification 786 indicated what hardness could be expected from the various classes of iron.

Mr. J. G. Pearce (Birmingham, Coventry and East Midlands Branch) mentioned that the Brinell hardness had been included for the first time in the B.S. Specification for cast-iron gears and gear blanks, but did not advocate its general inclusion in all specifications. There was, he said, no doubt that in that particular application the Brinell hardness number would increase with the tensile strength.

Mr. A. E. Peace (East Midlands Branch) asked that, in a general way, Brinell hardness should be related to graphite size, matrix structure and hard inclusions of phosphides and carbides, whilst Mr. W. G. Thornton (West Riding of Yorkshire) asked if any formulæ could be given relating to the Brinell hardness and the tensile and transverse strength of cast iron.

Magnetic and Electrical Properties

Mr. A. E. Peace (East Midlands Branch) thought that some mention might have been made of literature on electrical and magnetic properties of cast iron, and in particular mentioned the work of Partridge (Journal of the Iron and Steel Institute, 1925, No. 2, page 101).

Miscellaneous

Mr. G. W. Brown (Birmingham, Coventry and East Midlands Branch) said that he was of the opinion that the "test-bar system" only applied to a fairly small portion of the industry, and said that the majority of foundries were not concerned with test-bars.

Mr. C. H. Kain (East Anglian Section) drew particular attention to the high cost of producing high-duty cast iron and mentioned the special precautions which had to be taken to produce this class of iron, namely, good-quality expensive pig-iron, a high coke ratio; and more refractory sands. He also mentioned that there was increased wear on the cupola refractories and that larger feeders had to be used and that there were additional costs connected with fettling operations.

Mr. Kain also inquired why the term "modulus of rupture" had been superseded by "transverse rupture stress."

Mr. A. E. Peace (East Midlands Branch) stated that he would like to have seen mention of types of cast iron which showed resistance to corrosion and heat.

Mr. R. C. Tucker (Sheffield Branch) thought that the damping capacity of cast iron should be stressed in the report in view of the high values which were obtainable with this material, and the speaker also discussed the question of creep. He drew attention to the work which was being carried out by the National Physical Laboratory which did not cater for heat-resisting bars, and which, he thought, did not carry out the tests in the most suitable way . Cast irons were expected to withstand temperatures of 650 deg. C. and although the normal creep tests were suitable for superheated steam they were not suitable for testing furnace parts. He thought that the question should receive more attention and mentioned that he was carrying out various investigations himself.

Mr. C. Gresty (Newcastle Branch) claimed that the specification did not make satisfactory provision for the "border line" results. He wondered if, in the event of a test-bar being found to be white or chilled, and the relative casting being found not white or chilled, a second bar should be cast. He suggested that such provision be added to the specification.

Mr. S. E. Dawson (East Midlands Branch) asked what factor of safety there should be in working to the cast-iron specifications. As an example he mentioned that if a Grade A iron was made which had a tensile of just 12 tons, it might be rejected. He realised that many factors were involved and that one could make an iron of the same composition to suit a particular casting in various ways, by using different types of pig-iron or steel, or by variation of the melting practice. He thought that it was important to know whether, say, 13 or 14 tons per sq. in. tensile should be sought in order to be sure of reaching the 12 tons per sq. in. specified for Grade A iron.

Mr. C. Gresty (Newcastle Branch) commented upon the unsatisfactory position which he felt existed in connection with transverse and tensile testing, and thought it difficult to understand why such an unsatisfactory position should appear in a specification. He thought it was very much easier to meet the necessary transverse strength than it was the tensile, and he asked why the ratio between the two parts was not made constant in the specification.

CAST-IRON SUB-COMMITTEE'S REPLY TO THE DISCUSSION

The completion of the Sub-Committee's reply to the discussion has been prevented by the present war-time conditions. The Sub-Committee has, however, come to certain conclusions on the first two points raised, their reply being given below.

Methods of Running Test-Bars

The Sub-Committee recommend that independently-poured test-bars should be moulded and cast vertically. It is desirable that there should be no longitudinal joint owing to (*a*) risk of white iron dendrites running in from the flash at the joint and (*b*) risk of bars not being truly round. It is not possible to make any definite ruling as to the best position for the runner owing to the widely different characteristics of the irons to be tested, but top or bottom running should be used according to experience, and a combination of top and bottom running is not usually desirable owing to the risk of casting stresses. Centre running should be avoided. The specification stipulates that test-bars should be run in green or dry sand according to the nature of the sand used for the castings represented.

When using test-bars for routine control, conditions should be standardised as far as possible, and, subject to this, no definite rules need be laid down. The figure of 3 to 4 inches of sand round the bar, in a dry-sand mould, as given by Mr. Roxburgh, appears to be adequate.

If more than one test-bar is run in a box, it is desrable that they should be run simultaneously, with a controlled runner size so that they may fill at the same rate. This is particularly important when different-sized bars are run in the same box.

With reference to pouring temperature, the Sub-Committee agree with Mr. Gould that the bars should be run quickly and at as high a temperature as possible, but this only applies to foundries making the normal grades of cast iron. When iron is deliberately superheated in a special furnace, it is not always desirable to cast at the optimum temperature. In such cases the best pouring temperature should be ascertained and test-bars poured at that temperature under pyrometric control.

Cast-On Test-Bars

It is pointed out that Clause 5 in the specification states that cast-on test-bars "may be specified where the design of the casting and method of running permit." Thus, in cases presenting difficulties, bars may be run separately. The remarks of Mr. Pearce emphasise this point.

The Sub-Committee agree that separately-cast test-bars are desirable and more reliable, but recognise that the demands of inspectors for cast-on bars should be met where reasonably possible. Where test-bars are cast-on, particular care should be taken in placing the bars to see that they are not unduly influenced by the heat transferred from the casting, and that they are filled reasonably quickly with metal at a reasonably high temperature. Vertical running is usually desirable, but may be harmful if the bars fill very slowly in consequence.

NAME INDEX

SUBJECT INDEX