C. W. Bigg

(*President of the Institute*)

Mr. C. W. Bigg, who is Vice-Chairman and Assistant Managing Director of Messrs. Qualcast, Limited, served his apprenticeship with Messrs. Brown & Green, Limited, of Luton, and obtained experience in various light casting foundries. Eventually joining the Derwent Foundry Company, Limited, of Derby, he was placed in charge of the pattern department in 1913, and became successively foundry manager, works manager, and works director.

When the Derwent Foundry Company was reconstructed in 1928, and became Qualcast, Limited, he was appointed vice-chairman and assistant managing director.

Mr. Bigg's membership of the Institute of British Foundrymen dates from 1915, when he joined the East Midlands Branch, of which he was President in 1932.

He has been a member of the General Council since 1930, and has served the Institute on the Technical and Educational Committees and the Costing Sub-Committee.

PROCEEDINGS
OF THE . . .
INSTITUTE OF
BRITISH FOUNDRYMEN.

VOLUME XXX. 1936-1937.

Containing the Report of the Thirty-Fourth Annual Conference, held at Derby, June 8th, 9th, 10th, and 11th, 1937; also Papers and Discussions presented at Branch Meetings held during the Session 1936-1937.

Edited by T. Makemson, Secretary.

Institute of British Foundrymen.

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THE INSTITUTE OF BRITISH FOUNDRYMEN

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Oliver Stubbs. 1923.
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J. Bell, 60, St. Enoch Square, Glasgow, C.1.

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S. W. Wise, 110, Pullan Avenue, Eccleshill, Bradford, Yorks.

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F. C. Williams, Magor House (Fifth Floor), 74, Fox Street, Johannesburg.

PRESIDENTS AND 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.

F. Dunleavy, 28, Asquith Street, Gainsborough, Lincs.
E. R. Walter, M.Sc., The Technical College, Lincoln.

LANCASHIRE—BURNLEY SECTION.

J. Pell, 17, Mersey Street, Rose Grove, Burnley, Lancs.
W. Haworth, 37, Westbourne Avenue, Burnley, Lancs.

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

SCOTTISH—FALKIRK SECTION.

H. Cowan, B.Sc., Foundry Technical Institute, Meeks Road, Falkirk, Scotland.
H. McNair, "Braewick," Larbert Road, Bonnybridge, Stirlingshire.

WALES AND MONMOUTH—BRISTOL SECTION.

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A. Hares, 648, Stapleton Road, Bristol, 5.

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GERMANY.

Dr.-Ing. T. Geilenkirchen, Technischer Hauptausschuss für Giessereiwesen, Pempelforterstrasse 50/52, Düsseldorf.

ITALY.

Dr.-Ing. Guido Vanzetti, 73, Corso Venezia, Milan.

SOUTH AFRICA.

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

AWARDS 1936 - 37

THE "OLIVER STUBBS" GOLD MEDAL

1937 Award to Mr. P. A. RUSSELL,

"For his work in promoting the technical development of iron foundry practice,

(*a*) as Convener of the Cast Iron Sub-Committee of the Technical Committee;

(*b*) for his work in connection with the preparation of specifications, and

(*c*) for Papers given to various Branches of the Institute."

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.
1933.—J. W. Gardom.
1934.—V. C. Faulkner.
1935.—No award.
1936.—F. Hudson. } Two awards.
E. Longden. }
1937.—P.A. Russell, B.Sc.

MERITORIOUS SERVICES MEDAL

No Award was made in 1937.

The Meritorious Services Medal has been awarded as follows:—

1933.—F. W. Finch.
1934.—J. J. McClelland.
1935.—H. Bunting.
1936.—J. Smith.

THE "E. J. FOX" GOLD MEDAL.

The "E. J. Fox" Medal was established in 1936 by E. J. Fox, Esq., who presented the sum of £500 as a capital fund.

The Medal was established to commemorate the development of the Centrifugal Casting Process in this country, and is to be presented to those who have contributed in some outstanding way to the progress of the Foundry Industry, with particular reference to Foundry Metallurgy.

The Donor considered that the active association of the President of the Institute at that time, Mr. J. E. Hurst, with the development of the Centrifugal Casting Process, was a fitting opportunity to make this gift.

The first award of the E. J. Fox Medal was made in 1937 to—

Professor Emeritus THOMAS TURNER, M.Sc.,

"as a recognition of his work on the effects of silicon on cast iron, and his other contributions to the metallurgy of cast iron, which may be considered to have formed the foundation of modern foundry practice."

DIPLOMAS OF THE INSTITUTE

were awarded to—

Mr. H. H. SHEPHERD, for his Paper on "The Application of Science to the Control of Foundry Sands," given before the Birmingham and London Branches.

Mr. S. A. HORTON, for his Paper on "Patterns and Their Relations to Moulding Problems," given before the East Midlands Branch.

Mr R. BALLANTINE, for his Paper on "Developments in the Production of Ingot Mould Castings," given before the Lancashire Branch and the Falkirk Section of the Scottish Branch.

Mr. E. W. WYNN, for his Paper on "A Small Oil-Fired Rotary Furnace, and its Products," given before the Lancashire Branch.

Dr. C. J. DADSWELL and Messrs. T R. WALKER and F. WHITEHOUSE for their joint Paper on "The Manufacture of Iron and Steel Castings in Green Sand," given before the Sheffield Branch.

THE "EDWARD WILLIAMS" LECTURE

The "Edward Williams" Lecture was established in the year 1934.

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, D.Sc.

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

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The Institute of British Foundrymen

THIRTY-FOURTH ANNUAL CONFERENCE, DERBY

JUNE 8, 9, 10 and 11, 1937

The Thirty-fourth Annual Conference was held at Derby on June 8, 9, 10 and 11, under the Presidency of Mr. C. W. Bigg. The arrangements were made by the East Midlands Branch, with Mr. B. Gale, Secretary of the Branch, as Secretary of the Conference Committee.

ANNUAL GENERAL MEETING

The annual meeting of the Institute was held in the Assembly Rooms, Market Place, Derby, on Tuesday, June 8, with the retiring President, Mr. H. Winterton, in the chair.

On the motion of Mr. W. T. Evans, seconded by Dr. A. B. Everest, the minutes of the annual general meeting held in Glasgow on June 9, 1936, were taken as read, approved, and signed by the President.

The Annual Report of the Council for the session 1936-37 was then presented.

ANNUAL REPORT

This report covers the period May 1, 1936, to April 30, 1937, and the accounts are for the year ended December 31, 1936.

The number of members on April 30 was 2,065, which constitutes a record, the previous largest number, 1,919, being recorded in 1932. A year ago the membership was 1,892; the present figures therefore show a net increase of 173 in the past twelve months. Table I shows the changes in membership which have taken place during the year, and an analysis of the present membership is given in Table II, the figures for the previous year being given in brackets as a comparison.

Deaths

The Council regrets to report the deaths of 18 members, including some who had been most active in the work of the Institute and who were widely known throughout the industry. Among these are:—

Mr. Emile Ramas, Past-President of the Association Technique de Fonderie de France, and Honorary Member of this Institute.

Mr. John Haigh, of Wakefield, Past-President of the Lancashire Branch, and for many years a member of the Council of the Institute.

Mr. J. E. Cox, of Ilkeston, a prominent member of the East Midlands Branch.

Mr. Sidney Evans, a member of the London Branch, who was widely known throughout the industry in this country and on the Continent.

Mr. Ian S. Osborn, of Sheffield, who died at the early age of 36.

Mr. W. Moscrip, of Leven, Fife, a well-known member of the steel foundry trade, who, together with Mrs. Moscrip, took part in the visit to the recent Düsseldorf Congress and Exhibition.

Mr. T. E. Bashford, a founder and for several years treasurer of the Middlesbrough Branch.

Mr. J. M. Weir, of South Shields.

Mr. D. Dalrymple, a Past-President of the Birmingham Branch.

Mr. Harry Pemberton, of Derby, who joined the Institute over thirty years ago and was a Past-President of the East Midlands Branch.

Honours Conferred Upon Members

Among the honours which have been conferred upon members are the following:—

Sir Robert Hadfield, Bart., has been raised to the distinction of Commander of the Legion of Honour, and has been appointed an Honorary Member of the Institution of Civil Engineers.

Mr. J. Léonard, President of the Association Technique de Fonderie de Belgique, and Honorary Member of this Institute, was decorated by H.M. the King of the Belgians with the Cross of Chevalier of the Order of Leopold, on the occasion of the International Foundry Congress in Brussels, in September, 1935.

Mr. Vincent Delport has been elected President of the International Committee of Foundry Technical Associations.

Mr. W. J. Rees has been re-elected President of the Refractories Association of Great Britain.

Mr. A. C. Turner has been elected President of the Foundry Trades' Equipment and Supplies Association.

Finances

Referring to the income and expenditure account, the Report states that, due to increased subscriptions the income was slightly higher than in 1935. This increase of income has been practically neutralised by certain small increases in expenditure mainly in Branch expenditure, necessitated by increased membership and activities. The excess of income over expenditure for the year was £168 0s. 2d., compared with £166 18s. 4d., at the end of 1935. The finances of the Institute are in a sound condition, but as the numerous activities of the Institute are carried on almost entirely from the income derived from subscriptions, the most careful economy is necessary in order that this sound condition shall be maintained.

E. J. Fox Gold Medal

At the annual general meeting in June, 1936, the retiring President, Mr. J. E. Hurst, announced that Mr. E. J. Fox, managing director of the Stanton Ironworks Company, Limited, had presented the sum of £500 for the establishment of a Gold Medal to commemorate the development of the centrifugal casting process in this country. The medal was to be presented to the individual who had contributed in some outstanding way to the progress of the foundry industry, with particular reference to foundry metallurgy. Mr. Fox considered that the active association of Mr. J. E. Hurst, with the development of the centrifugal casting process, was a fitting opportunity to make this gift.

The Council gratefully accepted the munificent gift of Mr. Fox, and decided that the medal should be known as the E. J. Fox Gold Medal. It is intended that it should be awarded by the Council on the recommendation of two assessors, whose decision as to a suitable candidate might be made in collaboration with the President of the Institute. Sir W. J. Larke, K.B.E., and Sir Harold Carpenter, F.R.S., accepted the invitation to act as assessors for a period of three years.

On the recommendation of the assessors the Council decided to make the first award of the medal to Prof. Emeritus Thomas Turner, M.Sc.

Badge for Use by Vice-Presidents

The Council gratefully acknowledges the gift of a gold badge for the use of the Junior Vice-President.

Awards

Oliver Stubbs Medal.—The Council decided to make two awards of the Oliver Stubbs Medal in the year 1936, as follows:—

Mr. F. Hudson, " for the work he has done in promoting scientific foundry practice, and particularly his investigation work with relation to moulding sands, most of which has

TABLE I.—*Changes of Membership*, 1936–37.

	Subscribing firms.	Members.	Associate members.	Associates.	Associate students.	Total.
At April 30, 1936	49	778	926	120	19	1,892
Additions and transfers from other grades	18	132	150	11	8	319
	67	910	1,076	131	27	2,211
Losses and transfers to other grades ..	1	46	89	10	0	146
At April 30, 1937	66	864	987	121	27	2,065

been made known to the Institute through the various Papers that he has presented from time to time."

Mr. E. Longden, "in recognition of the many valuable Papers on foundry practice, particularly in connection with the shrinkage of castings, which have been presented to the Institute over a number of years."

Meritorious Services Medal.—The fourth award of the Meritorious Services Medal was made in June, 1936, to Mr. James Smith, President of the Newcastle Branch, "for his continuous efforts to promote the development of the Institute since he became a member in 1905."

Diplomas.—The announcement of the award of Diplomas for the year 1936 was made at the Glasgow Conference, in June, 1936. The names of the recipients and the Branches before which their Papers were given, are as follow:—

G. L. Harbach, Birmingham Branch.

A. Phillips, Burnley Section of the Lancashire Branch.

J. McGrandle, Scottish Branch.

Buchanan Medals and Prizes.—The Buchanan Medals and Prizes are awarded on the results of the examinations in foundry practice and patternmaking held by the City and Guilds of London Institute. The names of the recipients are given later in this report in the section headed "Educational Work."

John Wilkinson Medal.—This Medal is awarded annually to a member of the Lancashire Branch Junior Section, on the results of an examination. The winner in 1936 was Mr. James Holden.

Branch Activities

Membership of the Branches and attendance at Branch meetings and other functions, is one of the few contacts with the Institute made by a large proportion of the members.

In spite of the increasing amount of work of a national character now being undertaken, the

Council recognises that the work of the Branches is of fundamental importance. There are now ten Branches, together with five Sections of Branches, including two Sections which have been formed during the past year, namely: East Anglian Section of the London Branch, and the Bristol Section of the Wales and Monmouth Branch. The former has had a most successful session and caters for the increasing number of foundrymen resident in the Eastern Counties, while the latter, which was formed in October last, fills a long-felt requirement for regular meetings of the Institute in the West of England.

The Council expresses its thanks to the Branch-Presidents, secretaries, and other officials; to the authors of Papers; and to the directors and staffs of the various works which have been visited.

A two-days' meeting of the London and Birmingham Branches was held in London, in October, and was a very successful gathering.

South African Branch

It is with great pleasure that the Council records that as a result of the active efforts of the honorary corresponding member for South Africa, Mr. A. H. Moore, and of the efforts of Mr. A. H. Guy, following on his visit to this country in 1936, a Branch of the Institute has been formed in South Africa, with headquarters at Johannesburg. In addition to the 11 members already in that country, 40 new members have been enrolled, making a total initial membership of 51.

The President is Mr. T. Nimmo Dewar, managing director of the United Steel Corporation of South Africa, Limited. The first meeting of the Branch was held on March 10, 1937.

Board of Development

The Board of Development was formed in the autumn of 1935. After numerous meetings and considerable correspondence, a report recommending extensive changes in the Institute's publications was submitted to the Council and considered by the Branch Councils. The Board has since put forward a more comprehensive report containing several recommendations, the adoption of which, it is hoped, will materially increase the prestige of the Institute and its value to the members and to the trade in general. An Organisation Committee is now working out the details of these recommendations, and they will be submitted to the Council for further consideration in due course.

Kindred Institutions

At the invitation of the Iron and Steel Institute, a joint meeting with that Institute was held in London, on October 30, 1936, under the chairmanship of the President of the Institute of British Foundrymen. At this meeting, the Second Report of the Steel Castings Research Committee of the Iron and Steel Institute was presented and discussed.

Official support was accorded to the Congress of the International Association for Testing Materials, held in London from April 19 to 24, the President, Dr. A. B. Everest and the secretary representing the Institute at various meetings and functions in connection with the Congress.

The Institute has also co-operated with a number of similar institutions in establishing a Joint Committee on Materials and their Testing, for the promotion of the study of these subjects in Great Britain.

In addition to the foregoing, the close relations which have been established with other institutions have been maintained and strengthened, and many of the Branches have held joint meetings with the corresponding local Branches of other national bodies.

International Relations

The friendly relations with foundry technical societies in other countries have been maintained through the medium of the International Committee of Foundry Technical Associations. Over

TABLE II.—*Analysis of Membership, April 30, 1937.*

Branch.	Subscribing firms.	Members.	Associate members.	Associates.	Associates (students).	Total.
Birmingham	7 (3)	135 (121)	144 (124)	16 (16)	5 (4)	307 (268)
East Midlands	3 (3)	55 (49)	89 (82)	4 (5)	—	151 (139)
Lancashire	14 (14)	109 (111)	200 (213)	25 (31)	—	348 (369)
London	8 (6)	182 (171)	106 (97)	6 (6)	— (1)	302 (281)
Middlesbrough	1 (—)	24 (20)	33 (34)	6 (5)	6 (—)	70 (59)
Newcastle	7 (7)	32 (31)	30 (30)	47 (44)	10 (9)	126 (121)
Scottish	6 (4)	101 (95)	187 (183)	9 (8)	1 (1)	304 (291)
Sheffield	7 (6)	93 (82)	59 (57)	2 (3)	1 (1)	162 (149)
South African	8 (—)	27 (—)	14 (—)	2 (—)	—	51 (—)
Wales and Mon. ..	2 (2)	43 (32)	45 (33)	—	3 (3)	93 (70)
W.R. of Yorks	3 (3)	40 (43)	69 (62)	4 (2)	1 (—)	117 (110)
Unattached	— (1)	23 (23)	11 (11)	—	—	34 (35)
	66 (49)	864 (778)	987 (926)	121 (120)	27 (19)	2,065 (1,892)

forty members and ladies attended the International Foundry Conference and Exhibition held at Düsseldorf in September, the British party being under the leadership of the President of the Institute. Those who were present are indebted to the organisers of the Congress, The Technischer Hauptausschuss für Giessereiwesen; to Mr. W. Bannenberg, its President, and to Dr. Geilenkirchen, its director, for their cordial reception and their hospitality. A meeting of the International Committee of Foundry Technical Associations was held at Düsseldorf during the Congress, at which the Institute was represented by the President, and Mr. V. C. Faulkner and the secretary, who attended as the secretary of the Committee.

Arrangements are being made to participate in the next Foundry Conference, which will be held in Paris from June 18 to 24. This Conference will be of particular interest to members, as Mr. V. Delport, now President of the International Committee, will be the chief representative of all the foreign Foundry Associations at the various meetings and functions.

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

American Foundrymen's Association Convention, 1936, at Detroit—Mr. J. E. Hurst.

Conference of the Association Technique de Fonderie, Lille—Mr. G. L. Harbach.

International Foundry Conference, Düsseldorf—Mr. J. G. Pearce.

The authors of Exchange Papers at forthcoming conferences will be:—

American Foundrymen's Association Convention, 1937, at Milwaukee.—Mr. J. Roxburgh.

International Foundry Conference, Paris—Mr. H. H. Shepherd.

Additional Papers by Mr. J. E. Hurst and Dr. A. B. Everest will be given respectively to the American and International Foundry Congresses.

Papers were presented at the Glasgow Conference of this Institute on behalf of the American, French and German Foundry Associations, and all these Associations will present Papers at the forthcoming Conference to be held at Derby.

Foundry Exhibition

The Council has accepted an invitation on behalf of the Institute to visit the Foundry Exhibition to be held in conjunction with the Engineering and Marine Exhibition at Olympia in September next, and has also accepted an invitation from F. W. Bridges & Sons, Limited, the organisers, to organise a stand at this exhibition. This stand will be used mainly as a rallying point for foundrymen.

Educational Work

The educational work which has been described in detail in previous reports has continued successfully throughout the year. Examinations in patternmaking and in foundry practice and science carried out by the City and Guilds of London Institute in collaboration with the Institute of British Foundrymen, were held in May, 1936, and the results are as follow:—

	No. of candidates.	Pass 1st class.	Pass 2nd class.	Percentage of passes.
Patternmaking— Intermediate grade	35	8	13	60.1
Patternmaking— Final grade ..	19	5	9	73.7
Foundry practice and science	61	13	20	54.2

Prizes were awarded to:—

PATTERNMAKING—INTERMEDIATE GRADE.

Mr. F. N. Rand, of Constantine Technical College, Middlesbrough, Bronze Medal of the C. & G. of London Institute.

PATTERNMAKING—FINAL GRADE.

Mr. L. M. Abrahams, of L.C.C. School of Engineering and Navigation, Poplar, Silver Medal of the C. & G. of London Institute and Buchanan Prize of the Institute of British Foundrymen.

Mr. W. Brindley, of Wolverhampton and Staffordshire Technical College, Buchanan Prize of the Institute of British Foundrymen.

FOUNDRY PRACTICE AND SCIENCE.

Mr. V. G. Ellis, of Coventry Technical College, Silver Medal of the C. & G. of London Institute, and Buchanan Prize of the Institute of British Foundrymen.

Mr. A. J. Wilson, of Sir John Cass Technical Institute, London, Buchanan Silver Medal of the Institute of British Foundrymen.

Mr. G. M. Andrew, of Sheffield Foundry Trades Technical Society, Buchanan Prize.

Mr. G. F. Taylor, of Constantine Technical College, Middlesbrough, Buchanan Prize.

The certificates awarded to the candidates who passed the examination have been endorsed by the President of the Institute, who has also endorsed six certificates gained by candidates successful in passing the examination (moulders' course) of the Union of Lancashire and Cheshire Institutes.

National Certificates in Mechanical Engineering.—These certificates are issued by the Board of Education and the Institution of Mechanical Engineers, and six certificates were endorsed by the President of this Institute in respect of special foundry subjects.

The degree course in foundry metallurgy at the University of Sheffield, has now been in existence for nearly three years; the number of students who have enrolled this year represents an increase on those enrolled during the first two years of the course, and the course is making satisfactory progress.

In addition to the foregoing activities, the Council wishes to emphasise the value of the work done by the British Foundry School at Birmingham, which was established through the efforts of the British Cast Iron Research Association and of Mr. J. G. Pearce. The school provides a specialised course of one year's duration, for men who are already in the industry and who wish to equip themselves for more important technical work.

Annual Conference, Glasgow, 1936

The Thirty-Third Annual Conference was held at Glasgow and Edinburgh, from June 9 to 12, 1936, and the attendance was one of the largest of a long and successful series. Members and ladies were entertained at a reception at the City Chambers on Tuesday, June 9, by the Rt. Hon. the Lord Provost of Glasgow.

At the opening meeting on June 10, members were welcomed by the Rt. Hon. Lord Provost; Sir James Lithgow, Bt., President of the Reception Committee; Col. Norman Kennedy, President of the Glasgow Chamber of Commerce; and Sir Arthur Huddleston, director of the Royal Technical College.

Mr. H. Winterton was installed President in succession to Mr. J. E. Hurst, and Mr. C. W. Bigg and Mr. J. Hepworth, M.P., were elected respectively to the offices of Senior and Junior Vice-President.

On Thursday, June 11, the work of the Conference was removed to Edinburgh, the capital of Scotland, and following the session for the discussion of Papers in the morning at the Heriot-Watt College, the party was entertained at a reception at the City Chambers by the Lord Provost. Bailie Aldridge welcomed the visitors on behalf of the Corporation.

The thanks of the Institute are tendered to the Lord Provost of Glasgow; the Lord Provost of Edinburgh; the firms who arranged visits for members and ladies and to the staffs of those firms; to the authors of Papers; to the subscribers to the conference funds; and to all who assisted in the organisation and carrying out of the many duties connected with the arrangement of so large a gathering.

The Institute wishes particularly to record its appreciation of the work carried out and of the hospitality tendered by the Scottish Branch, and to express its congratulations to the Branch upon the success of the arrangements which were made. Congratulations and thanks are specially accorded to the President of the Branch, Mr. D. Sharpe; Mr. John Bell, conference secretary, whose perfect organisation won the admiration of all the visitors; and to Mr. A. Campion.

Edward Williams Lecture

The Second Edward Williams Lecture was delivered at the Glasgow Conference by Prof. A. L. Mellanby, D.Sc. The Third Lecture will be given at Derby on June 9, at the opening session of the Conference, by Dr. C. H. Desch, F.R.S.

British Cast Iron Research Association

The British Cast Iron Research Association continues actively to develop, and the year 1936-37 promises to be a record in income and activity. At the annual meeting in November, 1936, the Earl of Dudley was elected as the new President, with Lord Austin of Longbridge and Prof. Thomas Turner as new Vice-Presidents.

Mr. H. B. Weeks, chairman of the Council since the Association began, has been succeeded in that office by Dr. Harold Hartley, and Mr. J. T. Goodwin, M.B.E., has retired from his office as vice-chairman of the Council after twelve years in that capacity.

The Association has recently undertaken an important investigation, sponsored by the Institution of Mechanical Engineers, on high-duty cast irons for engineering purposes. It is proposed in this connection to investigate the mechanical properties of the whole range of cast irons suitable for engineering work.

Council

Four meetings of the Council and more than twenty meetings of standing and special Committees have been held during the year. The Council meetings were held at Glasgow, Birmingham, Bradford and Newcastle, and the average attendance was thirty-seven.

There have been four meetings of the Technical Committee, one meeting of the Technical Council and upwards of forty meetings of the Sub-Committees of the Technical Committee.

The Council of the Institute consists of:—

(*a*) *Ex-officio* members, *i.e.*, the President, Vice-Presidents, Past-Presidents, Branch Presidents and Branch secretaries.

(*b*) Members elected by the Branches.

(*c*) Members elected by ballot by the whole of the members.

The last named are ten in number, of whom five retire each year. The five who so retire at the Annual General Meeting on June 8 are:—

Prof. J. H. Andrew, Mr. V. Delport, Mr. E. Longden, Mr. P. A. Russell, and Mr. D. H. Wood.

All these gentlemen are eligible for re-election for a further period of two years and offer themselves for re-election.

The Council expresses its thanks to Mr. W. B. Lake, J.P., for his services as honorary treasurer and for his guidance in connection with finance; also to Mr. J. W. Gardom, Convener of the Technical Committee, for his leadership of the various activities of this Committee and of its Sub-Committees.

Annual Conference

The Thirty-Fourth Annual Conference will be held at Derby from June 8 to 11, when Mr. C. W. Bigg, President-elect, will be installed President.

H. WINTERTON,
President.

T. MAKEMSON,
Secretary.

BALANCE SHEET, DECEMBER 31, 1936.

LIABILITIES.

	£	s.	d.	£	s.	d.
Subscriptions paid in advance				219	2	0
Sundry Creditors				432	11	10
Secretary's Policy Fund				18	8	8
The Oliver Stubbs Medal Fund :—						
Balance from last Account	213	6	9			
Interest to date	7	17	10			
	221	4	7			
Less Cost of Medal	9	15	0			
				211	9	7
The Buchanan Medal Fund :—						
Balance from last Account	122	14	9			
Interest to date	4	12	2			
	127	6	11			
Less Cost of Medal and Prizes	4	9	10			
				122	17	1
The E. J. Fox Medal Fund :—						
Cash received				500	0	0
International Conference Fund :—						
Surplus (included in General Investments)				40	18	11
Accumulated Fund :—						
Balance at December 31, 1935	1,864	10	8			
Add : Excess of Income over Expenditure for the year ended December 31, 1936	168	0	2			
				2,032	10	10
				£3,577	18	11

ASSETS.

	£	s.	d.	£	s.	d
Cash in hands of Secretaries :—						
Lancashire Branch	25	6	2			
Birmingham Branch	41	7	10			
Scottish Branch	43	5	11			
Sheffield Branch	38	19	5			
London Branch	69	18	8			
East Midlands Branch	19	11	0			
West Riding of Yorkshire Branch	23	14	4			
Wales and Monmouth Branch	3	8	11			
Middlesbrough Branch	1	2	9			
				266	15	

	£	s.	d.	£	s.	d.
Cash in Hand :—						
Secretary's Policy Fund				18	8	8
Sundry Debtors :—						
Subscriptions due and subsequently received				51	13	0
Lloyds Bank Ltd.				639	13	11
The Oliver Stubbs Medal Fund :—						
£342 5s. 7d. Local Loans £3 per cent. Stock at Cost	200	0	0			
Balance at Lloyds Bank Ltd.	11	9	7			
				211	9	7
The Buchanan Medal Fund :—						
£125, £3 10s. 0d. per cent. Conversion Stock at 78¼ .	98	6	9			
Balance at Midland Bank	24	10	4			
				122	17	1
The E. J. Fox Medal Fund :—						
£462 19s. 3d., £3 10s. 0d. per cent. Conversion Loan at Cost				500	0	0
Investments :—						
£650, 3½ per cent. War Loan at Cost	630	8	4			
£300, 5 per cent. Conversion Stock, 1944–64, at Cost	297	14	11			
£653 19s. 0d. Local Loans 3 per cent. Stock at Cost	451	13	8			
£295 8s. 10d., 3 per cent. Funding Loan at Cost....	300	0	0			
				1,679	16	11
Furniture, Fittings and Fixtures as per last Account....	76	9	1			
Less : Depreciation 10 per cent.	7	12	11			
				68	16	2
Superannuation Insurance :— Unexpired Premium				18	8	7
				£3,577	18	11

W. B. LAKE, *Hon. Treasurer.*
TOM MAKEMSON, *Secretary.*

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.*
19–21, Queen Victoria Street, London, E.C.4.
March 18, 1937.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1936.

Expenditure.

	£	s.	d.	£	s.	d.
Postages				128	17	1
Printing and Stationery, including printing of "Proceedings"				692	17	9
Council, Finance and Annual Meeting Expenses				121	5	7
Medal for Past President				3	0	0
Branch Expenses :—						
Lancashire	133	1	10			
Birmingham	71	12	2			
Scottish	74	4	10			
Sheffield	45	13	3			
London	63	19	4			
East Midlands	43	19	3			
Newcastle	39	2	9			
West Riding of Yorkshire	28	17	10			
Wales and Monmouth	25	5	10			
Middlesbrough	31	19	3			
				557	16	4
Audit Fee and Accountancy Charges				12	12	0
Incidental Expenses	73	10	7			
Subscriptions :—						
International Congress, Testing Materials	10	10	0			
British Foundry School	5	0	0			
International Committee on C.I. Testing	3	0	0			
				92	0	7
Salaries — Secretary and Clerks				688	16	10
Superannuation Insurance (Secretary)....				55	5	10
Rent, Rates, &c., of Office, *less* Received				91	5	0
Subscription, International Committee				2	10	0
Depreciation of Furniture				7	12	11
John Surtees Memorial Examinations Grants to Branches				8	6	10
				2,462	6	9

	£	s.	d.
Excess of Income over Expenditure carried to Balance Sheet	168	0	2
	£2,630	6	11

INCOME.

	£	s.	d.	£	s.	d.
Subscriptions received :—						
Lancashire Branch				447	6	0
Birmingham Branch				356	8	6
Scottish Branch				358	16	6
Sheffield Branch				281	2	6
London Branch				470	18	0
East Midlands Branch				220	18	6
Newcastle Branch				118	11	6
West Riding of Yorkshire Branch				156	3	6
Wales and Monmouth Branch				107	2	0
Middlesbrough Branch				98	12	6
Unattached Members				53	9	0
				2,669	8	6
Add : Subscriptions in Advance, 1935	86	2	0			
Do., due 1936	51	13	0			
				137	15	0
				2,807	3	6
Less : Subscriptions in Advance, 1936	219	2	0			
Do., due 1935	65	12	6			
				284	14	6
				2,522	9	0
Conference Registration Fees				28	17	6
Sale of " Proceedings," &c.				10	8	11
Interest on Investments and Cash on Deposit				59	6	3
John Surtees Memorial Examination—Surplus				6	14	1
Profit on Sale of Badges				2	11	2
				£2,630	6	11

Adoption of Report

The Retiring President proposed the adoption of the General Council's Annual Report for the year ended April 30, 1937, which Report was taken as read.

Mr. Victor Stobie, M.I.E.E. (Past-President), who seconded, emphasised particularly the Institute's gratitude to Mr. E. J. Fox (managing director of the Stanton Ironworks Company, Limited) for his generosity in placing £500 at the disposal of the Institute for the establishment of a Gold Medal. The Annual Report was unanimously adopted, without discussion.

Accounts

Mr. W. B. Lake, J.P. (retiring hon. treasurer), presented the Accounts for the year ended December 31, 1936, and commented with satisfaction upon the figures, which reflected the increasing activity and the progressively improving financial stability of the Institute in the seven years during which he had served as hon. treasurer. Inasmuch as the occasion was the last on which Mr. Lake would appear before the meeting as hon. treasurer, he took the opportunity to thank his numerous friends in the industry for their many kindnesses to him during his period of office.

The resolution for the adoption of the Accounts was seconded by Mr. J. E. Hurst, and was carried unanimously without discussion.

Report of Technical Committee

Mr. J. W. Gardom (Convener of the Technical Committee) presented and proposed the adoption of the Committee's Annual Report. He took the opportunity to express his gratitude to all members of the Committee and Sub-Committees for their work, particularly having regard to the fact that in view of present-day industrial activity it was difficult for them to give the time necessary for the Committee's work. He was particularly pleased that the Costing Sub-Committee was presenting a report on "The Establishment of Costs in a Grey Iron Foundry" during the course of the Derby Conference.

Mr. F. J. Cook, M.I.Mech.E. (Past-President), who seconded, paid a tribute to Mr. Gardom for his work as Convener of the Technical Committee. He added that the Committee had devoted a great deal of energy to the work and the Institute appreciated it to the full. The Report was unanimously adopted.

FIFTH ANNUAL GENERAL REPORT OF THE TECHNICAL COMMITTEE

The Technical Committee was formed in 1931, its objects being:—

(1) To establish an organisation to study, and keep the members of the Institute in touch with, technical progress in various branches of the industry.

(2) To fulfil a need which had been felt for some time of establishing an organisation through which the Institute could be represented on various national and international bodies concerned with the preparation of specifications and with technical development.

The organisation of the Committee is representative of the Branches of the Institute, and also of the various phases of the foundry industry. Each Branch elects two members annually, and these, together with certain *ex-officio* members, form the Technical Council which meets as and when required. Additionally, there are a large number of co-opted members of the various Committees, selected on account of their special knowledge of some branch of the industry, and these, together with the Technical Council, form the Technical Committee which meets four times per year.

The activities to which reference is made in paragraph (1), namely, the study of technical development within the industry, is carried out mainly by eight sub-committees which cover almost every phase of foundry practice. Each sub-committee meets at least four times a year, and more frequently if required. Details of the work of these sub-committees during the past twelve months are given in the Sub-Committee Reports at the end of this Report.

In addition to these reports, reference may here be made to certain outstanding work which has been accomplished during the past year.

(*a*) THE STEEL CASTINGS SUB-COMMITTEE made a joint contribution to the discussion on the Second Report of the Steel Castings Research Committee of the Iron and Steel Institute, presented at a joint meeting of that Institute and of the Institute of British Foundrymen.

(*b*) THE MALLEABLE IRON SUB-COMMITTEE, in collaboration with the Cast Iron Sub-Committee, has been engaged for some time on compiling data which show the necessity of specifying tolerances of dimensions in the production of castings. A report containing much of this data and certain recommendations was presented to the Conference at Glasgow in June, 1936, and has since been discussed by a number of Branches of the Institute.

(*c*) THE COSTING SUB-COMMITTEE for some three years has been engaged in studying the subject of foundry costs; sectional reports have been published from time to time, and these reports have been discussed by various Branches. A comprehensive report covering the whole subject and embodying suggestions made in the discussions by the Branches has now been prepared, and will be submitted to the Conference to be held at Derby in June, 1937.

(*d*) THE NON-FERROUS SUB-COMMITTEE, realising that a very large number of almost similar specifications have been issued for certain non-ferrous alloys, has prepared draft specifications for two leaded gun metals, which it is hoped will cover a variety of requirements and thus replace a number of existing specifications. Before submitting these proposals to a standardising body, it was desired to have the criticism and advice of the members of the Institute generally, and with this end in view, these proposals were submitted to the Glasgow Conference in 1936, and have since been discussed by a number of Branches.

(*e*) THE REFRACTORIES SUB-COMMITTEE has prepared a tentative specification for Tests for Cupola Fire Bricks, upon which they also desire to have opinions and criticism before it is submitted to a standardising body. Certain members of the Institute have kindly agreed to work to this specification and communicate their views and experiences to the Committee in due course.

(*f*) THE CAST IRON SUB-COMMITTEE two years ago issued in conjunction with the British Cast Iron Research Association a booklet of Typical Microstructures of Cast Iron. During the past year, a second booklet of Typical Microstructures has been issued in collaboration with the same Association. The second series includes a number of typical microstructures of malleable cast iron.

The most important part of the work to which reference is made in paragraph (2) is carried out by the Technical Committee as a whole, additional to and in some cases in conjunction with the appropriate sub-committees, and consists of representation on standardising bodies, particularly on Committees of the British Standards Institution. The Institute, through the Technical Committee, is represented on the most important committees of this Institution concerned with the foundry industry, and an active part has been taken by the Technical Committee and the Cast Iron Sub-Committee in the preparation of the draft B.S.I. specification for High-Duty Cast Iron, and the revised B.S.I. specification No. 321-27, General Grey Iron Castings.

The Committee particularly acknowledges its indebtedness to Mr. P. A. Russell, Convener of the Cast Iron Sub-Committee, for his very active work in connection with these specifications. Copies of the drafts are now being considered by members of the appropriate sub-committees, who are invited to communicate their views on the draft specifications before they are adopted finally.

An International Committee consisting of representatives of foundry technical associations is actively engaged in studying the subject of testing cast iron, and Dr. A. B. Everest represents the Institute on this committee. A meeting of this committee was held in Düsseldorf in September, 1936, the Institute being represented by Mr. F. K. Neath and the Secretary.

Dr. Everest represented the Institute through the Technical Committee at the recent Congress of the International Association for Testing Materials held in London, and the President and other members of the Committee were present at most of the meetings of this Congress.

Representatives of the committee are collaborating with representatives of the Literary and Awards Committee in the preparation of an international dictionary of foundry terms, under the auspices of the International Committee of Foundry Technical Associations.

INQUIRY BUREAU. The Inquiry Bureau continues to give useful service to members who require specific information on foundry problems, or who require knowledge as to where certain information can be found.

NOMENCLATURE. The Committee is continuing to compile a list of standard definitions and terms which it is hoped will be published in due course.

The Technical Committee at present consists of over sixty members. The Convener wishes to acknowledge the indebtedness of the Institute to these members for their services, and he particularly wishes to thank the sub-committee conveners and secretaries for their work.

The thanks of the Institute are also tendered to the firms with whom the members are associated, for facilities which are given and to those firms who have carried out tests and other work on behalf of the Committee.

J. W. GARDOM,
Convener, Technical Committee

REPORTS OF SUB-COMMITTEES

Sub-Committee on Cast Iron

This Sub-Committee has been principally concerned with the proposals of the British Standards Institution for the revision of Specification 321 General Grey Iron Castings, and for the establishment of a new Specification for High-Duty Cast Iron. New size test-bars being incorporated in these Specifications, both of which have now reached the draft stage, and having been scrutinised by this Sub-Committee at all stages of their preparation, these drafts are approved by this Sub-Committee subject to a few minor alterations, particularly with regard to deflection values. A report embodying the main provisions of these Specifications has been circulated to all members of the Technical Committee, and this report or the full draft is available to any member of the Institute on application to the secretary.

The distribution of the second series of Typical Microstructures of Cast Iron has been carried out during the year, and the demand for these has been gratifying. Through the kindness of Mr. A. E. Peace, a complete series of lantern slides of both series of Typical Microstructures has been presented to the Institute, and is available on loan on application to the secretary of the Institute.

The Sub-Committee has continued its work in connection with the assembly of physical data for cast iron, with a view to the possibility of publishing a summarised list which should be of value to designers and users of castings.

The Sub-Committee is also engaged upon the collection of data on methods of running castings. In view of the wide field of this investigation, this work is proceeding slowly.

P. A. RUSSELL,
Convener.

Sub-Committee on Costing

Since its last report, the Costing Sub-Committee has held several meetings and discussed in correspondence various aspects of costing in a grey iron foundry, and, as a result, the entire subject has been covered and embodied in a report, the text of which was approved at a meeting of the Sub-Committee held in London on April 3. That report will be presented at the Derby Conference in June.

The main object of the Costing Sub-Committee has been achieved, but the question of issuing a simplified system for the smaller jobbing foundries is being considered, and an endeavour is being made to establish a form of cost sheet embodying the principles of the system and which could be adapted to various types of foundries.

The members of the Sub-Committee are prepared to remain on the Committee should it be decided to retain it in an advisory capacity with a view to giving advice to the industry on costing matters in so far as they relate to grey iron foundries.

V. DELPORT,
Convener.

Sub-Committee on Malleable Cast Iron

The work of the Sub-Committee on the subject of dimensional tolerances for castings was brought to a close early in the year, and the data were embodied in a report which was presented at the Glasgow Conference in June, 1936. This Paper has since been read to the majority of the Branches, and the committee are collecting the points raised in the discussions in the hope that more concrete recommendations for dimensional tolerances may be formulated.

The investigation on the practicability of using various-sized test-bars to represent a range of sections for malleable castings has shown considerable progress. The results of all the tests made have been collected and an attempt made to correlate the results with the varying sections. No final conclusions have yet been made on this subject, however, and it seems likely that further work will still have to be done before recommendations can be made for a revision of the B.S.I. Specification.

A. E. PEACE,
Convener.

Sub-Committee on Melting Furnaces

This Sub-Committee has for some time been engaged in the preparation of a report on foundry melting furnaces, with a view to providing data on modern melting practice. At the beginning of this year it was found that the scope of the report was too wide, and it was decided that in the first instance it should be limited to melting furnaces for grey cast iron.

The report will be divided into sections, each dealing with one type of furnace. Sections on the cupola, rotary furnaces and electric furnaces are now completed and further sections are in preparation.

L. W. BOLTON,
Convener.

Sub-Committee on Non-Ferrous Castings

The work of this Sub-Committee during 1936-37 has been mainly concerned with the consideration of criticisms raised on their report, "Recommendations for Two Leaded Gunmetals," presented at the 1936 Annual Conference of the Institute. The report has been presented during the session at a number of Branches and has provoked a certain amount of correspondence in the technical press. The reception accorded the report has been favourable and the Sub-Committee is encouraged to proceed with this work of preparing a suitable series of alloys for suggested standardisation. Further work of the same type on bronzes of higher lead content is in hand, and it is hoped that in due course similar recommendations for leaded phosphor bronzes can be put forward by the Sub-Committee.

G. L. BAILEY,
Secretary.

Sub-Committee on Refractories

The Sub-Committee has had several meetings during the year, and its recommendations for the specification and standard tests for cupola firebricks was finally approved by the Technical Committee at the meeting in Birmingham on March 6 for submission to the Institute members.

During the year the Sub-Committee has been further strengthened by the election of new members, and is at present actively engaged on investigating closely the characteristics of cupola ganister with a view to the preparation of a draft specification for submission to the Technical Committee. A great amount of useful investigation has been completed already, and it is hoped to be able to submit a considered report during the present year.

W. J. REES,
Convener.

Sub-Committee on Sands

The work of the sands questionnaire mentioned in the previous annual report has been completed. The tabulation and comments will be published later.

Recommended methods of dry sand testing are also ready for publication, and methods of sieve testing have been under consideration.

Sand testing equipment is being checked and resulting therefrom modifications to some existing equipment are recommended.

Much progress has been due to the co-operation of the Sub-Committee on Moulding Materials of the Iron and Steel Institute and the Sands and Refractories Committee of the British Cast Iron Research Association.

JOHN J. SHEEHAN,
Convener.

Sub-Committee on Steel Castings

Work has continued upon the three investigations detailed in the 1936 report:—

(*a*) Considerable data have been collected upon the effect of various heat-treatments on steels of normal compositions. A few further tests are required before the first tabulation can be completed.

In carrying out these tests it was found necessary to design a standard test block casting, and it is recommended that this should be used when bars are being prepared for investigating the properties of cast steels.

(*b*) All the valve castings under consideration are undergoing test by a well-known valve manufacturer, and all have successfully withstood the highest pressure tests. The castings are now being sectioned to ascertain heterogeneity, etc.

(*c*) Arrangements have been made with a refractories manufacturer to supply a uniform sand (to a specification agreed with the Iron and Steel Institute Steel Moulding Materials Committee and approved by the Sands Sub-Committee) for the making of special test castings. Some data have also been collected upon liquid steel temperatures in the foundry.

Difficulty is being experienced in deciding upon a suitable type of experimental casting for the making of tests, but trials of various forms continue.

A member of the Committee has prepared a very comprehensive bibliography upon the subject of steel castings defects, and this is available to any interested member.

C. H. KAIN,
Convener.

Second Congress of the International Association for Testing Materials

London, April 19 to 26, 1937.

Dr. A. B. Everest represented the Institute officially at the technical sessions of this Congress, and a summary of his report, presented to the Technical Committee, is as follows:—

The Congress was divided into four main groups, dealing respectively with metals, inorganic materials, organic materials, and finally, subjects of general interest. From the point of view of the Institute of British Foundrymen, Group A, dealing with metals, was undoubtedly the most important, sub-sections in this group dealing with the behaviour of metals dependent upon temperature and giving consideration to mechanical properties, especially creep and impact, at high temperatures, and also to oxidation and corrosion as affected by temperature. The second sub-section was devoted to progress of metallography and dealt essentially with the testing methods and the results of testing in the fields of microscopy, X-ray examination, electron interference, and so on. Some attention was incidentally given under this section to solidification of ingots and to recrystallisation. The third sub-section was devoted to light metals and their alloys, special reference being made in this connection to the mechanism of age-hardening and the study of single crystals.

In the fourth sub-section attention was given to the general subjects of workability and wear, referring especially to machinability on the one hand and to wear tests and their relation to service life on the other.

In the third group, dealing with light metals, some reference was made to cast aluminium alloys, whilst in considering the question of wear some two or three Papers made reference to cast iron. On the whole, however, among the 64 Papers presented in the metals section, the majority dealt generally with the fundamentals of testing as applied to metallurgical products, and there was not a great deal of direct concern to foundrymen.

In the group dealing with subjects of general importance, the relation between the results of laboratory tests and behaviour in service was considered. In this section, as in the main metals group, the general conclusion would appear to be that whilst testing methods are being increasingly perfected, and whilst more refined methods of investigation are throwing a new light on the fundamental properties of materials, there is still a very wide gap between results of laboratory investigations and the life obtained in service.

Awards

The Retiring President announced that the following Awards had been made for the year 1936-37 :—

The Oliver Stubbs Medal to Mr. P. A. Russell for his work in promoting the technical development of the industry, particularly as Convener of the Sub-Committee on Cast Iron of the Technical Committee.

Mr. E. J. Fox
(*Donor of the E. J. Fox Medal*).

The E. J. Fox Medal to Emeritus Prof. Thomas Turner, M.Sc.

Diplomas had been awarded to the following:—Mr. H. H. Shepherd for a Paper on "The Application of Science to the Control of Foundry Sands," read before the Birmingham Branch. Mr. S. A. Horton for a Paper on "Patterns and their Relation to Moulding Problems," read before the East Midlands Branch. Mr. R. Ballantine for a Paper on "Developments in the Production of Ingot Mould Castings," read before the Lancashire Branch and the Falkirk Section. Mr. E. W. Wynn for a Paper on "A Small Oil-Fired Rotary Furnace and its Products," read before the Lancashire Branch. Dr. C. J. Dadswell, Mr. T. R. Walker and Mr. F. Whitehouse, joint authors of a Paper on "The Manufacture of Iron and Steel Castings in Green Sand," read before the Sheffield Branch.

Honorary Member

The Retiring President proposed that Lord Austin of Longbridge, K.B.E., be elected an Honorary Member. He added that Lord Austin had been approached upon the matter and had said he was fully conscious of the honour, and the Institute felt that it was honouring itself by electing Lord Austin.

Mr. J. E. Hurst, seconding, said that Lord Austin, by reason of his many activities and the fact that he controlled very large foundries, would be a very worthy Honorary Member of the Institute. The proposition was unanimously adopted amid prolonged applause.

Election of President

The Retiring President said that his own very natural reluctance to relinquish office as President after so pleasurable a year was lightened by the fact that he would be followed by so worthy a successor as Mr. C. W. Bigg, whose work for the Institute had been continuous ever since he had joined. He was one of those men who was always alongside his fellows and was unanimously declared to be one of the right sort. He was second in command of one of the largest foundries in Derby, and it was a great pleasure to propose his election as President for the ensuing year.

Mr. V. Jobson (chairman of Qualcast, Limited), as a colleague and friend of Mr. Bigg for more than thirty years, seconded the proposal. Mr Bigg's associates in the company, he said, were very proud indeed that he had been selected for the honour, and they would do all they could during the year to ensure that he would be able to give to the Institute the time which his office demanded. There could be no better man for the office, for not only had he remarkable ability, but he had humanity and commanded the affection of his associates.

Mr. H. Bunting (retiring President of the East Midlands Branch) supported the proposal. The Branch, he said, had a good deal of pride in the fact that it had trained Mr. Bigg, and they knew that he would rise to any call that might be made upon it. He would follow worthily other members of the Branch who had served as Presidents of the Institute—Mr. S. A. Gimson and Mr. S. H. Russell.

Mr. C. W. Bigg was unanimously elected, and he expressed his great appreciation of the honour which the members had conferred upon himself personally and the Branch. He assured the members that any small talents or virtues that he might possess would be placed unreservedly at the service of the Institute.

Vote of Thanks to Retiring President

Mr. C. W. Bigg proposed a hearty vote of thanks to Mr. H. Winterton for his great services to the Institute, and congratulated him upon a very successful year of office as President. No man, he said, could have thrown himself more whole-heartedly into the job; every little bit of Mr. Winterton had gone to make a job of his presidential office, and he had succeeded. He could look back to a year of record membership; to the formation of the East Anglian and the Bristol Sections; to the formation of the South African Branch; to the joint meeting held with the Iron and Steel Institute in the autumn of 1936, and to the general expansion of the activities of the Institute. The feelings between the President and the Senior Vice-President during the past year could not possibly have been better than in fact they were, and Mr. Bigg acknowledged that he had been able to form a personal friendship with Mr. Winterton which he valued very highly.

Mr. F. J. Cook (Past-President), seconding, said Mr. Winterton had done much to bring the Institute to its present position, and his year of office had been very pleasurable and profitable to the Institute. The vote of thanks was carried with acclamation.

Mr. Winterton, responding, assured the members that his work during his year of office had been a labour of love, and he was indeed proud to have been able to help the Institute along. It had entailed a great deal of travelling, but he had done his best to visit every Branch and Section during the year; it was rather unfortunate that the South African Branch was not actually formed until rather late in his year of office, and he could find no reasonable excuse to pay a visit there! He took the opportunity to express his great appreciation of the support afforded him by the Vice-Presidents, hon. treasurer, the general secretary and all the members of the Council.

Election of Vice-Presidents

Mr. Bigg, proposing the election of Mr. J. Hepworth, J.P., M.P., as Senior Vice-President, paid a tribute to him in respect of his work for the West Riding Branch of the Institute, his very live interest as a specialist in the industry, and his wider experience as a national legislator, which should enable him to fill the post as Senior Vice-President with credit to himself and with benefit to the Institute. The resolution was seconded by **Mr. S. W. Wise**, the honorary secretary of the West Riding Branch, and was carried unanimously.

Mr. Hepworth, expressing his appreciation of the honour conferred upon him and upon the West Riding Branch, assured the members that he would give willingly as much of his time as he could possibly give to the Institute's work.

Mr. V. C. Faulkner, F.R.S.A. (Past-President), proposed that Mr. W. B. Lake, J.P., be appointed Junior Vice-President, and said that the reason why the Council had chosen this particular time to recommend Mr. Lake's election as Junior Vice-President was that in the ordinary course of events he would preside, as President of the Institute, over the International Foundry Congress, to be held in England two years hence. Mr. Lake, who was an important foundry owner, was the first man to make a steel casting with the aid of electricity in England, and the first to make a steel casting with the aid of the Sandslinger. He was also a very good employer, for he gave members of his staff every facility to participate in the activities of the Institute. In 1928 he had presided with great distinction over the London Branch, and subsequently had been a very strong supporter of the new East Anglian Section, which had been launched successfully. For the last seven years he had been hon. treasurer of the Institute, and it was hoped that in future he would play an even greater part in its development. Mr. Faulkner coupled with the proposal a hearty vote of thanks to Mr. Lake for his wonderful work in the past.

Mr. D. H. Wood, seconding, referred to the able manner in which Mr. Lake had piloted through the Finance Committee and the General Council a proposal that surplus funds in the Branches should be handed over to the General Council. The resolution was carried unanimously, and Mr. Lake briefly responded.

Election of Auditors

J. & A. W. Sully & Company, chartered accountants, were unanimously re-elected auditors for the ensuing year.

Election of Members of Council

The result of the ballot for the election of members to fill the five vacancies on the Council was as follows:—Prof. J. H. Andrew, Mr. V. Delport, Mr. E. Longden, Mr. P. A. Russell, Mr. D. H. Wood.

Civic Reception

In the evening the members and ladies attended a reception at Bemrose School, Uttoxeter Road, Derby, by kind invitation of the Worshipful the Mayor (Councillor Mrs. Petty, J.P.) and the Corporation of Derby.

OPENING OF CONFERENCE

On Wednesday morning, June 9, the members and their ladies assembled in the Guild Hall, Market Place, Derby, where they were officially welcomed by The Worshipful the Mayor of Derby (Councillor Mrs. Petty, J.P.), the President of Derby Chamber of Commerce (Mr. Cecil Murray, M.I.Mech.E), and the Principal of Derby Technical College (Dr. W. A. Richardson, O.B.E., B.A., D.Sc., B.Sc.(Eng.), F.G.S.), who were introduced to the meeting by Mr. H. Winterton (Retiring President).

THE WORSHIPFUL THE MAYOR OF DERBY assured the members and visitors that it was a privilege, in her capacity as the chief citizen of Derby, to extend to them a hearty official welcome.

Although Derby did not claim to be the oldest Borough in England, it was proud of the fact that it was considered a Borough even 1,000 years ago. Industrial people who had lived there had been pioneers in many ways. The first factory in England was built near the Derwent, where the electricity works now stand. Derby had played an important part in the development of silk weaving. That process had been a secret which Italy had very wisely secured from China and had carefully retained for many years; but John Loan, of Derby, had successfully entered into competition in the weaving of silk. There were some most wonderful examples of wrought ironwork in Derby, particularly in the Cathedral, of which the City was justly proud; it was hoped that many of the wonderful pieces of ironwork in various public places in Derby would eventually find their way into the safe care of the municipal authorities.

Commenting upon the fact that representatives of many countries were attending the Institute's conference, the Mayor emphasised that the more the representatives of the different countries met together in friendly conference and discussed their domestic and international troubles, the easier was the way towards that peace without which the world could never prosper. Difficulties must be discussed as brothers and sisters in one huge community—for that was what the world was coming to—and probably it lay with the present generation to make the choice as to whether the world was to go forward into an era of prosperity, happiness and peace, realising the spiritual values which made life so grand, or whether it would take the other line which led to destruction, misery and probably the end of Western civilisation. May the Derby convention of the Institute be interesting and encouraging, and contribute to the creation of the era of peace for which we all longed!

Mr. Cecil Murray, M.I.Mech.E. (President, Derby Chamber of Commerce), offering a welcome to the Institute, said he was not sure that he had the authority to speak officially on behalf of the Chamber of Commerce; but, knowing something of the business men of Derby and of the Institute of British Foundrymen, he had no hesitation whatever in offering the Institute a hearty welcome on behalf of the Chamber of Commerce.

Mr. Murray added that Derby was delighted that the Institute had paid to the Derby foundrymen the compliment of holding its convention in the city; and in offering the members and visitors a hearty welcome, he expressed the hope that their conference would be very happy and successful.

Dr. W. A. Richardson, O.B.E., B.A., D.Sc., B.Sc.(Eng.), F.G.S. (Principal of Derby Technical College), expressed his appreciation of the fact that he had been asked, as a representative of technical education in Derby, to join in welcoming the Institute. The foundry industry, he said, was a scientific industry; there were more applications of common science and uncommon science in the foundry than in any other section of an engineering works. It was amazing to a man such as himself, having some little scientific knowledge, to find how many real problems there were in the foundry, and how very interesting they were, despite the fact that the foundry itself was not, as a rule, a very attractive place. He congratulated the Institute on the very prominent part it was playing in the education of the young people in the industry. It seemed a tragedy that loam moulding, which was one of the arts of the world, to say nothing of the science, seemed gradually to be going out of practice; he knew of nothing more interesting or beautiful than a really good loam mould, and regretted that in a good many of our foundries only the older men were doing that work, there being no youngsters coming on in that direction.

The Institute had recognised that the young people needed education, and had taken great steps nationally and locally to establish technical educational facilities for them. The local Branch of the Institute in Derby had been very energetic and progressive, and Derby was one of the few areas in which the employers were giving their young workers the privilege of taking time off for the purpose of attending classes during the day. The Committee of the Branch had introduced that policy at the time when Mr. Bigg, the Institute's President-Elect—a gentleman for whom the whole town had a very great regard—was Branch-President. Mr. Bigg, and his predecessors in the office of Branch-President, had rendered great help to the Technical College, and he hoped they had seen no reason to regret having advised the foundry employers to allow the young people time off in order to attend classes at the College. As the result of that, the College staff were able to do their job better, and he hoped the industry was receiving something in return.

Dr. Richardson also said a word or two in praise of Mr. H. Bunting (retiring President of the East Midlands Branch), who not only could teach at the Technical College, but could also entertain the members of the Institute whenever they met! To the Technical College he had rendered very great assistance.

Appreciating how much the Institute and the local Branch had done for education, Dr. Richardson assured the members that he would be glad to do anything he could to assist.

Presentation of the Oliver Stubbs Medal

The Oliver Stubbs Gold Medal was presented by the Mayor of Derby to Mr. P. A. Russell, of Leicester, for his work in promoting the technical development of the industry, particularly as Convener of the Sub-Committee on Cast Iron of the Technical Committee.

In acknowledging the award, MR. RUSSELL said he was greatly flattered to receive the medal, which was held in great esteem by all members of the Institute. The award would be an encouragement to proceed with such work as he had been able to do, particularly in connection with the work of the Technical Committee; that work was very largely co-operative, and he accepted the medal partly on behalf of his colleagues on the Cast Iron Sub-Committee.

The E. J. Fox Medal

MR. H. WINTERTON, inviting Mr. E. J. Fox to present the Gold Medal established as the result of Mr. Fox's generous gift of £500, to encourage work in connection with the foundry and particularly with regard to metallurgical research, said that the recommendation of the assessors, Sir William J. Larke and Sir Harold Carpenter, that the first award of the medal be made to Emeritus Professor Thomas Turner, M.Sc., would be particularly popular, for the value of Prof. Turner's services to the industry was untold.

Mr. E. J. Fox, before formally presenting the medal, read the following extract from the assessor's report, dated March 24, 1937:—

> "We desire to recommend that the E. J. Fox Medal for the current year be awarded to Prof. Emeritus Thomas Turner, M.Sc., as a recognition of his work on the effects of silicon on cast iron and his other contributions to the metallurgy of cast iron which may be said to have formed the foundation of modern foundry practice. We feel that in thus honouring Prof. Turner the Institute will be honouring itself and placing the award of the E. J. Fox Medal in a category which will confer distinction on any future recipient."

Until a few years ago, said Mr. Fox, Prof. Turner was Professor of Metallurgy at Birmingham University, where he had established one of the best-equipped metallurgical departments in the country. His outstanding work was his research on the influence of silicon on cast iron, carried out as early as 1885, a classic work which had laid the foundation of scientific iron founding. His life-work had been the furtherance of metallurgical knowledge, both by personal investigation and by the guidance of students and other workers into useful fields of research, with special reference to industry.

It was not out of place to recall that two Prime Ministers of this country had been students of Prof. Turner; they were Earl Baldwin and the Rt. Hon. Neville Chamberlain. Sir Henry Fowler, whose name was known throughout the world and who was particularly respected in Derby, was another student of Prof. Turner. The researches of Prof. Turner covered all metallurgical fields, both ferrous and non-ferrous, and his vast contributions to our knowledge of the constitution of alloys, the shrinkage and expansion of metals, the corrosion of alloys, etc., indicated the full life he had devoted to the cause of science. His fame as a metallurgist had carried to all parts of the world, and his opinion was sought and respected in all branches of industry and education. Mr. Fox derived great pleasure from the fact that the first award of the Medal was made to Prof. Turner, first because it was a compliment to the name of Fox and his effort to provide some incentive and to encourage further research by the younger generation, and secondly, because the Medal started upon its career with the hall mark given to it by its recipient, which would result in making it a prize much coveted in the years to come, so that it would really encourage further research which would redound to the advantage of all founders of iron, who had almost a conceited belief in the merits of their metal and were daily working to secure improved results.

Mr. Fox formally presented the Medal to Prof. Turner, together with the certificate which accompanied it.

Prof. T. Turner, responding, confessed that he found it difficult to find appropriate words with which to express his gratitude. Although, he said, reference had been made to his deeds, Mr. Fox had kindly refrained from mentioning his misdeeds.

It was 52 years since he had read his Paper on the influence of silicon on the properties of cast iron. He had gone to the old Mason College to work under Tilden, who had asked what subject he would like to take up as a research; and he had selected the subject of the influence of silicon because his Professor, Sir William Roberts Austen, had mentioned in his lectures that they wanted to know what was the influence of silicon. Dr. Percy had said that there was an accumulation of analyses, but that they constituted a kind of labyrinth, and that it was necessary to explain and to correlate those analyses. Up to about 1855 or so the analyses available were, generally speaking, misleading and erroneous. Then at Woolwich some very accurate analyses of representative cast irons were made, which afterwards had proved to be most useful, though at the time they were unintelligible. Thus, said Prof. Turner, he had had the good fortune to have a problem suggested to him. He had had to learn how to melt the iron. He had been a student at the Royal School of Mines, but no iron founding was done there, and he had had to learn how to make his own moulds. A young man attached to a local foundry had assisted him. The first mould they had made was not dressed sufficiently and was a little dry, so that the metal ran out from the side and left a mark on the nice red tiled floor of the laboratory, which mark he believed was still visible. The next mould made was too wet and too solid, and he believed the metal in that case had made a mark on the ceiling! After that he had thought that he knew enough about the moulding to make his own moulds, and he had proceeded successfully. He had had to do the melting, the moulding and the analyses afterwards. Nowadays, of course, research was much more complex and there was a great deal of team work, but in the early days there were many simple problems which could be attacked by one man, and he did not think that the young researchers of to-day could derive quite the pleasure that older researchers did when they had found their experimental results gave smooth curves, that they could say definitely what the results were and that they had done the work themselves.

However, knowing the influence of silicon and having a large number of analyses available, it had become quite easy to experiment with irons which had the right amount of silicon but varying amounts of phosphorus, the right amount of silicon but varying amounts of manganese and the right amount of silicon but varying amounts of sulphur. So that within a short time he was able to say broadly what was the influence of each of the elements. He had never received any monetary recognition for that work and had had to meet some of the cost of it out of his stipend, which was £100 a year. The work had, however, given him great pleasure; it had helped him later in various ways and it had brought him many friends; perhaps the latter was the greatest reward that one could have for such work. It was not often that a man lived to see the work that he did more than 50 years ago being still appreciated by and of use to other people, nor did it fall to the lot of many to retain for so many years friendships such as those existing between himself and the foundrymen.

Finally, Professor Turner said that his family —Mrs. Turner and their son, Mr. T. H. Turner, who were present at the meeting—very much appreciated the honour the Institute had done him.

Vote of Thanks

Mr. H. Winterton proposed a hearty vote of thanks to the Worshipful the Mayor of Derby and to Mr. Murray and Dr. Richardson for the welcome they had extended to the members of the Institute.

The vote of thanks was seconded by Mr. Bigg, who acknowledged that he had a distinctly personal sense of obligation for all that had been done to contribute to the success of the Conference by the authorities at Derby. Those sentiments, he said, were shared by every member of the Institute. The vote of thanks was accorded with enthusiasm and the Mayor briefly responded and withdrew from the Conference.

Induction of New President

Mr. Winterton, inviting his successor formally to take office, expressed his personal appreciation of the support he had received during the past twelve months from officers and members of the Institute as well as from his colleagues in William Cumming & Company, Limited, who had had more work to do by reason of the fact that their Chairman had been away from the works many times. He formally invested Mr. Bigg with the Presidential Chain of Office, and wished him a very happy year.

Mr. Bigg, who was received with applause, formally occupied the Chair and said that he hoped to demonstrate during the next twelve months how very much he appreciated the honour.

Gift from Qualcast, Limited

Mr. Bigg announced with pleasure that his co-directors of Qualcast, Limited, wished to mark the occasion of his accession to the Presidential Chair of the Institute in a tangible manner and had offered the Institute the sum of £500 to form the nucleus of an endowment fund to be used to promote the work of the technical and educational Committees. The fund would be administered by trustees, and he invited the meeting to indicate acceptance of the gift, which would be subject to confirmation by the General Council in due course.

Mr. S. H. Russell (Past-President), proposing that the meeting should indicate its acceptance of the gift and its gratitude to the directors of Qualcast, Limited, said that some of them felt a little overwhelmed by the very substantial amount of the gift. He had not the slightest hesitation in saying that subsequently it would be accepted by the General Council with very grateful appreciation, and that it would be administered with care. The aim was to use the money as the nucleus of a larger fund, which it was hoped would grow until the interest it earned would be sufficient to foster the different enterprises undertaken in connection with the work of the two Committees. It was the dearest wish of Mr. Bigg that in time the Institute should be in a position to finance work of urgency and importance, provided always that that work did not cut across the work of any other body.

Mr. J. W. Gardom (Convener of the Institute's Technical Committee) seconded. The first thought of a hard-working metallurgist, he said, when so munificent a sum was offered was "Let us take it and do something with it," and all who were concerned with the progress of the Institute's work were indeed grateful to the donors. It seemed, he added, that the President had been aptly named (Charles Bigg) for "Charles" was the name of one of our most lovable monarchs, and the President was "Bigg" in heart and in thought. All must feel the seriousness of the matter and the necessity for ensuring that the money was spent wisely. It was a big sum but it might very easily be thrown away unless the greatest care was exercised. The problem of appointing trustees was a matter to be considered very thoroughly from among the men who had real business in them quite apart from their scientific attainments. His knowledge of the work of the Technical Committee provided sufficient proof that there were ample opportunities for spending money wisely and well. It must be borne in mind that the use of the results of the research work that was done must be considered very carefully. Academic research scholars, with whom he had had some connection, would be among the first to admit that their good work was sometimes ruined, or at any rate it was not used properly in industry. The Institute's Technical Committee was composed of men who could understand thoroughly the value of anything that was put forward by an academic scholar, and could show the value of such work to the foundry industry. By so doing they would overcome some of the troubles which foundrymen experienced to-day. The resolution was carried with acclamation.

Mr. V. Jobson (Chairman, Qualcast, Limited), who was invited to respond, said that his colleagues and himself had felt that a fund ought to be established if possible, and their idea was to use the £500 as a nucleus; he hoped others would build up the fund and that much useful work would be done through its agency. He personally appreciated very much the assistance he had received at all times from technical people.

Presentation of Badges

A Past-President's badge was formally presented to Mr. H. Winterton; the Medallion worn by the President's wife was presented to Mrs. Bigg, and the Vice-Presidents' Medallions were presented to Mr. Hepworth and Mr. Lake.

Honorary Treasurership

It was announced that Mr. S. H. Russell (Past-President) had been elected hon. treasurer to the Institute in succession to Mr. Lake.

Visitors from Overseas

A hearty welcome was extended to the many members and visitors from overseas who were attending the Conference. They included Mr. O. W. Ellis (Director of Metallurgical Research, Ontario Research Foundation, Toronto, Canada); Mr. Spring, Mr. Thomas, Mr. Galbraith, Mr. C. R. Day and Major Briggs from Australia; Mr. Drakenburg from Sweden; Dr. Rohrig (Germany); Mr. and Mrs. Bean (Persia); Mr. and Mrs. McNab (Singapore); Mr. Paul Fassotte (Brussels) and Mr. W. A. Geisler (Germany).

Mr. Bigg then delivered his Presidential Address.

PRESIDENTIAL ADDRESS

Mr. Winterton and Gentlemen:—

Does our industry from the community in general, receive tangible recognition?—recognition commensurate with its contributions to, and importance in, the general scheme of things. Or, to put it very crudely indeed, for what the foundryman does, what does the foundryman get? I am not going to develop this theme simply on the lines of an application for an increase in salaries or profits. I am going to attempt to indicate the bearing this question has on certain of our problems.

One of the most urgent problems with which we are concerned is the recruitment of personnel, and by personnel I mean not only the heads of departments, but the whole body of recruits for the different sections of the whole of our industry, which must contain the material from which the heads of departments are made. Unless we get the right type of recruits, we can never expect to have men directing our industry who will keep it in a position worthy of its importance.

I do not suggest that we should legislate on the basis that every lad coming into our industry is going to be worthy of a managerial position. We want the type of youth which is likely to contain among its ranks a good proportion who can be developed into controlling and directing executives. If that is achieved, we can rest assured that among the large remainder there will be a healthy supply of good craftsmen and technicians. What do we require in our foundrymen, and what are our chances of getting such men? Our industry's need is for men with practical experience, which practical experience has been informed, strengthened and enlarged by a sound technical training.

Internal Training Essential

Through my membership of the Institute, I have been brought into fairly close contact with our activities in connection with the different educational bodies with which we co-operate in efforts towards increasing the knowledge of the foundryman. I am full of enthusiasm for what is already being done, and for still further developments in these several directions, but no matter what facilities are placed at the disposal of our young men by these very excellent arrangements, it does not relieve the industry of one little bit of its own great responsibility in this matter. I want to emphasise that the real training for our industry must be in and by the industry itself. We shall never be able to get ready-made foundrymen from any outside source. We have got to make them.

In spite of the fact that the responsibility of thought and of judgment is tending to pass from the operator to the administrator, I can imagine no industry where the human factor will prove so permanently and largely a necessity as in the foundry. No matter to what degree we may develop our different forms of specialisation, organisation and mechanisation, unless these are scientifically based on craft experience they will fail.

I am of the opinion that in the higher executive, directing and controlling a concern, there must be a good leavening of practical knowledge, sufficient to prevent the directional control from soaring too far up into the clouds of impracticability. Far too seldom does the practical foundryman achieve or even aspire to a place in the direction of things, and because of this, it must of necessity follow that consideration of the foundry's needs and problems is usually belated and scanty.

It is our responsibility as an Institute to aim at producing for and in our industry men who combine technical and practical knowledge of a sufficiently high quality to ensure for them the leading places in our industry, and secure for the industry itself a leading place in the larger industrial world.

Lack of Technical Co-operation

I am not digressing if I take this opportunity of referring to the difficulties which are sometimes encountered when the technical and the practical men meet. You will not accuse me of exaggeration when I say that the practical lions and the technical lambs of our industry, and also of our Institute, too often refuse to lie down together.

Why is it? First of all, there is so often very little understanding one of the other. From the man working on the floor, with all the varying complexes which only working on a foundry floor can give, we have his very human, but quite unjustified, resentment of receiving instructions or even assistance from a colleague who he considers has never soiled his hands or taken off his sanguinary coat, and who, because of these deficiencies in his training, simply cannot be aware of the thousand and one problems a poor moulder has to face, and on the other side, there is sometimes an attitude indicating that the man on the floor is of no account, and can be treated simply as a hewer of sand and a thrower of water.

What are we going to do about this? I do not wish to be considered harsh in my judgment, but there are times when I hold the opinion that where we are concerned with the processes of thought, and the habits engendered by a lifetime's experience, to effect a change is tremendously difficult, and in some cases almost impossible, but we can and must so legislate that in the foundryman of the future these two vital factors are welded as closely as possible into one. I need not emphasise the achievements of the non-technical foundryman. The world is full of tributes to his amazing practical and artistic skill, and he can claim that until fairly recently he got along with little or no technical assistance, because it was not at his disposal.

Better Type of Recruits Needed

Our Institute exists mainly for the provision of this technical knowledge and assistance, and depends for its continued success on a supply of men who can appreciate the benefits to be derived from its membership. The examination of our requirements results in the opinion that for the proper functioning of our industry we need combined practical and technical intelligence of a very high degree.

An association of technically and commercially uninformed artisans, no matter what their individual skill, cannot keep our industry or our Institute in the front rank.

Now I arrive at the question: Is our industry in any of its branches attracting to its ranks in any numbers the type of man indicated as necessary? One's own experience, the opinions generally expressed when foundrymen foregather, our trade journals, are all eloquent of the fact that we are not. The Foundry Trade Journal when dealing with this matter a few months ago said "It has been a commonplace for years that the quality of the youths entering founding is lower than that of those entering the engineering trades for such occupations as fitting, turning, and so on. Fathers who are moulders are less willing than they were that their sons should follow in their trade, and consequently the calibre of entrant is bound to diminish."

Why is it so? What governs a young man in his choice of a career? His own inclinations, desires and reasoning, coupled with the advice of his elders, to all of whom the main question is "What does the career under consideration promise in working conditions and material prospects?" Some of you may be of the opinion that we as an Insitute are not concerned with the material prospects side of the problem. Can we as an Institute consider our industry's development in research, organisation or personnel—and you must agree that we are vitally concerned with these three aspects—without being forced to give consideration to, and to form some opinion on, the material prospects phase of the situation? In any case, in developing my arguments this morning, I am unable to escape it.

Modern Youth

Modern youth is criticised as has been the youth of all time, but we have to remember that the modern youth is more critical than his predecessors. The ambitious, well-intentioned youngster does exist even to-day, and we want him in our industry. What do we offer to such a youth in search of a career in whatever section of our industry his particular conditions and training fit him for? Are we able to say that the conditions and rewards of our industry, apart from isolated examples, are such as to be attractive to intelligent and aspiring young men? Can we expect the type of youth who is going to develop into this man of dual and complete attainments, to whom we have referred, to be attracted to any but the most exceptional foundries? Is it not easy for him to find a much more congenial calling, and if a lad is willing to brave the conditions he will find in so many foundries, are the usual material prospects such as to offer some compensation for the unsatisfactory conditions which exist?

The knowledge and skill required in a foundry are certainly not less, and are most probably more, than those required in much more remunerative and less unpleasantly arduous occupations.

General Improvement Essential

Lord Austin, at our Birmingham Branch dinner, said that he had never been able to understand why the foundry had always been the "Cinderella." Can we expect ambitious young men to be attracted to an industry which carries such a label? There is plenty of evidence that this is one of our industry's main problems and we as an Institute have to face it. If this reasoning be correct, then we must aim at less arduous toil in more attractive surroundings by improving the construction and lay-outs of our foundry buildings and by the introduction at a much accentuated rate over the present one of methods and plant for elimination of the heavier tasks attached to the production of castings, and as an industry we must be prepared to negotiate on competitive monetary terms for men capable of filling responsible posts. I submit that this difficulty with regard to personnel has to be considered on a very much wider basis than just a shortage of recruits. I contend that it is largely a reflection of the general conditions of our industry, and that a satisfactory supply of recruits can only be expected as a parallel of a decided improvement in those general conditions.

Lord Austin is a very able man, a man so able and successful as to render his opinions worthy of serious consideration, and for him to refer to the foundry as the "Cinderella" is another reminder of our lowly status in the industrial world. To many of us, this represents another very real problem, and I would like to devote a few moments to its consideration.

Assessing the Blame

Let me quote further from Lord Austin's speech at Birmingham. After referring to the foundry as the "Cinderella," he continued by saying, "The foundry still lags behind other departments. I do not think it is the fault of the foundryman, but the fault of the financier and the engineer, who have not appreciated as they should have done the big things there are to be gained in a well-organised, well-equipped and well-run foundry."

I am going to ask, "Does the foundryman himself appreciate what is to be gained by a well-organised, well-equipped and well-run foundry?" I do not blame the financier and the engineer. I would like to convince you that the responsibility is ours. Is it not true that our industry for longer than any other, relied almost solely on what I have called "the individual skill of technically and commercially uninformed artisans," and that even to-day a large section of the industry has changed but little in this respect? This being so, what chance have we of getting our deserts from the technical and commercial giants with whom we have to battle? We cannot expect the financier or the engineer, of their own volition, to show us the consideration we think we deserve. We have to save ourselves or we are lost. One's impression of the situation is very largely this: Here are we, claiming to be the basis of all engineering industry, continually bemoaning the fact that we are the "Cinderella," that we are called upon to make castings of improbable design at impossible prices, that neither the designer nor the buyer gives any consideration to the foundry, that the foundry from both the designer and the buyer has to take what it can and not what it ought to get. Is not this very largely a confession of failure on our part?

Designers' Difficulties

Let us deal first of all with our complaint about that much-maligned individual, the designer, who, many of us think, is too often prone to ignore what to us are fundamentals. The designer does generally realise to the best of his ability that the efficiency of the ultimate product demands that the design of the casting shall be dictated, not only by the requirements of the engineer, but by expert knowledge of the materials and processes used in the production of castings. Foundrymen are continually claiming that this expert knowledge is not evident in much of the work of the designer. If such be the case, then it means that sufficient knowledge of this type does not exist among the designing fraternity. Is not the responsibility for this also largely our own? The knowledge of our industry must come from our industry. Have the conditions in our industry been such as to produce sufficient men with this expert knowledge, and the ability to interpret that knowledge in the form of design or to the draughtsman so as to influence general casting design along the right lines? Am I not correct in stating that so far the users and designers of castings have not had a tremendous amount of help and instruction from the foundry industry itself? We must not console ourselves with the statement that they will not let us help them. We have somehow got to convince them that we can do so. They have not, and they will not, look to the ordinary non-technical foundryman for this assistance. If we provide the right sort of help in this connection, the engineer and the designer will be glad to avail themselves of it.

Ambassadorial Requirements

We are all agreed upon the desirability of improving the status of our industry and our Institute. This means that we are claiming recognition and consideration from our industrial contemporaries, but we shall not convince the engineer, the designer, or the financier from, or in, the sand heap. We must have men in our industry with the ability to present our case in the drawing offices, the laboratories, and the board rooms of the industries for which we cater.

I suggest to you that the problems of foundry personnel and foundry status are closely connected. Improve the one, and you will improve the other, but we shall not attract to our industry the type of man we require, nor shall we improve the general status of the industry, unless and until we improve the general conditions of the industry, and by general conditions, I mean everything that goes to make up the life of a foundryman. It was in this connection that I asked the question, " For what the foundryman does, what does the foundryman get? "

I believe that we are unanimous in the opinion that the general conditions in our industry are not what they should be. How can they be improved? If we, as an industry, were " well organised, well equipped, and well run " we should have good conditions, we should compete successfully for the best among the recruits to industry, we should command the consideration of the engineer, and the respect of the financier.

A Badly-Organised Industry

Does our industry in general consist of foundries that are well organised, well equipped, and well run? I am afraid the answer has to be in the negative. Let us consider for a few moments the question of organisation. A lecture on this subject is outside my present purpose, but I want to emphasise its importance as affecting the problems under consideration. I hold the opinion that in our industry as a whole, as well as in our individual foundries, organisation is not very strongly in evidence.

In referring to organisation as applied to the whole of an industry, many people at once think of a strong trade association for the maintenance of price levels. I am going to claim that the greatest protection for our or any industry is efficiency, and it is this rather than price maintenance which should be the object of trade associations. Efficiency in an industry is the only guarantee to the community of real service from that industry. We as an Institute have no desire or claim to study the question of profits, but we exist for the promotion of efficiency in the industry. Given all round efficiency, profits will not be problematical.

Increased Efficiency Essential

We are vitally concerned that our services to the community shall be of ever increasing value. This latter, to put it very simply, means that the purchasing power of the community in relation to our industry must be continually increasing, and for that to be achieved, we must produce better castings at relatively lower prices, and yet maintain a high and improving level of living for all employed. There is evidence in several highly-successful industries that this can be done by efficient methods, and our policy should be to convince industry that the Institute of British Foundrymen exists for the scientific advancement towards efficiency along the lines of education, research and development of every phase of foundry production.

What does organisation mean as applied to the individual foundry? The dictionary tells us that science is knowledge reduced to system. I would say that organisation means effort reduced to system. Its application ultimately means effort reduced *by* system.

The foundry industry generally is run on the lines of prodigality of effort, and surely, faced as we are by the probability of a serious shortage of personnel in all the branches of our industry, we should realise the value of any factor contributing to the conservation of effort.

The analytical mind should not be confined to the laboratory. There is a tremendous field in our foundries for analysis and the systematising of effort. Any effort which by proper organisation could be avoided is waste effort, and I would venture the opinion that waste effort costs our industry more than waste castings.

Organisation is more important than equipment. Much good equipment has been rendered unproductive and uneconomic by bad organisation, but good organisation will very quickly discover the necessity and the wherewithal for good equipment.

Organisation is the proper and most important exercise of the managerial function. I hesitate to mention the word "management" in close conjunction with the word "scientific," because together they have been much abused, but we should realise that all good management must be scientific, even if all scientific management is not good management.

Organised Management

Let us aim, then, at organised management. The functions of a manager are too often limited to the making of arbitrary decisions, and the maintenance of discipline, and often, through lack of organisation, we find these two factors keeping him in a perpetually harassed state, without anything material being achieved in the shape of investigation or development. By applying the analytical and dimensional faculties to the direction of the energy expended in our foundries, we shall be conducting research in an almost unexplored field.

Organised management will devise systems which weld the many separate units contributing to production into one harmonious whole. Systems which ensure that the knowledge, experience and effort which are expended on a job to-day are to-morrow, not hanging by the slender thread of human memory, or lost in the limbo of forgotten things, but have left behind them in some easily accessible form, records which will contribute materially to every future job. Working along these lines of record, analysis and comparison, our foundry managements will appreciate the value of good conditions and will achieve them. They will see the necessity for good equipment, and will acquire it, and by their knowledge of their own particular circumstances, they will be in a position to select the best type of equipment for their own particular job.

My remarks so far have been intended as a plea for developments in management and equipment as contributing to better conditions and prospects leading ultimately to improved personnel and status.

Our Institute striving towards progress by means of education, research and development, is becoming increasingly conscious of the importance of the economic factor, so conscious as now practically to be forced to take steps to increase its income in order to provide the wherewithal for the maintenance of its progress, and to my listeners no doubt this plea for better conditions terminates mainly in a question regarding the wherewithal. They are probably quite convinced that with good conditions and good equipment, everyone connected with the foundry would have a better time, but where are these things coming from? Many claim that for years it has been difficult to keep one's head above water, in spite of economies in regard to salaries and plant expenditure, and so with a scarcity of personnel because of the poor conditions and remunerations existing, and an inability of the capital involved to improve those conditions, because of the inadequate returns such capital is receiving, many foundrymen find themselves at a loss for a solution to these problems. Yet for the realisation of our ideals, a solution has to be found.

Interlocking Progress

Let me repeat that I am fully alive to the fact that as an Institute, we are not supposed to be concerned with the economics of the industry, and by some I may be thought to be treading on dangerous ground, but as an Institute, we are actuated by a desire that our industry should progress, because we can have no existence apart from the industry, and the vitality of the industry is largely the measure of our own. In dealing with these problems of personnel and status, I am, as you see, brought up against the question of general conditions, and in dealing with the latter, I find it impossible altogether to avoid contact with the economic factor.

Adequate General Remuneration

Lest any among you should fear that I am going to talk about profits, let me define the limits of my considerations in this way: We, as a craft and industry, were hard at work at the very foundations of civilisation, and we have, ever since, continued to make tremendous contributions to the well being and progress of mankind, and as an important constituent of that larger organism, the community, we have a right to claim a return for our services such as will enable us to work under good conditions with such remuneration as those engaged in an important industry are worthy, with something left over for research and development. All these things should be accounted for in assessing the value of our products.

That explanation claims a return for our efforts which is at least equal to our expenditure, and whether we are under a capitalistic or communistic *régime*, such return in some form must be assured if those engaged in the industry are to maintain what is generally accepted as good conditions of work and living. So, leaving profits out of the picture entirely, we will only consider ensuring to our industry a return based upon the value of its products. The remuneration of our industry is the governing factor in its standard of working conditions and life for all engaged in it. Continuous development, with constant improvement in working conditions, is the only standard we can be asked to consider. There can be no such development or improvement unless the return for our products, at its minimum, is equal to the efficient cost of those products. Anything less is detrimental to the industry and those engaged in it, and is eventually detrimental to the community.

It may be comparatively easy to achieve such a minimum at a time when demand exceeds supply—it may even be possible to approach an unjustifiable maximum, which will later have to be paid for in reaction—but what we want is the knowledge which will enable us, in both good and bad times, to consider the question " What ought we to get?" as well as, or even preferably to, the question " What can we get?"

My argument is not for increased prices. I claim that a well-organised, well-equipped, well-run foundry industry will result ultimately in the lowering of the cost of its services to the community, but such an industry will also have the knowledge and power to take some part in the assessment of the value of its products.

Need for Proper Costing

Now comes the question, " Has the foundry industry in general the knowledge necessary to assess the value of its products? "

I do not hesitate to reply in the negative, and I am equally emphatic in stating that to this particular weakness in our industry's structure can be attributed many of the disabilities which we as foundrymen consider to be our portion. It is because of this that I hold the view that in bringing the subject of costing to the fore, our Institute is doing a very real and necessary service to the industry.

I believe that many foundrymen think that costing is a job solely for the accountant, and is something quite outside the scope of the industry itself. To them I would like to say that costing is as integral a part of our industry as is the laboratory, and there exists no more important adjunct to organised management than a good costing system. Its value as a dimensional factor in the works as distinct from the office cannot be exaggerated.

A costing system, to be efficient, must be so modelled as to embrace and cater for the special circumstances attached to each industry and department, and should be so simple as to be interpretable by the head of the department concerned. Such a system can only be achieved by the co-operation and understanding of the foundry executive with the cost accountant.

Costing is not an abstruse subject. Its main constituents should be logical reasoning and simple arithmetic, and I suggest that none of our deliberations at this conference will be of more important interest than those which centre round the report of the Costing Sub-Committee. I am not going to give you a foretaste of the Sub-Committee's findings, but in connection with the points I have raised I am anxious to direct your attention to what I consider to be an indispensable factor in the building up and maintaining of efficiency and good conditions in our industry.

The thirty-four years during which our Institute has existed have witnessed a more than remarkable development on the technical side of our industry. We have extended the knowledge of our materials to almost indescribable limits. The quality and scope of our products is evinced in the demands made upon us. There is not a section of industry to which by our products we do not make considerable contributions. Yet in spite of all this, among the foundry's chief problems are its lack of recruits and its lowly status. In my remarks I have endeavoured to point to improved conditions resulting from a higher level of organised efficiency as a possible solution.

The past, present and potential demand for castings, combined with the mental and physical efforts necessary for their production, form the fundamental basis of our industry's importance. With us lies the responsibility that our general organisation and efficiency is such as to produce conditions attractive to the best brains available and to ensure that the status of the foundry is among the highest in industry.

A hearty vote of thanks was accorded the President, on the proposal of Mr. H. Winterton, for having presented some of the problems of the foundry in a completely new light and in a very convincing manner.

The "Edward Williams" Lecture

Dr. C. H. Desch, F.R.S. (Superintendent, Metallurgical Department, National Physical Laboratory), delivered the third "Edward Williams" Lecture, his title being "Physical Factors in the Casting of Metals."

Vote of Thanks

Mr. J. E. Hurst (Past-President), proposing a vote of thanks to Dr. Desch, said that the subject was peculiarly interesting to foundrymen. The value of the "Edward Williams" Lecture lay in the fact that specialists in particular branches of investigation work and in various sections of industry put forward up-to-date knowledge and surveyed all the work with which they were concerned. Inasmuch as the individual members of the Institute were operating in every branch of the foundry industry and of necessity became specialists in their particular branches, the opportunity which the "Edward Williams" Lecture afforded was very welcome to them.

One of the allegations by practical men against the metallurgist in the past was that he had been very academic and tended to deal with academic subjects. The lecture by Dr. Desch, however, would demonstrate very clearly that that allegation had absolutely no justification in fact. In recent years there had been a sort of reorientation of the attitude of metallurgists in investigation work and they tended to study subjects in connection with the casting and working of metals; the practical man might regard that as a victory for the attitude he had expressed in the past.

It seemed that Dr. Desch had wandered about among the various metals in a delightfully carefree manner; steel, cast iron, brass, bronze, gold, silver, platinum and gallium and others of the rarer metals had come within the purview of his lecture. It seemed that the reorientation of the attitude of metallurgists during recent years might be tending to break down the old-established divisions which had arisen in metallurgical study. Mr. Hurst had in mind the broad division of ferrous and non-ferrous metallurgy. It would appear that in the modern study of metals, divisions based on composition were fast disappearing.

The vote of thanks was seconded by Mr. H. Winterton and carried with acclamation. Dr. Desch briefly responded.

The following Paper was then discussed:—"Recommendations Concerning the Establishment of Costs in a Grey Iron Foundry," by the Costing Sub-Committee of the Technical Committee. The Paper was presented by Mr. V. Delport, Convener of the Sub-Committee.

The Conference adjourned at 12.45 p.m. Members lunched at the Assembly Rooms, where they were joined by the ladies who had inspected the works of the Royal Crown Derby Porcelain Company during the morning.

During the afternoon parties of members visited the following works:—

Bamfords, Limited, Uttoxeter.
Ley's Malleable Castings Company, Limited.
Qualcast, Limited.

At each works the party was entertained to tea, and the thanks of the Institute were conveyed to the directors and staffs. The ladies spent the afternoon in visiting the parks of the Borough of Derby and were entertained to tea at Darley Park.

ANNUAL BANQUET

A very large number of distinguished guests and members attended the annual banquet, which was held at Bemrose School, Derby, on Wednesday, June 9. The modern school buildings provided an admirable setting for such a function, and the floodlighting of the buildings added considerably to their attraction.

The President and Mrs. Bigg received the members and their guests before dinner. The company included the Worshipful the Mayor of

Derby (Councillor Mrs. Petty), Mr. A. Hutchinson (President, Iron and Steel Institute), Mr. W. R. Barclay (President, Institute of Metals), Sir J. Arthur Aiton and Lady Aiton, Mr. H. Winterton (Immediate Past-President of the Institute of British Foundrymen) and Mrs. Winterton, Mr. J. Hepworth, M.P. (Senior Vice-President) and Mrs. Hepworth, Mr. W. B. Lake (Junior Vice-President) and Mrs. Lake, Mr. E. J. Fox, Mr. F. D. Ley (Chairman of the Reception Commitee), Mrs. F. E. Russell, Mr. W. Allan Reid, M.P. (Senior M.P. for Derby) and Mrs. Reid, Mr. S. H. Russell (hon. treasurer and Past-President of the Institute) and Mrs. Russell, Mr. C. Murray (President, Derby Chamber of Commerce) and Mrs. Murray, Dr. C. H. Desch, F.R.S. (head of the department of metallurgy, National Physical Laboratory), Dr. W. A. Richardson (Principal, Derby Technical College) and Mrs. Richardson, Mr. A. C. Turner (President, Foundry Trades' Equipment and Supplies Association), Mr. J. W. Gardom (Convener of the Institute's Technical Committee), Mr. Barrington Hooper (managing director, Foundry Trade Journal), whilst other Past-Presidents present included Mr. F. J. Cook, Mr. John Cameron, Mr. V. C. Faulkner, Mr. V. Stobie, Mr. R. Stubbs and Mr. J. E. Hurst.

The Toasts

The loyal toast having been honoured, MR. ALFRED HUTCHINSON, M.A. (President of the Iron and Steel Institute), proposed success and prosperity to the Institute of British Foundrymen. It was a pleasure to be present, he said, first in his personal capacity, and also as President of the Iron and Steel Institute, which, as the oldest of the Institutes existing for the furtherance of research in the iron and steel trade, considered it to be a responsibility as well as a pleasure to encourage all allied bodies connected with the various branches of the industry as a whole.

A further personal reason why he was glad to be entrusted with the toast was that, though he was never a foundryman, the first ten or fifteen years of his business life were spent on a blast-furnace plant and the greater part of the pig-iron produced there was consumed in foundries. His particular job was to visit customers and clear up any complaints as to the quality of the iron supplied, a task which had afforded him ample opportunity to see how foundries were run. In those days he had found them to be run mainly on rule-of-thumb lines, the practical management being largely in the hands of foremen with little technical knowledge of chemistry or of the importance of sulphur and silicon contents or of the uses of fluxes in the cupola. In one instance within his memory the only flux was blast-furnace slag from the slag heaps of the neighbouring blast-furnace plant! There was, of course, a general belief in the appearance of the pig-iron on fracture as an indication of its suitability for the light castings or heavy pipes made; but he could recall only one works—and that was making a speciality—at which a chemist was employed at that time, and there they had confided to him that the employment of a chemist saved them at least 2s. 6d. per ton on the cost of their pig-iron mixture! Microscopic examination was unknown, and a macroscopic examination of a fracture had often led to curious inferences.

Institute Creates New Outlook

As the darkness of ignorance had prevailed in those early days, the dawn was at hand, and the sunrise had taken the form of the foundation of the Institute of British Foundrymen. It had in view the very worthy objects to initiate, conduct and supervise researches into the science and technology of the art of metal and alloy production, casting and working; to organise the technical education of the workers and to collect and distribute information on the art and science of foundry work. In so doing, it had paid due attention to the need for research and inquiry on the scientific matters connected with all real progress in industry. All foundry work was based on truly chemical and physical laws, and the chemical investigation as to the value of metallic and non-metallic contents in the substances used—not only in the pig-iron, but also in the coke, flux and casting sand—must be scientifically pursued and thoroughly understood if we were to improve quality and reduce costs. Only the trained scientific man could carry out such work. Therefore, the chemist had come into his own, and the result of such scientific work had produced little short of revolution in foundry practice. Foundry mixtures, by analysis in contrast to the old rule-of-thumb methods, had given better castings in every sense, improved quality and increased strength.

It was not only in the quality of the finished casting that improvement had taken place. New mixtures of iron and non-ferrous alloys had been produced, never dreamed of in his early years in the industry. However, he did not wish to leave the impression of having given credit to the chemist alone; it was much more than a matter of pure chemical research. The practical bearing on the day-to-day work in the foundry, on the structure of the cupola, the lay-out of the whole works and the mechanisation of the works as a whole, indeed, the truly scientific management of the whole works, had resulted from the advance of our technical knowledge. One of the chief contributions to the transformation from the old to the up-to-date foundry had been the good work of the Institute. The awakening to the value of scientific knowledge had become contagious. Managers and directors alike had become aware of the value of the interchange of knowledge, of discussions at regular meetings of the Institute of matters so vital to progress. Further, the Institute organised the spread of knowledge and technical efficiency. Papers were read and discussed by its members and by members of similar societies which had sprung into existence in other foundry centres. The belief in secret mixtures and secret nostrums had gone; the Institute had sounded the death knell of such old-fashioned methods. Mutual discussions of improved methods, mutual interest in every kind of technical advance, interest in the other fellow's method of attacking problems and free visits to each others' works were all to the good.

Mr. Hutchinson paid tribute to the officials of the Institute for the successful development of its work, and coupled with the toast the name of Mr. Bigg, the President of the Institute.

Wider Dissemination and Use of Knowledge Necessary

The President, on rising to respond to the toast, was received with prolonged applause. It was a source of great pleasure, he said, to hear the Institute referred to in so complimentary a manner by the President of a kindred body of such eminence as the Iron and Steel Institute, and it was a source of pride that the achievements of the I.B.F. were such as to merit fully the high praise that was bestowed upon it. It was a fact that no voluntary organisation had ever contributed more to the progress of an industry than the Institute had made to the progress of the foundry industry—and it was equally true to say that no industry was more in need of such contributions than was the foundry industry! He never hesitated to claim that the Institute was doing a tremendous amount of vital work in collecting and distributing knowledge to the industry. A professor at one of our universities had suggested recently that we were suffering from a surfeit of knowledge, and had said that our problem lay in bridging what he had called the ever-widening gulf between the specialised knowledge of the expert and the profound ignorance of the ordinary man. The President was not altogether in agreement, however, with the idea that we possessed too much knowledge, for we could not have too much. Rather did the trouble lay in either the non-application or the wrong application of the knowledge that we possessed. He emphasised, however, the latter part of the professor's remarks, with reference to the gulf between the knowledge of the expert and the ignorance of the ordinary man, and said that observation would convince us that to a degree that gulf was exemplified in the foundry industry. A tremendous amount of knowledge had been acquired, but it was in all too few hands; more experts were wanted in the application of knowledge. Many of our experts expended all their energies in the acquisition of knowledge; its application was equally important, however, and the guidance of the distribution and application of our expert knowledge should surely be one of the chief tasks of the Institute. The foundryman had no use for "knowledge done up in bundles," but wanted it in a readily applicable form. To the foundry industry the value of knowledge could be assessed only by reference to saleable castings.

The Institute, he continued, catered for the whole industry—from the man working on the floor to the technician and the executive, right up to the managing director. That wide range of membership, with its consequent variety of thought and expression, formed an ideal medium for bridging the gulf referred to, in order to enable the knowledge of the expert to be distributed and applied in the industry. Because of that, no single individual or firm in the industry could ignore the Institute's claims to their support.

Although it was time to consider "shutting off the blast," said the President, there remained still one charge to come down; it was a charge made up of 50 per cent. appreciation and 50 per cent. gratitude, which he hoped resulted in a close homogeneous mixture of good-will. That was the prelude to his expression of appreciation and gratitude to all who had contributed to the successful Derby conference. The generous response of so many friends to the appeals made for the "sinews of war," and the hospitality and assistance in many ways rendered by The Mayor and her colleagues in the Corporation, placed every member of the Institute under a deep sense of obligation to Derby. He paid a personal tribute to Mr. B. Gale for his help and guidance; to the many firms whose works were visited, for the splendid facilities and hospitality they had provided; to Dr. Richardson and his staff at the Technical College; to Mr. T. Makemson, the Institute's general secretary; to Mr. S. H. Russell, the convention "Chancellor of the Exchequer"; and to the East Midlands Branch. He was indeed proud of that Branch, and did not know what the Institute would do without it! The members of the Branch had thrown themselves into the work of organising the Conference with a readiness and ability which could have left no doubt as to their ultimate success. The bulk of the work had fallen on the shoulders of the Branch Secretary, Mr. B. Gale, who had done his job with a quiet efficiency which had won the admiration of all.

A Presentation to Mrs. Winterton

On behalf of the Past-Presidents of the Institute, who appreciated the self-sacrifices made by the wife of a President during his year of office, Mr. Bigg presented to Mrs. Winterton a Crown Derby tea service as a tribute to the charming and gracious manner in which she had supported her husband, Mr. Harry Winterton, during his period of office as President.

The presentation was made amid the cheers of the company; and Mrs. Winterton, expressing her thanks, voiced the hope that many of her friends in the Institute would visit her and share the joy of using the gift.

The Borough of Derby

Mr. J. Hepworth, M.P. (Senior Vice-President of the Institute), proposing "The Borough and Trade of Derby," said it was both a privilege and a pleasure to do so, particularly because the hospitality and kindness extended to the Institute had been *par excellence*. The management of the Borough, he said, stood out in regard to its social and educational facilities; and the beautiful building in which the Institute's banquet was being held provided ample evidence of the care which was devoted to the education of the youth of the Borough. That was to be expected, of course, where there was a lady at the head of affairs, as was the case in Derby.

On the whole, therefore, the citizens of the Borough had every reason to be proud of their industry and of the way in which the Borough was managed. He wished the town continued prosperity, and coupled the toast with the names of the Mayor and Sir Arthur Aiton.

THE WORSHIPFUL THE MAYOR OF DERBY (Councillor Mrs. Petty, J.P.), who received a great ovation, responded on behalf of the Borough. Derby, she said, was one of those fortunate cities which had developed a variety of industries—and if some of the hard-headed gentlemen of other shires had been as far-sighted in the past as had the people of Derby, they might have had less problems to face in their own neighbourhoods! However, the response on behalf of the industrial life of Derby could well be left in the hands of Sir Arthur Aiton.

Derby had a definite history from the days of the Roman occupation. It had its "Little Chester," the very name of which indicated Roman occupation, and in the caverns of Derbyshire there were many traces of pre-historic man. The Mayor also commented on the part played by the Saxons, the Normans and the Danes in Derby's history, and pointed out that the Danes had chosen the name of "Derby." As a borough, Derby had a history covering a period of 1,000 years at least. A distinctive feature with regard to Derby was the fact that every one of its citizens had two Parliamentary votes; that state of affairs had continued since the 13th century, a record of which the city was justly proud. Again, it was the first city outside the city of London to provide a domestic water supply. It was provided by a local engineer who had helped many other towns in a similar manner.

Sir J. Arthur Aiton, responding on behalf of the trade of Derby, supported the Mayor's remarks concerning the varieties of industries in the Borough, and commented upon the enterprise of the Borough Development Committee, which had resulted in his selection of Derby as the site of his works thirty years ago. His firm had recently erected a large new foundry designed for them by a member of the Institute.

Touching on the problem of training personnel, Sir Arthur said that if we were to continue to employ men who were little better than machine tenders, even though the foundries in which they were employed were beautifully designed and well managed and organised, we should lose the splendid skilled foundrymen of this country. Already it was difficult to secure their services, for we could not expect to raise such men by machine moulding. His firm's foundry had its own school, and Dr. Richardson and his staff at the Derby Technical College helped in the training of the men by the classes they had arranged. Though the scientific knowledge was absolutely necessary, the best would not be obtained from foundries if men were not trained to carry out the actual work or to make foundry work attractive to the better class of man it was desired to attract.

Mr. S. H. Russell (hon. treasurer and Past-President of the Institute) proposed "The Guests." It was impossible, he said, within the limited time at his disposal, to mention all the guests individually and to expound their virtues, because the guests and their virtues were numerous; and to attempt to generalise was equally unsatisfactory. However, he mentioned some of the guests particularly, assuring all that they were most cordially welcome and that their presence was greatly appreciated. He paid tributes to the Mayor and her colleagues, including the Corporation officials, who had made it possible for the Institute to hold its convention in Derby, and had placed the Bemrose School at the disposal of the Convention Committee; to the President of the Iron and Steel Institute (emphasising with great appreciation the co-operation between the Iron and Steel Institute, the Institute and the British Cast Iron Research Association); to the President of the Institute of Metals; to Dr. Desch, a representative of the National Physical Laboratory; to the Principal of the University College, Nottingham, and the Principals of the Technical Colleges in Derby, Leicester and Loughborough, emphasising the great debt which the East Midlands Branch of the Institute particularly owed to the education authorities of those towns; and to the Members of Parliament, heads of business, and the ladies. He coupled with the toast the names of Mr. W. R. Barclay (President of the Institute of Metals) and Mr. E. J. Fox, to whom he referred as one of the oldest and staunchest friends of the Institute.

Mr. W. R. Barclay, O.B.E. (President, Institute of Metals), in his response, commented on the close interest between the Institute of Metals and the Institute in the work they were doing, and said he believed that the branch of metallurgy with which the Institute had been concerned had a more distinguished and honourable history than perhaps any other branch. It was difficult to discover just when foundry work had begun. It was surprising, and perhaps a little humiliating, that hundreds of years ago craftsmen were producing glorious works of art in metals. Craftsmanship was one of the concerns of the Institute which it must always place in the forefront. Both the practical and the scientific worker were essential to the industry, for the skilled workman and the skilled research worker could be successful only in the degree to which both sought to obey to the very utmost of their power the laws of nature.

Mr. E. J. Fox took advantage of the late hour to scrap the speech he had intended to make (following the example of Mr. Barclay), and contented himself with an expression of thanks for the hospitality extended to the guests, and the hope that he would have the pleasure of welcoming many members of the Institute to the Stanton Ironworks on the following day. He claimed to be a foundryman, because his interests were occupied in re-melting 10,000 tons of iron per week, a quantity far in excess of that which was remelted by any other undertaking in the world.

Following the banquet, the members and their guests enjoyed dancing until a late hour.

THURSDAY, June 10

The Conference resumed at 9.30 a.m. at the Derby Technical College.

The President, Mr. C. W. Bigg, presided over Session A, and later in the proceedings vacated the chair, which was then taken by Mr. F. J. Cook, Past-President.

Mr. J. Hepworth presided over Session B, which was devoted to Papers on non-ferrous subjects.

The following Papers were presented and discussed :—

Session A.

" Wear Tests on Ferrous Alloys," by O. W. Ellis (presented on behalf of the American Foundrymen's Association) ; " Additional Data on the Manufacture of Ingot Moulds," by R. Ballantine; " Foundry and Laboratory Characteristics of Cupola Coke," by Dr. H. O'Neill and J. G. Pearce.

Session B.

" The Elimination of Gaseous Impurities in Aluminium," by Professor Georges Chaudron (presented on behalf of the Association Technique de Fonderie, France) ; " Re-melting Aluminium in the Foundry," by H. Rohrig (presented on behalf of the Technischer Hauptausschuss fur Giessereiwesen, Germany) ; " Notes on the Structure and Characteristics of Aluminium Alloys," by H. C. Hall; " Trends in the Non-Ferrous Foundry," by Dr. L. B. Hunt; " The Use of Nickel in Non-Ferrous Alloy Castings," by J. O. Hitchcock.

Greetings

Immediately after the presentation of the American Exchange Paper in Session A:—

Mr. V. Delport said that in connection with the Paper from Mr. Ellis, and the exceptional pleasure everybody had had from it, he would like to announce that he had just received a cable from the American Foundrymen's Association in which the Board of Directors send their greetings and best wishes for the success of this Conference.

Mr. T. Makemson said that the Institute had also received greetings from the French Foundry Association which read: "We send our British colleagues cordial salutations and best wishes for the Conference." Greetings have also been received from several Institute members, including Mr. A. Harley, Past-President, who has been seriously ill.

The British Foundry School

Mr. Pearce then made a statement as to the position of the British Foundry School.

Mr. C. C. Booth, commenting on this, said that whilst he had been listening to the President's brilliant address, he felt that the members of the foundry industry might be charged with gross neglect. All yesterday's speakers emphasised the necessity for educating the younger members of the industry, yet this was a point which had been for many years sadly neglected.

Two years ago the British Cast Iron Research Association and the Institute of British Foundrymen, in collaboration with a number of other technical associations, started a Foundry School. It had been said that it was unfortunate that this should have been done so soon after the inauguration of another excellent course at Sheffield University, but he did not think that there was any real clash between the two. The course given by the Foundry School was a curtailed one, and it was essentially for men with some previous foundry experience.

He would like to emphasise the excellence of the training given. He showed the examination Papers to the Principal of a large London technical institute, and he commented that anyone, who could answer it well, as all those who had taken the course did, would have a mass of very valuable knowledge.

Continuing, he said from the report circulated it will be seen that there were 13 students for the first year, but now the second year only five. Although the educational authorities, it is thought, are not likely to withdraw the very substantial grant which they make towards the upkeep of the School, and it amounts to nearly three-quarters of the total, as taxpayers foundrymen would not wish their money to be spent on an object which was receiving so little support from the industry which it was planned to assist.

It is for the members of the Institute to follow the President's lead, and assist this cause as much as possible with men even more than with money, and thereby to assure that the young men in the industry were given a suitable training. If one firm alone was not able to send a student, it might be possible to send one from, say, three or four. It might even be possible for each Branch to arrange for one or two students to be sent by its members. He sincerely hoped that this excellent project was not going to be allowed to drop from lack of interest after the valuable lead given by the President.

The Conference adjourned at 12.15 p.m.

A party of members proceeded to the Stanton Ironworks, where they were entertained to lunch and afterwards inspected the works. The remainder of the members and the ladies lunched at the Assembly Rooms.

During the afternoon parties of members participated in each of the following visits:—Herbert Morris, Limited, Loughborough; Loughborough College.

Hospitality was extended to the visitors at each establishment, and thanks were tendered to the directors and staff of Messrs. Herbert Morris and to the Principal and staff of Loughborough College.

Parties of ladies visited the following establishments:—Messrs. Webb & Corbett, Limited, Tutbury Glass Works; C. H. Elkes & Sons, Limited, biscuit manufacturers, Uttoxeter; Boots Pure Drug Company, Limited, Beeston.

On Thursday evening members and ladies were entertained by the East Midlands Branch at a social held at the Assembly Rooms, Derby. A concert party provided entertainment, and dancing was held throughout most of the evening.

During an interval in the proceedings, MR. C. W. BIGG (President) paid a tribute to the work of Mr. B. Gale, the Secretary of the Conference. Although many members of the Branch. he said, had contributed to the success of the Conference, on Mr. Gale had fallen the main burden, and the members of the East Midlands Branch were anxious to give to Mr. Gale some token of their appreciation.

Presentation to Mr. Gale

MR. H. BUNTING (retiring President of the East Midlands Branch), in presenting Mr. Gale with a cheque on behalf of the Branch, said that the gift was in no way a payment for services, but a tangible recognition of very valuable work.

MR. GALE, in responding, was received with loud applause. He briefly expressed his thanks, and voiced his appreciation of the co-operation he had received from the other members and officials of the Branch.

Excursion to Derbyshire Beauty Spots

On Friday about 100 members and ladies took part in an excursion through the beautiful scenery of Derbyshire. The party left Derby by motor-coaches and proceeded by way of

Ashbourne and Longnor to Buxton, where luncheon was served at the Spa Hotel.

After luncheon, Mr. Bigg (President) took the opportunity to propose that the sincere thanks of the members who had attended the Conference be tendered to the President and officers of the East Midlands Branch for the wonderful arrangements they had made for a most successful Conference.

Mr. H. Winterton (immediate Past-President of the Institute) seconded the proposal, and as one of the visitors to Derby, spoke of the most hospitable manner in which the visitors had been received by the Mayor and Corporation, and by members of the East Midlands Branch.

Mr. H. Bunting, responding on behalf of the Branch, expressed the delight of the members of the Branch in having the opportunity to organise a Conference and in entertaining their colleagues from other districts.

In the afternoon the party continued their tour and proceeded via Bakewell to Matlock, where they were entertained to tea at the New Bath Hotel by the President and Mrs. Bigg.

Mr. F. J. Cook (Past-President) expressed the thanks of the members to the President and Mrs. Bigg for their hospitality; Mr. J. Cameron (Past-President) seconded, and also took the opportunity to congratulate the East Midlands Branch and Mr. A. E. Peace and Mr. H. L. Sanders on the very excellent souvenir booklet which had been issued.

Mr. C. W. Bigg (President) replied.

The journey was afterwards resumed, the party arriving in Derby during the early evening.

THIRD EDWARD WILLIAMS LECTURE

PHYSICAL FACTORS IN THE CASTING OF METALS

Paper No. 605

By C. H. Desch, D.Sc., Ph.D., F.R.S.

Many physical properties are involved in the filling of a mould with liquid metal for the production of a casting. These factors vary greatly in their relative importance, and it has sometimes happened that an exaggerated significance has been attached to one or other of them. Laboratories in which metallurgical research is conducted are often asked to undertake exact measurements of certain physical properties of metals which exert only a minor influence on the quality of a casting, many practical foundrymen being under the impression that difficulties which they experience are connected with that particular property. The aim of this lecture is to review these factors, very briefly, and to indicate which are likely to deserve most attention. It should hardly be necessary to add that the skill of the foundryman remains one of the most important factors, and it is not susceptible of quantitative expression.

"Flowing Power"

The first condition of obtaining a satisfactory casting is that the metal shall flow evenly into the mould, and shall fill it completely before such freezing occurs as to offer an obstruction to its further flow. This property has been called by the French metallurgists "coulabilité," a word which is slightly clumsy, but far less so than its uncouth English rendering "castability." I am glad to learn that it is not popular amongst foundrymen, and that we may be able to avoid its use. "Fluidity," which is often preferred, has the disadvantage that it has a specific physical meaning, as the reciprocal of the viscosity, and although it has been proposed to abandon it in that sense, its old associations stand in the way of its adoption. I prefer "flowing power," which is not too cumbrous and does not carry with it any suggestion of being an exact physical constant. The figure used to express the flowing power will depend on the apparatus employed for the experiment, and on many conditions of casting. It is the resultant of a number of physical factors which are capable of being expressed quantitatively, but it remains an empirical quantity. Much has been done in recent years to standardise the methods of determining the flowing power, and reference should be made to the Second Report of the Steel Castings Committee issued last year by the Iron and Steel Institute, and especially to the excellent survey of the whole subject by Dr. R. H. Greaves.[1]

Roughly, the values obtained for the flowing power will depend on two kinds of factors, one set depending on the conditions of the experiment, including the form, material and surface of the mould, the casting head, and the degree of superheating of the metal before pouring, and the other involving the properties of the metal or alloy. This second set includes viscosity, surface tension, gas content, formation of surface films, as of oxide or nitride, the range over which solidification takes place, change of volume during solidification, and crystal thrust. There are other factors which affect the quality of the resulting casting, although not among those which govern the flowing power. These include the contraction in the solid state; the strength at temperatures near to the freezing point; the liability to segregation; and the tendency to form small or large crystal grains, the last being dependent in many instances on the previous history of the metal, that is, on the highest temperature to which it was heated before cooling to the temperature at which it was poured.

Experimental Conditions

It is mainly the second group of conditions with which this lecture is concerned, but a few words must be said about the first group—the conditions of the experiment. The flowing power is now most often determined by casting in a spiral mould, and measuring the total length of mould which is filled by solid metal, the conditions of casting having been fixed beforehand. This device was first introduced in Japan,[2] having been developed from the simple wedge test of West, and has been adopted by many later workers, for cast iron, non-ferrous metals and alloys, and steel.[3] Sand moulds are commonly used, but iron moulds have also been employed. A plumbago facing gives a longer casting than when unfaced sand is used, and, when the conditions are such as to give a long casting, a dry-sand mould gives, as might be expected, a greater length than one of green sand. Increasing the degree of superheat naturally increases the flowing power, as the metal can travel farther before it has cooled to the freezing point, and this increase with temperature is practically linear.

Viscosity

The first of the physical properties mentioned, that of viscosity, has been credited with a far greater influence on the flowing power than it actually possesses. In reality, the viscosity of metals is very low, the kinematic viscosity being less than that of water in all the examples investigated, and as it changes only slightly with change of temperature, it is really a negligible factor in casting. How, then, has the very general belief arisen that metals differ widely in viscosity, and that difficulty in flowing is caused by increased viscosity, which varies rapidly with the temperature? Probably because a metal which is flowing badly often appears to be viscous or treacly, when the effect is actually due to the surface tension of a thin and tough film, or to the presence of much gas in the form of minute bubbles, producing a foam. The "head" on a glass of beer flows with much more difficulty than the mass of the liquid, owing to surface tension in the innumerable thin films which separate the bubbles. Viscosity of the liquid metal could only become important if the channel to be filled were a fine capillary, and even then its influence would be outweighed by other factors.

It has been urged that, although metals are very fluid above their melting point, yet in the interval between the beginning of freezing and the solidification of the last eutectic or other fusible portion, there is a sudden and even enormous increase in the viscosity. This is quite contrary to what is known of viscosity, and there is no reason to suspect any such discontinuous change. It is true that an experiment to determine the viscosity by one of the usual methods is likely to be interfered with by the presence of crystals, blocking the channel if the method be one of flow through a capillary, or adhering to the surface of the pendulum or cylinder if one of the torsional methods be used, but such an effect has nothing to do with true viscosity. The unlikelihood of any real increase during freezing may be shown by very simple reasoning. Consider a system of alloys forming

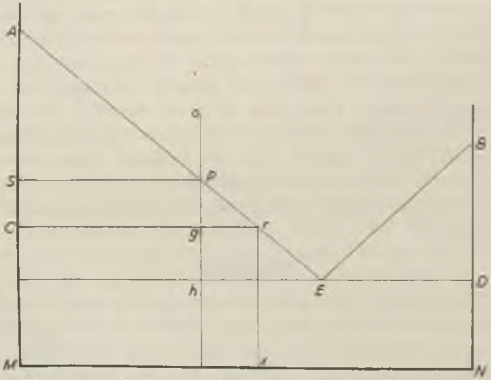

Fig. 1.—Typical Constitutional Diagram of a Single-Eutectic forming Alloy.

a single eutectic (Fig. 1). A liquid alloy *o* on cooling begins to freeze at the temperature *p*, depositing crystals of the metal A. By the time that the temperature has fallen to *q*, the alloy consists of crystals of A with a liquid of composition *r*, but this liquid, taken by itself, has a viscosity which lies between those of the metals A and B, this being the general rule for alloys.

The diminished flowing power is not, then, due to any increase of viscosity during the process of freezing (in metallographic terms, in the interval between the liquidus and the solidus) but to some other cause. The most obvious is obstruction of the channel by the growing crystals, and this is the real reason. If the freezing of the alloy were to begin by the formation of small crystals suspended freely in the liquid, there would be some increase in viscosity, as suspended particles do hinder flow, and a liquid in which more than a small proportion of particles is suspended, if tested in a viscometer, will give a higher value than the same liquid free from solid particles. Actually, such a precipitation of free crystals as a shower is only known to occur when a liquid is strongly undercooled, whilst in most instances the undercooling of metals and alloys is limited to a few degrees at most.

Flow after Initial Solidification

I am indebted to my colleague, Mr. V. H. Stott, for pointing out that, in the experiments conducted with a cast iron spiral mould by Portevin and Bastien,[4] the curves showing the lengths of casting with different degrees of superheating for a number of metals of low melting point indicate that a considerable portion of the total length must be due to flow occurring after solidification has begun. When the interior of the mould has been coated with crystals of solid metal, the volume of liquid which traverses the constricted channel in unit time, being proportional to the fourth power of the radius, will fall off very rapidly as the thickness of the solid layer increases. Moreover, should the crystals formed be dendritic, projecting into the interior, they will have a greater effect in retarding the flow than if they were simple polyhedra. Pure metals and solid solutions crystallise mainly as dendrites, whilst intermetallic compounds are more often polyhedral, and eutectics tend to form spherulitic masses, which probably offer the least resistance of all. There is, however, another reason, discussed later, why eutectics give longer castings than alloys differing from them somewhat in composition, which is of even greater importance.

Viscosity Measurements

There are two main methods of measuring the viscosity of a liquid metal: by allowing it to flow under a constant head through a capillary tube, and by using some form of torsional pendulum. The first can only be applied to metals of fairly low melting point, the capillary being of glass or silica. Many measurements of this kind have been made. In the second, which may be used even up to very high temperatures, a disc or cylinder is suspended in the molten metal, and on setting it into torsional oscillation, the damping in successive swings is measured, the " logarithmic decrement " being a measure of the viscosity. Using a horizontal disc of fired alumina, suspended by a phosphor-bronze wire, the viscosity of molten tin was determined at the National Physical Laboratory over a range of temperature from 240 to 800 deg. C.[5] No discontinuity in the viscosity curve could be found a few degrees above the melting point. In the apparatus used at Aachen for cast iron,[6] suspended cylinders were used as pendulums, and the viscosity curves showed an abrupt change of direction, corresponding with the deposition of the first crystals. The viscosity was diminished by increasing the carbon or the phosphorus, but increased by sulphur, probably on account of the separation of sulphide particles.

In a modification of the pendulum method, two concentric cylinders are used, one of which is stationary, while the other can be rotated, and the liquid occupies the annular space between the two. This method has been much used in the scientific study of steady and turbulent flow in liquids.[7] It presents practical difficulties when applied to metals, but such an arrangement has been used in the study of cast iron, with results similar to those obtained with the solid pendulum. Grey and white cast iron were found to behave very similarly.

TABLE I.—*Surface Tension of Some Common Metals.*

Metal.	Temp., deg. C.	Surface tension, dynes per cm.
Antimony	640	350
Bismuth	269	378
Lead	327	452
Mercury	20	465
Tin	232	526
Cadmium	320	630
Zinc	419	758
Silver	998	923
Copper	1,131	1,103
Gold	1,120	1,128
Iron (2.2 per cent. C)	1,420	1,500
Iron (3.9 per cent. C)	1,300	1,150

The temperatures from antimony to zinc are the melting points, and the measurements were made at a slightly higher temperature; for the remaining metals the temperature of the experiment is given.

The conclusion is that the viscosity of metals plays only a minor part in their casting behaviour, and that the effects which have been attributed to viscosity are mainly due to other causes. It does not seem necessary, therefore, to undertake difficult and refined laboratory measurements of this property on behalf of the foundry industry, although determinations are needed for certain theoretical purposes.

Surface Tension

The surface tension of a metal or alloy is another physical property which may affect the casting quality. Molten metals do not wet their moulds, unless in such exceptional cases as mercury or molten tin in a mould of tinned copper, which may be neglected. In a narrow channel, therefore, there is a resistance to the flow of the metal owing to its surface tension, but this effect becomes less marked as the diameter of the passage is increased. Actually, the amount of the resistance so produced is small in most castings, provided that the metal has a clean surface, a condition which is not always fulfilled, as mentioned below. As a rough indication, values given in Table I may be taken for the surface tensions of some of the common metals, at temperatures not much above their melting points.[*]

Metals of high melting point thus have a higher surface tension than the easily fusible metals. From the figures for the two alloys of iron and carbon, it appears that steel has a higher surface tension than cast iron, and pure iron would probably give a still higher figure. The surface tension of water at 20 deg. C. is only 81, so that the values for the metals are relatively high.

The surface tension diminishes as a rule with increasing temperature, but cadmium and copper are anomalous in this respect, the value increasing up to a maximum and falling again as the temperature is still further raised.

There is at present no satisfactory means of determining the surface tension of a solid. It seems likely, however, that the metals will arrange themselves in about the same relative order in the solid state as in the liquid, and this supposition accords with certain interesting features of their crystallisation, which have an indirect bearing on casting conditions. Under the influence of surface tension, a body tends to assume the form which gives it the smallest possible surface, so that an isolated drop of a liquid becomes spherical. This is true of solids as well as liquids, but the effect is only perceptible at temperatures near to the melting point. An examination of microsections of alloys containing primary crystals embedded in a eutectic will show that metals with a high surface tension, such as copper, form crystals with much rounded outlines, whilst when the metal has a low surface tension, such as antimony, it forms dendrites with sharp angles. Gold gives highly rounded forms, and even below the melting point, sharp-angled crystals of gold, prepared by etching, become rounded if heated.[9] When the first shell of crystals forms at the surface between the metal and the mould, it will make a difference to the flow whether the crystals so produced are angular or rounded, as the rounded forms may be expected to offer less resistance, although it cannot be said that there is any definite evidence on this point. Some experiments would be worth making. Surface tension also determines to a great extent the forms of the crystal grains in a casting, and the liability of some alloys to intercrystalline fracture is connected with changes in the surface tension at the grain boundaries, the causes of which are now the object of study at the National Physical Laboratory.

Searching Power

The effect of surface tension in determining the "searching power," or degree of penetration of the molten metal into the sand of the mould, has been very fully dealt with by Prof. Portevin and Dr. Bastien in their Paper contributed to this Institute last year.[10] The condition here is one of penetration into very narrow capillary spaces, and the presence of surface films, discussed below, assumes great importance.

If gases are being continually evolved from a metal during casting, its flowing properties may be influenced in more than one way. A lively evolution of small bubbles, causing an effervescence, as in casting a certain class of steel, may appear to make the metal more fluid, but the effect is probably only apparent, and in a narrow channel there will certainly be an increased resistance to flow. One difficulty in applying data as to surface tension to the case of a metal flowing in a channel arises from the fact that the metal is often not in actual contact with the mould, but is separated from it by a thin layer of gas, either issuing from the metal or arising from the material of the mould. The "interfacial tension" between metal and solid is then altered, perhaps considerably. Experiments by Schumacher indicate that if glass could be completely freed from its adhering layer of gas, it would be wetted by mercury.[11]

Surface Film Effects

A surface film of a foreign substance affects the flowing power far more than any possible variation in the true viscosity or in the surface tension. Aluminium provides a striking example. On exposure to air, aluminium forms immediately a thin layer of the oxide, alumina. This film is very tenacious. In the Paper contributed to this Institute last year by Prof. Portevin and Dr. Bastien,[10] determinations of the apparent surface tension of oxidised and clean aluminium were described, the effect of the oxide film being to increase the value to nearly three times. This result is probably too low, as it is difficult to obtain a surface of molten aluminium which is not covered by a very thin film of oxide. That film has such strength that it is possible to melt a long, freely suspended loop of aluminium wire by passing an electric current through it, without rupture, the skin being strong enough to retain the weight of the molten metal. Using this method quantitatively, Portevin and Bastien were able to show that the oxide skin had a tensile strength of 2 kg. per sq. mm. (1.3 tons per sq. in.). Aluminium and magnesium can form skins of nitride as well as of oxide.

A short lead wire could be heated in the same way, either by passing an electric current or by enclosing in a heated tube, to above its melting point without fracture if in air, being sustained by its oxide coating, but in nitrogen it broke directly the melting point was reached.[12]

This property of aluminium also affects alloys in which it is present. The difficulty of casting aluminium bronze (the copper alloy containing 8 to 10 per cent. of aluminium) is caused by the formation of such a tough skin, which hinders pouring and, by becoming broken into fragments, is entangled in the metal, making a dirty casting. Brass forms a much less tenacious film during pouring, and the zinc oxide which is produced breaks up very readily, again causing defects. A brass containing aluminium forms a skin of the tough kind, so that a surface of such an alloy in the crucible shows little evaporation of zinc unless it be stirred, when the protective film is broken, and a puff of vapour escapes.

When the oxide is soluble in the molten metal, no film is formed, so that copper, iron and nickel pour in a clean stream, although they may contain solid matter in suspension. Moreover, if two of the constituents of the alloy can form a mixture of oxides with a lower melting point than that of the alloy itself, the surface film will be liquid instead of solid. This, of course, is the case when a flux or a deoxidiser, such as phosphorus, has been added which reduces the melting point of the oxide mixture sufficiently. The conditions of oxidation of some of the metals have been the object of study at the National Physical Laboratory. The film formed on molten tin, for example, may be either smooth and compact, or bulky and corrugated, the bulky form allowing oxidation to go on rapidly, whilst the other is protective.[13] It was found that the difference corresponded with a difference in the arrangement of the minute crystals of the oxide, the loose film having the crystals arranged at random, whilst the compact skin had a definite "preferred orientation." This difference, which assumes great importance in connection with the oxide films on solid metals, deserves further study in the case of molten metals. The orientation was determined by the method of electron diffraction.

Magnesium is another metal which forms a troublesome oxide skin, which must be removed by a suitable flux if clean castings are to be obtained. According to Dr. Greaves, an over-oxidised steel which has been killed with aluminium is also liable to be contaminated by fragments of an alumina skin which become detached from the surface and entangled in the stream. It is known that some of the other deoxidisers used in the war as substitutes for manganese gave trouble from this cause. Such suspended particles not only interfere with the free flow, but give rise to inclusions in the solid metal, injuring its quality.

Freezing Range

A pure metal freezes at a constant temperature, but in most alloys the process extends over a range, and the extent of this range is of importance in determining the flowing power. Eutectic alloys, and such as occupy a minimum on the freezing-point curve, as in the alloys of copper and gold, freeze at a constant temperature, like pure metals. Guillet and Portevin[14] showed that in the alloys of tin with lead and with bismuth the curves showing the variation of flowing power with composition had maxima at the eutectic compositions, whilst there was no such indication in the curves of viscosity, or of its reciprocal, fluidity in the scientific sense. Portevin and Bastien[15] concluded, from a study of a number of alloys of low melting point, that the flowing power varies (in any one system of alloys) inversely as the solidification interval, and is thus greatest for pure metals and eutectics. This has been confirmed by other workers. The statement that " It has been assumed in the past that the position of the liquidus on the temperature axis for any particular alloy gives the point where that alloy possesses zero fluidity,"[16] is clearly incorrect, as many investigators have shown that flow takes place below that temperature, and the results of Prof. Andrew's experiments confirm their conclusions as to the influence of the temperature range of solidification. The very small number of points used in the construction of the curves in the Paper referred to do not justify the deductions as to the effect of the peritectic transformation in the alloys of iron and carbon.

Ternary Alloys

Experiments have been extended to ternary alloys,[17] and it is found, as might have been expected, that a ternary eutectic, which freezes at a constant temperature, has the greatest flowing power of all the alloys included in the system. Once more the flowing power is (roughly) inversely proportional to the range of temperature over which solidification takes place. The conclusions are in accord with the observed behaviour of phosphoric cast iron,[18] which is well known to be more fluid than a similar iron containing less phosphorus.

The reason is to be found in the separation of the primary crystals, which form a shell, obstructing the flow. As mentioned above, the habit of the crystals affects the resistance which they offer, and alloys with a long freezing range mostly deposit primary crystals of the dendritic type. The effect is complicated by the existence of crystal thrust, referred to later.

Volume Change on Solidification

The methods of determining the total shrinkage of alloys used for castings are well known, and it is not proposed to review them here. It is, however, of importance to know the actual change of volume during the process of freezing, and this subject falls next to be considered. Several methods have been employed. The simplest is that of the dilatometer used in measuring the coefficients of expansion of liquids, a rigid vessel having a neck in which the level of the liquid can be read. For the examination of the freezing range, special care has to be taken that solidification takes place regularly from the bottom upwards. This method was used for metals by most of the older workers.[19] Corrections have to be made for the change of volume of the mould with temperature, and any internal cavities cause errors. Aluminium and some of its alloys were examined in this way, using electrical contacts to determine the level of the metal in the refractory vessel.[20] A second method consists in suspending the metal in a crucible from one arm of a balance, the crucible being immersed in a bath of a liquid of known density and coefficient of expansion, and measuring the displacement over a range of temperature.[21] This method, although it will give the total volume change satisfactorily, as shown by the results of Sauerwald,[22] suffers from the defect that there is a great lag of temperature between the bath and the metal, and thermal equilibrium is practically impossible of attainment. Thus, in one series of experiments, the sudden change of volume of antimony on freezing was recorded as 560 deg. C., whilst the freezing point of antimony is 631 deg. Using a balance in this way, it is not possible to use a stirrer to obtain equilibrium, and unknown temperature gradients exist in the system.

Mechanism of Freezing

In order to obtain a more complete picture of the process of freezing, experiments were undertaken in the writer's laboratory during his tenure of the chair at Sheffield University, to ensure that readings of volume were only made under conditions of thermal equilibrium. It was decided to use a differential method, and an apparatus was constructed[23] and afterwards improved and used for an extensive series of measurements of metals and alloys up to 450 deg. C.[24] The apparatus consists essentially of two similar bulbs of glass or silica, immersed side by side in a stirred bath of oil or fused salts so that they can be brought accurately to the same temperature, and communicating with a differential manometer. One of the bulbs contains a known quantity of the metal, the space above it being filled with nitrogen, whilst the other contains only nitrogen. The differences of expansion or contraction recorded by the manometer then correspond with the changes of volume of the metal. Many precautions are necessary to eliminate sources of error. To ensure clean specimens, it was found essential to melt the metal beforehand in a high-frequency induction furnace in a good vacuum, and while in that state to filter it through a fine capillary in order to remove any skin of oxide. Readings may be taken as slowly as is desired, the system being brought to a steady temperature before each adjustment of the manometer, so that thermal lag disappears completely. A few of the results obtained by Goodrich are shown in Fig. 2.

The advantage of this method is that it is possible to measure accurately the change of volume on freezing, distinguishing that part which corresponds with the separation of primary crystals from that due to the eutectic.

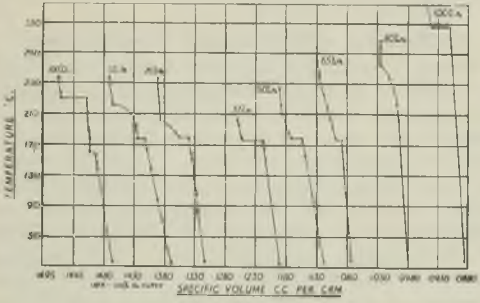

FIG. 2.—SPECIFIC VOLUME/TEMPERATURE CURVES OF LEAD/TIN ALLOYS.

The only appreciable error may arise from the production of small intercrystalline cavities owing to a part of the final contraction occurring after the mass of the crystals has become rigid, thus making the apparent contraction slightly too small, but the effect of this was found to be only slight.

In experiments involving a great lag of temperature, as when an alloy is suspended in a liquid without stirring, the measurements indicate a range of temperature of as much as 20 degrees over which the freezing of a pure metal occurs, the curves of expansion or contraction in the liquid and solid state being drawn, with an intermediate branch representing the freezing. With the method employed by Goodrich, readings in the solid and in the liquid state could be brought to only 0.2 degree C apart, and the temperature-volume curves of an alloy could be drawn with an accuracy equal to that of a thermal analysis, with the added advantage that as much time as was required to ensure equilibrium could always be allowed. The process is, however, tedious, as the taking of a complete curve occupies several days. Points were determined both with increasing and with falling temperature, and in irregular order, so as to eliminate any drift. The process of freezing proved to be quantitatively reversible.

Difficulties with Elevated Temperatures

There is no reason why this method should not be extended to higher temperatures, using silica or porcelain vessels. A special problem presents itself in the case, so important for the foundryman, of cast iron and steel. Gastight vessels for such high temperatures are not easy to construct, and so far the dilatometer method has not been used to determine the change of volume of these metals on solidification. The measurement of the contraction in the liquid state, however, is not so difficult. Using a molybdenum resistance furnace, and determining the level of the liquid surface by observing the reflection of a molybdenum wire lowered to make contact with it by a micrometer, it was found possible to make satisfactory measurements of the density of pure iron above its melting point.[25] Since the expansion of iron up to a temperature just below the melting point has been determined accurately by X-ray measurements of the lattice parameter,[26] the change of volume on freezing can be calculated. Values are given in Table II. The density method just described also appeared to succeed with white cast iron, but as the results differed considerably from those obtained by other methods they are to be treated with reserve, the removal of carbon during the experiment by the reducing atmosphere (hydrogen + nitrogen) which has to be used, introducing an error.

In another method, also used for iron and steel,[27] the molten metal is enclosed in a U-tube of refractory material, enclosed in a furnace at constant temperature, whilst a similar U-tube containing mercury is kept at atmospheric temperature. By applying gas pressure to one limb of each U-tube, differences of level can be produced, and a measurement of these gives the

TABLE II.—*Volume Changes on Freezing.*

Metal or alloy.	Percentage change of volume on freezing. (— indicates contraction, + expansion.)	Author.
Tin	— 2.97	Goodrich.
Lead	— 3.85	,,
Bismuth	+ 3.47	,,
Zinc	— 4.48	,,
95 per cent. Sn + 5 per cent. Sb	— 2.81	,,
85 per cent. Sn + 15 per cent. Sb.. ..	— 1.91	,,
50 per cent. Sn + 50 per cent. Pb ..	— 2.30	,,
87 per cent. Pb + 13 per cent. Sb.. ..	— 2.15	,,
Aluminium	— 6.7	Stott.
87.4 per cent. Al + 12.6 per cent. Si ..	— 3.5	,,
Y-alloy	— 4.8	,,
Iron	— 2.86	(Mean of several.)
Iron	— 2.4	Ericson.
Grey cast iron ..	+ 1.2	,,
White cast iron ..	— 3.6	Honda and Endo.
Copper	— 4.0	Bornemann and Sauerwald.
Silver	— 4·7	Endo.
Gold	— 4·9	,,

ratios of the density of the molten iron and mercury. This method has the advantage of being independent of the coefficient of expansion of the tubes, but is difficult on account of the lack of refractory materials which are impervious to gases at such high temperatures.

Simplified Tests

Measurements have been made also using very simple means.[28] If a mass of metal, preferably spherical, be cooled quickly from the melting point, in such a way that a uniform solid crust is formed, the contraction during freezing will produce a hollow in the interior. In the subsequent cooling, the contraction of the hollow mass will be the same as if it were solid, and by determining the volume of the cavity when cold, the percentage contraction on freezing may be calculated. It has to be assumed that the mass retains its spherical shape, and there is usually some distortion. This is allowed for by measuring any obvious depression in the surface, but such a correction is not always easy, and the existence of distortion is responsible for the rather erratic results obtained. The method was, however, applied to iron, with specimens varying from the small shot produced by a free fall to masses of 200 grams. It was used by the same experimenter in a study of grey iron, and the results indicated that the expansion which all foundrymen know to occur takes place during freezing and not, as has sometimes been supposed, after solidification is complete, by a reaction in the solid state. Instead of a cavity in this instance, a drop of molten metal was formed, and was extruded during freezing, appearing on the surface.

This expansion is, of course, caused by the formation of graphite, which has a much larger specific volume than either the solution from which it is derived, or the carbide which takes its place in a white iron. This is a metal which would give very interesting results if it could be studied over a wide range of temperature in a dilatometer of the kind described above. The experimental difficulties would be considerable, but the work might be justified on account of its importance to the foundry industry.

A few of the most trustworthy results are shown in Table II. The only pure metals which expand on freezing are bismuth, antimony and gallium, and this exceptional property affects their alloys, neutralising the contraction due to the other metal, to an extent depending on the composition. Stott has shown how the contraction of an alloy may be calculated with fair accuracy from a knowledge of the behaviour of its component metals, remembering that the variation of specific volume with composition is not far from linear, both in the liquid and in the solid states.

Crystal Thrust

A factor which is commonly ignored is that of the thrust which may be exerted by growing crystals. An apparent expansion during solidification is sometimes observed when determinations of density show that the volume has actually diminished. The writer has summarised the history of the subject on an earlier occasion.[29] It will be enough to mention one familiar example. When plaster of paris is mixed with water in a test-tube, the mass seems to expand during setting, and the glass will burst. The volume after setting is, however, less than that of the original plaster plus that of the water. The effect is due to the crystals pushing against one another, and increasing the apparent volume, the resulting mass being porous. In the same way, with the modification of Keep's contraction apparatus employed by Prof. Turner, in which the metal is cast in a sand mould in the form of a T-shaped bar, one end of which is held by a fixed pin, whilst the other is attached to an extensometer, an expansion is often observed during setting.[30] This expansion increases as the freezing range becomes greater, this result having been confirmed for a number of copper alloys, especially those with zinc. Determinations of density show that the alloys have really contracted during freezing, and that the apparent increase of volume is represented by a considerable porosity, distributed throughout the cast bar. A part of this may be accounted for by the liberation of dissolved gases during freezing, but that this is not essential is shown by the example of the setting of plaster, mentioned above. The growth of a mass of crystals, if of dendritic form, may, and often does, lead to an outward push, the crystals seeming to repel one another as the liquid between them freezes. The result is that an outer shell is formed, and the contraction of the liquid metal contained in it, as it freezes in its turn, leaves small cavities, which may be so distributed that the casting appears solid unless examined under the microscope.

The addition of zinc to tin-base bearing metals was found to cause internal porosity, and this was attributed[31] to expansion of the zinc during solidification, followed by contraction of the eutectic enclosed in it. Zinc does not expand, and the effect is due to thrust. Type-metals which behave in this way give sharp impressions of the mould, and it was long believed that they, like bismuth and some of its alloys, actually expanded, but determinations of the density prove that this is not so. Antimony, when present to the extent of 10 per cent., reduces the contraction to a very small amount. As the effect appears in the outermost shell of crystals, it is chiefly found in the narrow portions of a casting, and becomes negligible where the section is large. For the purposes of the foundryman this apparent expansion is the same as a true expansion in castings of small section, but it has the effect of making the shrinkage allowance depend on the size. True expansion during solidification, as mentioned above, is exceptional in alloys. Quantitative measurements of crystal thrust have only been made with non-metallic substances, and from the nature of the cast the property could not be expressed by a simple constant.

Latent Heat and Thermal Conductivity

There are, of course, other physical factors which enter into the process of flow and solidification. Such are the latent heat and the thermal conductivity. More accurate values of the latent heat of fusion (or solidification) of metals are needed, only a few of the pure metals having been satisfactorily studied. Measurements of this property are in progress at the National Physical Laboratory, as are determinations of the thermal conductivity of metals and alloys in the solid state. In the liquid state this property is of less importance, as convection, or turbulent flow, brings about a quicker exchange of heat than conduction can do, but in steady or streamline flow it will have an effect, and for this reason some accurate determinations are desirable. The property would in all likelihood vary in a simple fashion over a range of alloys, so that it would only be necessary to make a few selected determinations.

Segregation

Nothing has been said as to the effects of segregation, but reference may be made to a very full review of the nature of inverse segregation, the form which prevails in most of the alloys used by the foundryman.[32] It is naturally one of the factors which determine the quality of the resulting casting, but it is of a rather different character from the purely physical properties considered above. Mention should, however, be made of a possible effect of the degree of superheating to which the metal has been subjected before pouring. When heating has been carried far, and the metal is allowed to cool before casting, certain properties appear to depend on the maximum temperature which has been reached, the previous history of the liquid leaving an impress on its properties. This is particularly true of the grain size. It is often found that a larger grain size is obtained when the maximum temperature reached has been high than when it has been low, although the actual degree of superheat at the moment of pouring is the same. This may be explained in more than one way. It depends sometimes on the more complete elimination of suspended films, as of aluminium oxide, which hinder the growth of large grains, but it is not certain that this is the only cause. There is good reason to suppose that the regular arrangement of the atoms in a crystal is not completely broken down when the metal melts, but that aggregates of atoms, like extremely minute crystals, remain. On cooling, these form the nuclei from which crystals may grow. With increasing temperature, these aggregates tend to break up, so that a strongly superheated liquid would contain less nuclei, and would consequently give larger grains. There are indications, especially in the case of bismuth, which has received most attention, that this actually occurs. It is an important question, which calls for further study.

A better knowledge of the physical factors which affect casting properties is of the greatest importance, and an attempt has been made in this lecture to indicate which of them deserve attention, and which may be neglected for practical purposes. The writer acknowledges freely, however, that the acquired skill of the practical founder is something which, whilst not subject to quantitative expression, stands high in the rank of the factors controlling the quality of the casting, and it would not be right to conclude without a tribute to the value of such an Institute as this, in which the men who have such knowledge and skill can meet to compare their experience, and so to add to the progress of this ancient craft, now based on a scientific study of metals.

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PAPERS PRESENTED AT THE DERBY CONFERENCE

Paper No. 606

RECOMMENDATIONS CONCERNING THE ESTABLISHMENT OF COSTS IN A GREY IRON FOUNDRY

By the Costing Sub-Committee
of the Technical Committee

Constitution of the Sub-Committee

Following a recommendation of the Technical Committee, the principle of the formation of the Costing Sub-Committee was adopted as a result of a resolution of General Council at the meeting held in Birmingham in October, 1932. The Sub-Committee was formed in the year 1933, and met initially on January 13, 1934. The constitution of the Sub-Committee is as follows:—

Mr. C. W. Bigg, Qualcast, Limited.
Mr. F. O. Blackwell, The Davis Gas Stove Company, Limited.
Mr. C. C. Booth, Booth & Brookes, Limited.
Mr. V. Delport (convener), Penton Publishing Company, Limited.
Mr. W. A. Hodson, Leyland Motors, Limited.
Mr. H. J. Roe, Birmingham.
Mr. A. Young, British Bath Company, Limited.

SUMMARY

A costing system is the only means of knowing whether costs are recovered in the selling price; of measuring any profit or loss made for a given rate of production; and of knowing what resources may become available out of income for further development.

It is necessary that the costing system should be based on standard principles in order that costs may be established on a comparable basis for the whole industry.

Fundamental Principles.—(A) Each job should be charged with its full costs, including its

proper share of overheads; (B) the undertaking should be divided into a number of departments, in each of which the various grades of metal, types of castings, etc., should be classified; (C) all inventories and records should be kept methodically and correctly.

Divisions of the System.—There are four main divisions: (1) melting; (2) moulding; (3) core shop, and (4) cleaning and fettling, together with the following auxiliary departments: pattern shop; maintenance department; heat, light and power; despatch department, etc.

Divisions of Costs.—The costs are divided into two chief groups:—

(1) *Direct costs* are those items which can be charged specifically against a job, and include:—(*a*) *Metal*, which is charged at the actual cost of the metal going into good castings delivered. (*b*) *Moulding and Coremaking*, covering the value of moulding and coremaking labour expended in the making of moulds and cores, and when made specially for the job, moulding boxes, patterns and tackle. (*c*) *Fettling and Cleaning*, against which only direct labour is charged.

(2) *Indirect costs* are those items which cannot be specifically charged against a job, and are an expense of the department to be allocated to the various jobs; in the case of metal and a certain section of the fettling and cleaning department, these are charged on a tonnage basis, and other sections as a percentage on direct labour.

Melting Department

The object of the system, as applied to the melting department, is to arrive at the *cost of the metal at the spout per ton of good castings produced.*

Cost of Metal.—The customer is to be charged with actual cost of the metal going into good castings delivered, plus the metal losses. As regards scrap, the customer is to be charged only with cost of any irrecoverable alloys. The cost of home scrap is the same as the cost of pig-iron and bought scrap mixture going into the charge.

Metal costs should be classified as between the various mixtures used.

Cost of Melting.—The customer is to be charged with total melting costs, which include labour, coke, power, materials, etc. From the point of view of melting costs, castings should be classified on the basis of the proportion of good castings to metal melted. The items of direct and indirect costs are:—

Direct costs: pig-iron; bought scrap; home scrap; alloys.

Indirect costs: labour; fuel; limestone; ganister and supplies; plant maintenance and repairs (labour and materials); laboratory; light and power; loose tools and plant; National Health and Unemployment insurance; supervision; share of fixed charges, etc. These indirect costs are to be allocated on a tonnage basis to the various classes of castings in the same way as melting costs.

Moulding Department

Direct costs in the moulding department consist of: moulding labour, and those moulding boxes, patterns, tackle and requisites that can be identified specifically with a job. The castings should be classified in accordance with method of making the mould.

Indirect costs: moulding indirect labour (which includes all labour which cannot be directly charged to a job, *i.e.*, shop labourers, crane drivers, etc.); moulding sand, including the cost of preparation; supplies and tools (chaplets, nails, shovels, riddles, etc.); fuel for drying ovens, etc.; moulding boxes, foundry tackle, patterns, except when these can be charged direct to a job; plant maintenance and repairs; National Health and Unemployment insurance; supervision; share of fixed charges.

Indirect costs and fixed charges should be allocated on a direct labour percentage basis.

The Core Department

Cores must be identified with the job for which they are made, and their cost should be applied to the respective jobs. Direct costs, including labour and materials, should be, as far as possible, charged to each job, and core boxes and jigs, etc., made specially for a job should also be charged against that job.

Indirect costs include: coremaking indirect labour, which includes all labour which cannot be directly charged to a job, *i.e.*, shop labourers, etc.; core sand, oils, and compounds, including the cost of preparation; supplies and tools (*i.e.*, sprigs, wire, brushes, shovels, riddles, etc.); fuel for core ovens; tackle; plant maintenance and repairs; National Health and Unemployment insurance; supervision; share of fixed charges.

These should be allocated on a direct labour basis.

The Pattern Shop

The pattern shop is an auxiliary department, and all patterns made for a specific job should be charged to that job. Generally speaking, the same principles apply to the pattern shop as those set out for the core shop. Direct costs include pattern-making material and labour. Indirect costs include pattern-making indirect labour; supplies and tools; plant maintenance and repairs; National Health and Unemployment insurance; supervision, and a share of fixed charges.

The Cleaning and Fettling Department

The cleaning and fettling department covers all operations from the time castings are knocked out of their moulds until they are cleaned and dressed, exclusive of special surface treatment.

There are two sections: (*a*) where labour is the main item of the cost and one casting is dealt with at a time. All costs other than direct labour are to be allocated on direct labour wages basis. Section (*b*) is applied where the main items of cost are power and depreciation of plant and where several castings are treated together. A simple system consists of adding up all the costs pertaining to this section and allocating them to each job on a weight basis. For large foundries castings are to be classified and separated according to time taken, and in each case the cost of operation should be allocated on a weight basis. When castings can be taken out as they are cleaned, such as in sandblasting, they should also be classified in accordance with the time taken. and their cost allocated on a ton-hour basis.

Indirect costs in the cleaning and fettling department include: fettling indirect labour, which cannot be directly charged to a job; supplies and tools (*i.e.*, hammers, chisels, shot, grinding wheels, oxygen, acetylene, welding tools, etc.); fuel; plant maintenance and repairs; National Health and Unemployment insurance; supervision, and a share of fixed charges.

Inspection charges are usually charged to the job and in repetition work they are dealt with as an oncost on productive departments.

In *other auxiliary departments* for generating heat, light and power: the cost per unit is worked out and applied to the various departments, as explained. If a maintenance and repairs department exist, the individual cost is charged against the appropriate section, subsection or job, but for general repairs the cost is an overhead on the appropriate department.

Packing and despatching are considered as an overhead on the moulding department.

Freight can usually be determined for each job and added at the end of the cost sheet.

General Overheads

The comparable production costs are reached at the despatch point. General overheads, such as directors' fees, management and staff salaries, storekeeping, selling costs, financial charges, etc., are then added on at the end of the cost sheet and allocated as a percentage of moulding and core shop wages.

FOREWORD

It should be unnecessary to emphasise how essential it is for the management of a foundry to have a correct costing system. If no attempt is made to know the actual cost of production, those who are responsible for the fixing of prices and for the finances of an undertaking are completely in the dark as to when the business is operating at a profit or at a loss.

At any time, a correct costing system is necessary, because unless costs are known, one cannot be certain that they are recovered in the selling price. A costing system is the only means of actually measuring any profit or loss made for a given rate of production, and of knowing what resources may become available out of income for further development. Costing also shows in what directions efficiency should be increased and waste eliminated.

A costing system should not be used simply to work out average costs for certain periods; this would be sufficient only in the exceptional case of a foundry manufacturing consistently one class of castings. In the large majority of cases, the production of a foundry comprises several types of castings of different weights, and differing also owing to the grade of the metal and the complication of the casting itself.

Where these conditions obtain, each class of casting should be costed separately; otherwise, and unknown to the management, the profit made on some classes of castings can easily be offset, partly or entirely, by a loss made on other types. If selling prices are based arbitrarily, at so much per ton, on an average cost of production, certain castings will be quoted at a price that will discourage customers, whilst others will be offered at such a low price as to depress the market unfairly for that class of casting. A correct costing system is, therefore, an essential requirement for the individual foundry, and provides an accurate basis for estimating and checking selling prices.

Whilst the necessity for a correct costing system is generally recognised, the benefits to the industry as a whole of a system based on standard principles are not, perhaps, so widely appreciated. By the adoption of such a system, costs can be established on a comparable basis; differences in costs for given types of castings can then be accounted for by the particular circumstances of each foundry, due to proximity of sources of supply, transport facilities, management and efficiency. In fact, a standard cost system would be a measure of a foundry's efficiency, allowing, of course, for the material conditions under which the foundry must operate.

In working out costs over a period, every item of expenditure incurred during that period must be taken into account and absorbed in the cost; the cost figure arrived at for the production during that period will be reliable, provided that the principles governing the system are sound. When costing a given job (as, for instance, a one-ton casting) or when costing for one class of casting, it is possible that only a close approximation to the exact figure can be arrived at. It can be stated, however, that if a correct procedure be used consistently, the cost figure will be sufficiently close in each case for all practical purposes. On the other hand, it must be emphasised that if the costs arrived at by different systems be widely different, only one system may be correct, and all the others are wrong.

A system embodying the principles that have been adopted by experienced firms, which obtain consistently comparable figures that can be interlocked (without discrepancy) with the financial accounts of the undertaking, can be considered as a sound system. It has been the object of this Sub-Committee to elaborate a system based on the best current practice in use by the most up-to-date foundries, and thus to propose a standard set of costing principles which can be adapted to the requirements of various types of foundries, and acceptable to the industry as a whole.

FUNDAMENTAL PRINCIPLES

Three fundamental principles form the basis of the whole system:—

(A) So far as is practically possible, *any expense, including oncosts, incurred in making* *a job should be a direct charge against that job;* in other words, *each job should be charged with its full cost, including its proper share of overheads.* As a result, overheads should be broken up and allocated in a fair proportion to the various jobs undertaken.

(B) *The undertaking should be divided into a number of departments,* and where a variety of castings is made it is necessary, in each department, *to classify the various grades of metal, and the various types of castings or cores.*

The division of the undertaking into departments makes for a more clear-cut and intelligible system, which makes it easier to trace any potential source of waste or condition of inefficiency. Further sub-division within each department enables the various factors of expenditure to be allocated in such a way that each class of castings will bear its proper cost in conformity with principle (A).

The division into departments and sections does not necessarily entail endless classification of all physical objects; it is mainly a classification on paper, by means of well-thought-out forms and cost sheets, which, once adapted by the management to a particular undertaking, forms the basis of normal clerical work. The classification will be more or less extended in accordance with the circumstances of each undertaking, and, generally speaking, the smaller the foundry the more simple will be the application of the system.

(C) The third principle is equally important as the two first ones, and embodies the methodical and correct keeping of all necessary records and inventories, covering such items as stocks of raw materials, supplies, partly-finished and finished castings, scrap; issues from stores; daily cast reports and records of weights charged into the cupola; job cards; records of wages and times, etc.

Such records and inventories are essential as it is from these that the figures constituting costs are extracted; they are the foundation of the whole system. If records and inventories are not properly kept, then the whole cost system, however sound it may be and however scientifically it may be built up, will give incorrect results—in just the same way that an adding machine will give an incorrect result if the wrong key has been tapped.

Divisions of the System

The manufacture of a casting, owing to its very nature, is the result of a number of definite processes. The metal must be melted; moulds must be prepared in which the metal will be cast; in a large number of cases, cores must be made and placed in the mould. Finally, before being despatched, gates, heads and risers must be removed from the casting, which must have a clean appearance and generally pass inspection. Each of these stages involves a special type of labour and should bear a certain quota of overhead charges or oncosts, besides the actual cost of the labour expended on the particular job.

In applying the principle of classification already enunciated, it is, therefore, natural to divide the undertaking into departments corresponding to those stages. This division enables costs to be checked at each stage, provides for a fair allocation of costs to different types of castings, and also permits of a closer control of the working of each department.

The four main divisions of the system, which apply to any grey iron foundry, correspond to the following departments:—

I.—Melting department.
II.—Moulding department.
III.—Core department.
IV.—Cleaning and fettling department.

In addition, there are a certain number of auxiliary departments that contribute to the proper functioning of the main divisions listed above. Among the most usual auxiliary departments are:—The pattern shop; maintenance department; heat, light and power; and despatch, etc. In the smaller foundries these auxiliary departments need not all be considered separately, but in an undertaking of a certain size, their use clarifies the costing system and enables a better control of operations to be effected.

MELTING DEPARTMENT

Factors Governing Melting Costs

The object of the system, as applied to the melting department, is to arrive at the *cost of the metal at the spout per ton of good castings produced.*

Both for the purpose of estimating a selling price and for calculating actual costs over a period of time or for a given order, the value or cost of all of the following factors that intervene in the operation of the melting department must be known, by means of the properly-kept records and inventories:—

(*a*) Price of the various brands of pig-iron and alloys.

(*b*) Cost value of home scrap.

(*c*) Price of bought scrap.

(*d*) Price of coke.

(*e*) Price of limestone.

(*f*) Price of ganister, bricks, supplies and tools.

(*g*) Wages of all labour employed in the melting department.

(*h*) Cost of repairs and maintenance of melting plant.

(*i*) Cost of power for blowers and other mechanical devices requiring power.

(*j*) Other departmental oncosts which, according to the circumstances of the case, should be charged to the melting department, such as cranes, hoists, whole or part of laboratory expenses, etc.

(*k*) Percentage of fixed charges, which in certain cases should be charged to this department.

The price of items (*a*) and (*c*) to (*f*) should be the price actually invoiced for the materials "delivered at the yard." Any depreciation of stock should be entered into a special account and charged against the stock account of the particular item.

The following records must also be carefully kept:—

(A) Inventories of the stocks of pig-iron, alloys, returned scrap, bought scrap, limestone, ganister, etc.

(B) Weight of each charge going into the cupola, each component being weighed separately.

(C) Weight of gates, runners, risers, wasters, overrun, etc., which return to the stock of home scrap.

(D) Weight of good castings, obtained from the foundry, cleaning and despatch departments, including foundry tackle made.

(E) Daily cast report.

Loss of metal in melting and handling will be calculated from the above records.

The costs of the melting department comprise: (1) cost of metal; (2) cost of melting, and (3) oncosts.

Cost of Metal

The customer should be charged with the actual cost of the metal going into good castings delivered, plus the cost of metal losses arising from the making of those castings. He should not be charged with the cost of the metal going into the scrap returned to stock, exception being made for high-priced additions. In that case, the total cost of the alloys should be charged, except when the alloy scrap can be used again for a similar type of casting, in which case an allowance should be made, proportionate to the value of the alloy present.

The metal costs include the cost of pig-iron, bought scrap and home scrap, and of any additions (ferros, nickel, etc.) that are charged into the cupola or into the ladle. The cost of pig-iron, additions and bought scrap are obtained from the corresponding inventories. The cost of home scrap will be the average (mean) cost of the pig-iron and bought scrap that go into the charge in the proportion in which they are charged, or, in other words, the cost of the purchased metal going into the mixture.

The cost of metal can be worked out:—(*a*) Directly for the actual tonnage of good castings produced, in which case the cost of metal losses must be added and calculated on the whole charge; (*b*) for the total tonnage of metal charged into the cupola, which will include metal losses, in which case the cost of the scrap returned must be deducted at the same value as the metal mixture. The cost, divided by the tonnage of good castings produced, gives "the cost per ton of the metal mixture going into good castings."

Metal costs should be classified as between the various mixtures that may be used in the foundry. Scrap returned from these mixtures should be stocked separately and used only in conjunction with the mixture from which it originates. This is particularly important in the case of mixtures containing alloys.

Cost of Melting

The customer should be charged with the total melting costs applying to all the metal charged into the cupola for making up his order. Whereas in the case of metal costs the customer is charged only with the cost of the metal going into good castings delivered, plus metal losses, in the case of melting costs he must also be charged with the cost of melting the scrap that is returned to stock, *i.e.*, gates, runners, wasters, overrun, etc., otherwise that cost will not be recovered.

The melting costs include primarily the following items:—All labour employed in the melting department and stock-yard attached thereto; cost of coke; power; materials *ex* stores (limestone, ganister, etc.).

Whether the yield of good castings produced is large or small, melting costs are incurred for all the metal melted; castings should, therefore, be classified on the basis of the production of good castings to metal melted, consideration being given to the relative weight of runners, risers, etc.; the castings should be classified accordingly on the cost sheets, and each class costed separately. The number of classes depends upon the conditions of each undertaking.

To determine melting losses for the various classes of castings, the aggregate tonnage of good castings produced and of all scrap produced in each class should be deducted from the weight of the metal mixture charged into the cupola. The remaining figures will give the melting losses. A general check can be obtained by taking the aggregate stock of pig-iron and of scrap existing at the beginning of the period of costing, plus purchases, and deducting from this tonnage the stock of pig-iron and scrap existing at the end of the period plus the tonnage of good castings produced.

Oncosts

A distinction should be made between departmental oncosts, which apply direct to the melting department, and fixed charges, a share of which is charged to this department. Departmental overheads in the melting department consist mainly of supervising, plant repair and maintenance, laboratory expenses and plant depreciation. The salary of any employee whose time is given to the melting department should be charged to that department.

Plant repair and maintenance covers the cupola plant; cranes and hoists used for the operation of the melting department, which includes the stockyard, blowers, electric gear, etc.

Laboratory expenses must be charged according to circumstances. If a laboratory is used exclusively for cupola control and metal

TABLE I.—*Cost of Metal.*

MIXTURE "A."

		£	s.	d.	
40 tons of	pig-iron (*a*) at £4 per ton	160	0	0	
20 ,,	pig-iron (*b*) at £3 10s. per ton	70	0	0	
20 ,,	bought scrap at £2 10s. per ton	50	0	0	
80 tons	average price £3 10s. per ton	280	0	0	
40 ,,	home scrap at £3 10s. (average price)	140	0	0	
Iron melted 120 ,,	total cost of mixture	420	0	0	
35 ,,	less scrap returned at £3 10s.	122	10	0	
Iron used 85 ,,	cost of metal going into good castings	£297	10	0	(A)
		T.	c.	q.	
	Tonnage of good castings produced (67½ per cent. of total melt)	81	0	0	(T)
	Cost of metal per ton of good castings produced $\frac{A}{T}$	£3	13s.	6d.	

Metal loss (for reference) 3.33 per cent. of total metal.

NOTE.—*The above figures are taken at random and for the purpose only of illustrating the application of the system.*

analysis, it should be charged to the melting department. If a laboratory is also used for testing sands, for mechanical tests on castings, for micrography, etc., it should be possible to break up the laboratory expense between the melting department and the foundry, each bearing a share as a departmental oncost.

Melting plant depreciation is, obviously, a departmental overhead and should be added to cost of metal. Fixed charges in the melting department comprise a share of rent or depreciation of buildings, insurance, and local taxation, in proportion to the floor space occupied by the melting plant and the stock-yards (pig-iron, scrap and coke).

Departmental oncosts and fixed charges are allocated to the various classes of castings in a similar way to melting costs. In each class, the total of melting costs and oncosts, divided by the tonnage of good castings produced, gives a cost per ton, which, added to the cost per ton of the metal mixture, gives the "total cost of the metal at the spout per ton of good castings produced."

Application of the System

Cost of Metal.—For each mixture the cost of metal is calculated as shown in Table I.

Cost of Melting and Oncost.—The various items of cost of melting and oncost are added up for a period of costing (Table II).

The castings are divided into classes corresponding to the yields of good castings to metal melted. As the melting costs and oncost increase in proportion to the tonnage of metal melted, the total amount (B) of these items of cost should be divided between each class of castings proportionately to the tonnage of metal melted in each class: it is then a simple matter to divide the melting costs and oncosts in each class by the tonnage of good castings produced in each class, and arrive at a cost per ton of good castings produced.

If a certain job is made from mixture A and comes under Class No. 2, *e.g.*, 65 to 70 per cent.

Table II.—*Cost of Melting and Oncost.*

		£	s.	d.
Labour, charging, etc.	wages book	8	0	0
Coke, limestone	price as per inventory	16	0	0
Plant maintenance and repairs (labour and materials)	at cost	5	0	0
Ganister, supplies	price as per inventory	4	10	0
Loose plant	at cost	1	10	0
Supervision	pay roll	1	10	0
Light, power	measured or estimated	2	10	0
Share of fixed charges (rent, rates, depreciation, etc.)	allocated on floor space, etc.	3	10	0
		£42	10	0 (B)

(Iron melted, 120 tons = 7s. 1d. per ton of metal melted.)

Good castings produced, 81 tons ($67\frac{1}{2}$ per cent. of melt) = 10s. 6d. per ton (Class No. 2).

Note.—*The above items and figures are taken at random and for the purpose only of illustrating the application of the system.*

yield of good castings to metal melted, the cost per ton of good castings of the metal mixture A is added to melting costs and oncost per ton of good castings pertaining to Class No. 2, and the result gives "the cost of the metal at the spout per ton of good castings produced" for the job.

COSTS IN THE MOULDING DEPARTMENT

Direct Costs

Direct costs are those which can be charged specifically to a job. In order to conform with the first fundamental principle—namely, that "an expense incurred for a job should be charged to that job"—one should aim at bringing in as much as possible under the heading of "direct costs." Items which must be considered under this heading are:—Labour, moulding boxes, patterns and tackle when specially made for a job, and certain consumable materials wherever it is possible that such materials can be charged direct to the job. In order to apply the principle that wherever possible costs should be applied direct to their specific job, each job should be timed so that the correct amount of direct labour costs can be charged to the job.

Furthermore, in order to be able to apply the correct share of overhead costs to each job, castings should be classified in the moulding department in accordance with the method of preparing the mould; therefore, a distinction should be made between machine-made moulds, hand-made moulds, loam moulding, dry-sand moulds, green-sand moulds, and there should be corresponding divisions in direct labour costs when making up the periodical cost sheets. In certain cases the moulding machine section should be sub-divided into sub-sections in accordance with the type of machine used.

Moulding Boxes.—In accordance with one of the fundamental principles of the system, whenever moulding boxes are made for a specific job, their actual cost, less scrap value, must be considered as a direct charge against that particular job. Any other boxes, purchased or made in the foundry and used for general purposes—that is to say, those that are not used for a specific job—should be debited at cost to a " box part account." This account should be liberally depreciated and the depreciation charged to the moulding department as a departmental overhead. This account should be credited with the scrap value of discarded boxes at the time they are scrapped.

Foundry Tackle.—This is treated in the same way. When made for a specific job, it is charged to the job; when made for general purposes, it is debited to a special account and liberally depreciated.

Patterns.—The same principles apply to patterns as those established for moulding boxes; patterns made for a specific job should be charged against the job. The method of establishing pattern costs is explained in a special section dealing with the pattern shop considered as an auxiliary department.

Materials.—Such materials as chaplets, sprigs, wires, etc., should, whenever possible, constitute a direct cost against the job. When this can be done, such materials should be the subject of a stores issue, against an identification such as an order number, which ensures their direct charge to the specific job. In other cases the charge is to be entered against the foundry.

Indirect Costs

Indirect costs cover costs which, by their very nature, cannot be ascribed directly to any particular job. Indirect costs comprise:—Indirect labour; moulding sand; miscellaneous supplies and tools; repairs, etc., and a share of general overhead expenses. As many separate accounts as possible should be kept, in order to enable costs to be properly analysed. A list of some such items is given at the end of this section.

Indirect Labour.—This account covers the wages of all labour employed in the moulding department that cannot be accounted for under the heading of "direct labour"; it includes the wages of men occupied in the sand mixing and reclaiming plant, the wages of men in charge of mould-drying stoves, the wages of men in charge of repairs. The wages of men whose duties are divided between the moulding and another department should be divided in proportion to the time spent in each department.

Moulding Sand.—New moulding sand is included in this account. Labour employed in the sand preparation plant for reclaiming used sand, and depreciation and maintenance of sand plant, are to be charged against the moulding department in the "departmental overhead" account. In some cases, the sand preparation plant can be considered as an auxiliary department, the total cost of which is charged as a departmental overhead of the "moulding department"; this procedure enables a better control of the cost and efficiency of the sand-preparing plant to be effected.

Miscellaneous Supplies and Tools.—In general, the cost of plumbago, blackings, etc., and loose tools should be spread over the moulding department. In foundries that are divided into separate sections, these costs should be allocated between the various sections, bearing in mind the general principle that "a charge incurred for a job should be a direct charge against the job": for instance, spare parts or tools used specifically in conjunction with moulding machines should be charged to the machine moulding section. Special tools used for loam moulding should be charged against that section.

In accordance with the same fundamental principle, fuel used in the mould-drying stoves should be a charge against the dry sand moulding section, as well as the maintenance and depreciation of the stoves. Again, as far as possible, chaplets, sprigs, wires, etc., should be charged against the job for which they are used. As previously stated, whenever materials can be charged direct to a job this should be done. The safest way to ensure that all such supplies are accounted for is to charge them against the moulding department at the time they are issued from stock, and a proper system of stores issuing and accounting, with direct charging wherever possible, should be instituted.

Repairs.—Unless men are fully employed in doing repair jobs, labour costs for repairs are included under the general heading of "indirect labour." All materials and spare parts used in the repair of moulding equipment and of ladles are to be charged as a departmental overhead against the moulding department, or its various sections, *pro rata*. In the larger undertakings, repairs and maintenance of plant and equipment may constitute a separate auxiliary department: in such cases the costs of this auxiliary department are classified and allocated to the four main departments and their respective sub-sections as departmental overheads.

Foremen, Clerks, etc.—In those undertakings where a number of foremen and clerks are fully employed in the moulding department, their salaries constitute a departmental overhead.

Heat, Light and Power.—These items of expenditure can be measured or closely estimated in proportion to their utilisation by the various sections of the moulding department. Heat and light can be allocated on a floor basis; power can be allocated on the basis of consumption of the various plants utilising power. This is a departmental overhead. In those undertakings which operate their own power plant, these items constitute an auxiliary department, in which the cost per unit of the medium of power can be determined. This cost is then allocated on the basis established in the preceding paragraph.

Fixed Charges.—These include rent, rates, taxes, depreciation of buildings and plant, insurance, etc. For depreciation and insurance of buildings, a departmental factor can be worked out on a floor basis. Depreciation of plant and equipment should be computed on the basis of value and probable life of each kind and type of plant. Rent, rates and taxes are worked out on a floor area basis.

An allocation should be made at the beginning of each year for each department or section of the undertaking. All items of general expense that can be definitely allocated to the moulding department should be so charged. Such items of general expense that cannot be divided between the various departments of the undertaking, such as administration expenses, social charges, selling costs, outward freight, financial charges, bad debts, etc., are dealt with at a later stage.

Method of Allocating Overheads in the Moulding Department

The various methods of allocation, on the basis of direct wages, time, space and tonnage, were considered and compared at length at several meetings of the Sub-Committee and discussed by correspondence. It has been found that the simplest and soundest method applying to the average-size foundry is that based on direct labour. This method is open to some criticism in certain cases, but so are all the other methods. The Sub-Committee has ruled out the tonnage basis as definitely unsound; the space and space-time methods have been found too complicated and open to objections.

In certain cases the time method would be acceptable, but it has been found that for the majority of cases, and in view of the fact that in any case wages must be accurately recorded. the "direct labour" method is the best to adopt for a uniform system, and the one least likely to offer the risk of inaccuracies and complications. The Sub-Committee therefore recommends that overhead charges in the moulding department be computed on the basis of "direct labour."

Where a fair number of apprentices are employed, it is recommended that the percentage of overheads applied to apprentice wages should be increased in relation to the difference between ordinary moulders' wages and apprentices' wages, taking into account the relative numbers of men employed in each category. A formula* is available which gives the correct percentage applying to each category, but if the result be obtained by approximation, care should be taken and a check made to ensure that the full amount of overheads has been accounted for.

The Sub-Committee cannot offer recommendations applying to widely exceptional cases, except that the fundamental principles of this system should be applied, but that their detailed application should be adapted to the circumstances of the case and governed by common sense.

NOTE.—Knocking-out costs must not be overlooked; their treatment depends upon the organisation of the foundry. In most cases the knocking-out station is in the moulding department; in other cases in the fettling department. It may be treated as a direct or an indirect cost. In any given case, the principles of the system must be applied to that particular case.

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[*] The formula is as follows, x being the percentage applying to the experienced moulder's wage, and y the percentage applying to the apprentice's wage :—

$$x \text{ per cent.} = 100 \frac{O}{M + pA}$$

$$y \text{ per cent.} = px \text{ per cent.}$$

Where O is the amount of overheads to be allocated during a given period.

M is the total amount of wages paid to the experienced moulder during the period.

A is the total amount of wages paid to the apprentice during the period.

p is the amount by which the unit wage of the apprentice is smaller than the unit wage of the experienced moulder—*i.e.*, if apprentice wage is $\frac{1}{2}$ the moulder's wage, or twice as small, $p = 2$; if $\frac{1}{3}$, or three times as small, $p = 3$.

Application of the System

The following is a list of certain current items of cost that make up the overhead expenses relating to the moulding department. This list is not exhaustive and should be modified in accordance with the circumstances of each undertaking; it is given merely as a guide. Certain headings, such as box parts, foundry tackle, materials *ex* stores, are included to cover those items that could not be charged as " direct costs " against a particular job.

Labour, unproductive : Wages.
,, ,, : Salaries.
,, ,, : Stores.
,, ,, : Packers.
Box parts : Labour.
,, ,, : Materials.
Foundry tackle : Labour.
,, ,, : Materials.
Sand : Labour.
,, : Materials.
(or cost of sand preparation auxiliary department.)
Drying stoves, labour and materials.
Materials *ex* stores.
Coal dust.
Moulding machines, repairs, labour and materials.
Plant repairs, labour and materials.
Salaries.
Coal and gas.
Power, light and heat.
Handling of materials, castings, etc.
Workmen's compensation insurance.
National Health Insurance.
Unemployment Insurance.
Laboratory wages and salaries.
,, materials.
Rent and rates.

Depreciation of boxes.
,, ,, fixed and movable plant, etc.

Those items that can be allocated to a particular section of the foundry should be extracted from this list and allocated to the proper section; for instance, the cost relative to drying stoves, including fuel, should be charged to the dry-sand mould section; repair and depreciation of moulding machines should be charged to the machine-moulding section; tools used for loam moulding should be charged to the loam moulding section, etc.

All the other items that apply to all sections of the foundry are then totalled; the ratio of the total amount relating to these items to direct labour costs in the moulding department is taken. In each section of the foundry, the ratio of overheads specifically charged to that section to direct labour costs in that section is also taken.

For instance, if total direct wages in the moulding department during a costing period amount to £200, and all items of indirect cost applying to all sections of the foundry total £160, the percentage to apply to direct labour costs to cover these items is 80 per cent., or for each 20s. of direct labour 16s. should be added. If direct wages in the dry-mould section amount to £120 and the overhead applying specifically to that section amounts to £30, 25 per cent. of direct labour costs should be added further for that section, or 5s. for every £1. In the same way, the moulding machine overhead might be 15 per cent. of direct labour costs for that section.

Applying this to a job made from mixture A, yielding 67½ per cent. of good castings, made with dry-sand moulds on a moulding machine, the overhead applying to all sections of the foundry will be 80 per cent. of direct wages charged to the job, plus 15 per cent. for the moulding machines, plus 25 per cent. for the drying stoves; therefore, the percentage overhead for this job will be 120 per cent. of direct wages. This gives:—

	£	s.	d.
Cost of metal at the spout, per ton of good castings (obtained from melting department, Mixture "A," Class 11)	4	4	0
Direct Labour	2	15	0
Overhead—120 per cent. of L	3	6	0(L)
Patterns, cores, boxes, etc.	0	15	0
TOTAL COST	£11	0	0

This gives the cost per ton of good castings of the job up to the point where it leaves the moulding shop.

THE CORE DEPARTMENT

The core department is just as much a productive department as the moulding department—therefore, core costs must not be considered as an overhead charge against the moulding department, but must be calculated in the same way as moulding costs. Furthermore, cores must be identified with the job for which they are made and their cost charged accordingly to the respective jobs.

Wages must be carefully recorded, a separate record being kept of direct wages paid to the coremakers, as this will be the basis for the allocation of overheads. For this purpose also, core jobs should be classified on the cost sheets, as between green-sand cores and dried-sand cores, hand-made and machine-made cores.

As far as is possible, efforts should be made to treat the cost of the sand, core oils, binders, etc., constituting the core mixture in a direct manner. The cost per cwt. of any particular core mixture can be ascertained quite simply. The weight of mixture required for any particular core is also easily ascertained. In this way the cost of a mixture for particular cores can be arrived at.

Like moulding boxes, core boxes and jigs made specially for one job should be charged to that job. Other equipment for running production should be debited to a special account and liberally depreciated, this depreciation being charged as a departmental overhead against the core department. Core-irons, wires, grids, etc., should not be overlooked. In large engineering jobs they may rise to a considerable amount. In any case, they should be properly issued from stores and properly accounted for.

Departmental overheads include, in addition to the items already mentioned in the section relating to the moulding department, maintenance and depreciation on such items as the core-drying ovens, core machines, etc. Core wastage in general should be charged in the core shop, and the resulting cost of good cores is charged to their respective jobs in the foundry. As in the moulding department, the overheads of the core shop should be allocated to the various jobs on the " direct labour " basis.

The Pattern Shop

This is considered as an auxiliary department. In accordance with the fundamental principle of the system, patterns made for a specific job should be charged to that job; if made for a special client, the cost should be charged to the client. As in other departments, the expense of the pattern shop includes:—(*a*) Direct costs—*i.e.*, direct wages and material; (*b*) indirect costs —*i.e.*, indirect materials, such as screws, varnish, paint, and (*c*) overhead expense which cannot be charged direct.

As regards direct costs, these are charged direct to the patterns made for special jobs, and to running patterns respectively. Any indirect costs that can reasonably be charged to specific jobs should be so charged. All other overheads are calculated as a percentage of "direct labour," so that specific jobs should bear their proper share of such overheads. Then all new running patterns are capitalised, and their depreciation, together with maintenance, repairs, and overheads not already charged to specific jobs are charged as an oncost of the moulding department.

THE CLEANING AND FETTLING DEPARTMENT

This department covers all operations effected on castings from the time when they are knocked out of the mould until they are cleaned and dressed. Any other special treatment of the surface of a casting—as, for instance, enamelling or other finishing operations—is not included in the cleaning and dressing department and is outside the scope of the present system.

It is recommended that the cleaning and fettling department should be divided into two main sections:—(*a*) A section where labour is the main item of cost and where one casting is dealt with at a time, such as is the case for chipping, grinding, filing, wire-brushing, etc.; (*b*) a section covering operations in respect of which the principal item of cost is power and depreciation of plant, and where a number of castings are treated together, such as is the case for tumbling, sandblasting, pickling.

With regard to section (*a*), labour is a direct cost applying to each job, and all departmental overheads, including the cost of files, chisels, brushes, hammers, emery wheels, etc., are to be allocated on a direct wage percentage basis. In quite a number of foundries where plant is not used, this system will apply quite simply.

As regards section (*b*), a simple system consists of adding up all costs, including power, labour, depreciation of plant, abrasives, shot, and departmental overheads less any portion charged to section (*a*), and allocating the total cost to each job on a weight basis.

For the larger foundries where various types of plant are used, such as tumbling barrels and sandblasting plant, a more precise system is recommended. It will be realised that weight is not the only factor that intervenes in these types of plant; the time necessary to clean various kinds of castings is another variable factor, which depends more upon the shape and degree of intricacy of the casting than upon its weight.

In tumbling barrels, all the castings are put in and taken out at the same time, and if there is only one barrel, its cost cannot be allocated otherwise than on a weight basis, but if a foundry uses more than one tumbler, it should be possible, as a result of experience, to allocate the barrels to classes of castings, putting together those castings that take the same time to clean. The direct cost of operation of each barrel can be arrived at, and for each one that cost is charged to the castings on a weight basis; the overheads of the tumbling section should be added, also on a weight basis.

In sandblasting, in those cases where the castings can be taken out when they are cleaned without disturbing the other castings for which the operation is not completed, the castings can be classified or tabulated in accordance with the time taken to sandblast them. Experience will tell to which class a particular casting should belong. Taking into account the total tonnage passed during a given period, the cost of operating the sandblasting section, including overheads, can then be charged to the castings on a ton-hour basis.

Castings Inspection Charges.—When special inspection is effected for a specific job, the cost should be charged to the job. In other cases inspection costs should be charged as an oncost on the departments concerned.

Other Auxiliary Departments.—In undertakings that operate their own light, heat and power plant, this should be considered as an auxiliary department, and the cost per unit should be worked out, taking into account all overheads applying to that department. The cost of heat, light and power thus being known, it can be applied to the various departments of the undertaking, as explained in the costing system.

If there is a separate maintenance and repairs department, whenever possible individual costs should be worked out and charged to the appropriate place. For general maintenance and repair work, the cost is an overhead on the appropriate department.

Packing and Despatching.—These items should be regarded as an overhead, and calculated as a percentage of productive labour in the moulding department.

Freight.—This is an item the cost of which is usually determined for particular jobs, and it can be added at the end of the cost sheet.

GENERAL OVERHEADS

There are a number of items, additional to actual production costs, such as directors' fees, workmen's mess rooms and clubs, financial charges, etc., which cannot easily be allocated to any particular department. There is also the question of selling costs and publicity.

At the stage now reached it can be stated that all actual manufacturing costs have been considered, and if such costs are calculated by means of a system that is uniform for the industry, there is available a basis upon which such manufacturing costs can properly and fairly be ascertained and recorded. The point is, therefore, reached where the main object of the Sub-Committee has been fulfilled, provided that the principles that they have endeavoured to establish prove acceptable.

As for the items of expenditure referred to in this paragraph as "general overheads," it is suggested that they should be considered apart from, or in addition to, the actual manufacturing costs. The items now under review vary considerably from one undertaking to another. There are cases where directors are in charge of a department and receive a fixed salary, which then becomes a departmental oncost. Some undertakings may be in the fortunate position of having no financial charges. Some are not of sufficient size to finance and maintain workmen's clubs, etc. Publicity and selling costs vary widely. These items, by their very nature, may tend to distort the truly comparable value of actual manufacturing costs arrived at so far.

It is, therefore, suggested that the basic production cost figure is that arrived at at the despatch stage, and before freight is added. Then, to complete the costing process of any given undertaking, the general overheads must be added to the manufacturing cost figure, and allocated as a percentage of productive labour on direct moulding and core shop wages.

The recommendations set out in this report are postulated in the hope that, subject to any adjustments and additions that may arise from the discussion, they will be accepted as guiding principles by the industry at large, which will then be provided with a proved and comparable costing system.

Finally, the Costing Sub-Committee is prepared to remain constituted in an advisory capacity in order to facilitate the application of the system, particularly as regards the smaller jobbing foundries, and to co-operate with such foundries in adapting the system to their particular case.

DISCUSSION

Mr. A. Sutcliffe suggested that to a practical foundryman the Paper was worthless. He was prepared to go with the Costing Sub-Committee to try to apply its recommendations to a jobbing shop, and he was not optimistic about the results. No two men worked alike in a jobbing foundry. One would use more sprigs or more facing sand than another; one would make more wasters than another. Only the moulders on the floor could produce the castings, and that fact rendered costing difficult. There were also difficulties with regard to patterns, some of which seemed to be constructed rather for appearance than for use. How were they to be costed? Sometimes they were designed by the drawing office and made by a joiner; they had to be twisted in various places, and a great deal of time had to be spent in putting them right. He had nothing against this Paper, but, being a craftsman, he felt that the Sub-Committee was catering more for the repetition and mechanised foundry than for the jobbing shop.

The President, Mr. C. W. Bigg (a member of the Sub-Committee) accepted Mr. Delport's invitation to reply to Mr. Sutcliffe. He said that if any of the moulders used more sprigs than they should use, he would very quickly find out the reason. The management should be capable of deciding the correct number of sprigs to use for a job, and it should not be left to the discretion of the individual men on the floor. As to the other questions raised by Mr. Sutcliffe, he said that to every other man in the room they answered themselves.

Mr. J. H. Cooper emphasised that the purpose of the Paper was to help founders to deal with their problems from their different angles and to secure the best possible results. It seemed, he said, that Mr. Sutcliffe was regarding the Paper in the wrong light, overlooking the fact that founding was team work and was not individualistic.

A Simplified Scheme Needed

Mr. C. E. Williams (Past-President), in a tribute to the Costing Sub-Committee, commented jocularly that perhaps he was to blame for having given them the task of getting their figures and recommendations together, for during his year of office as President he had suggested that it would be a good thing to impress upon the small jobbing founders particularly that there were other factors in their costs besides pig-iron and coke. Sometimes it seemed to him that a founder added together only the costs of his pig-iron, coke and labour, adding 10 per cent. for profit; the Paper contained suggestions which would enable the small founder to arrive at cost figures which were nearer the truth than would be the case if he shut his eyes to the fact that there were such things as sand, springs, blacking, etc. The work of the members of the Sub-Committee had involved them in considerable travelling and expense, and the members had devoted a great deal of their time to the work, which was very heartily appreciated; but it would be a good thing if they could throw out a somewhat simpler scheme, suitable for application to a jobbing foundry.

Costs, Overheads and Piece-work

MR. J. ROXBURGH said it was perhaps safe to assume that most foundries, whether large or small, had some system of costing in operation. Probably in the beginning the costing systems used in some cases were devised and introduced by persons who were not altogether familiar with or appreciative of the diversity of products and processes used in the foundry. It was, therefore, a matter for congratulation that the Costing Sub-Committee, composed of foundrymen, had gone to the trouble of investigating costs from inside the industry. He believed that, generally speaking, the principles enunciated and the recommendations made in the Paper could form a basis upon which a proper costing system could be devised Therefore, he felt that the industry should accept the recommendations generally. The Sub-Committee had pursued the correct course in applying the overheads to the direct costs, but perhaps a point such as that was worthy of still further attention. It was well known that in any scheme of payment by results the prices set should be such that an average man could earn time-and-a-quarter. For instance, in the case of a piece-work job where 500 hours was allowed, and where the job was actually done in 400 hours, the moulders earned a bonus of 100 hours. He contended that the overhead figure should apply to the actual number of hours worked, *i.e.*, the 400 hours, and that the cost of the extra 100 hours was merely added on. If the cost of the 100 hours was £7, that amount should be spread over the whole cost of the casting.

The Sub-Committee were also to be congratulated on the fact that, in regard to metal and melting costs, they had gone a great deal further than they had in their preliminary report, and the bogie of the price of domestic scrap had been brought nearer solution in the present report than in the previous one. If, as they had suggested, the scrap resulting from each type of metal mixture were weighed and booked out to its respective pile in the yard, and any scrap used from this pile booked back again to the foundry, a correct record of each type of scrap material would be obtained. The finished castings resulting from each type of metal mixture would also be recorded and, from this information, the cost of metal would resolve itself into purchases of metal and scrap against each mixture, divided by the weight of finished castings obtained from each mixture.

This report was of immense importance to the industry, and an executive of a foundry should not only know his costs, but should be able to interpret them so that they would serve as a reliable guide to help him to improve the efficiency of his department. It was particularly significant that the President, in his address that morning, had laid particular emphasis on the subject of costing in the foundry.

Establishment of Fundamentals

The **President** said that, as a practical man, he had endeavoured to found all his later reasoning on the principles he had acquired at the bench in his early days. Messrs. Qualcast, Limited, had been moderately successful, and a tremendous amount of the success it had achieved was attributable to the realisation of the importance of applying proper costing principles. Costing had a value as a dimensional factor in the works as distinct from the office; that was one of its main values to the works executive, and he regarded the cost book as the barometer for the works.

From the statements made, he said, it might be thought that it was well nigh impossible to arrive at a costing system for a jobbing shop;

but, in fact, that was not so. The Sub-Committee was out to establish principles. No matter how small a shop or how varied its work, an intelligent trial could be made of costing, and he was sure that even Mr. Sutcliffe would be keen about it if he would give it an unbiassed trial.

In a tribute to the Costing Sub-Committee, the President said that the members had had to devote a certain amount of time to the work, but they had all enjoyed it. He proposed a hearty vote of thanks particularly, however, to Mr. Delport, the convener, who had had to devote a tremendous amount of time to the formulation of the results of the Sub-Committee's discussion.

Mr. C. C. Booth, as a member of the Sub-Committee and, therefore, as one who appreciated the enormous amount of work Mr. Delport had done, seconded the vote of thanks. The members of the Sub-Committee, he said, had discussed many problems which they had met in their own works, and great credit was due to Mr. Delport for the able manner in which he had interpreted their statements and had committed them to paper.

The vote of thanks was carried with acclamation.

Mr. Delport, responding, said that the real fundamental matter contained in the report had resulted from the discussions of the views and experiences of the whole of the members of the Sub-Committee, so that any expression of thanks to him should be allocated to the Sub-Committee as a whole.

Costing, he continued, was really a question of good management, and there could not be good management in a foundry without a costing system. He hoped that members of the Institute would study the Report and would contribute constructive criticisms and suggestions; those criticisms and suggestions would be considered and the results of the Sub-Committee's investigation of them would be embodied in a final report.

COMMUNICATIONS

A Means of Simplification

Mr. S. H. Russell (Past-President and hon. treasurer of the Institute) wrote that he fully endorsed all the recommendations regarding the necessity of costs. The only criticism was that it appeared to be drawn up purely from the point of view of foundries making large quantities from the same pattern, and that the average jobbing founder would be rather frightened by the amount of data he was required to collect. The essential items in costing were:—(1) Cost of metal at the spout; (2) skilled-labour cost of producing the casting (*i.e.*, moulder and coremaker); and (3) the cost of non-productive labour, *i.e.*, foremen, fettlers, labourers and works staff. This could be expressed as a percentage of the skilled labour cost, and whilst it was admittedly somewhat approximate, usually averaged out very closely, the intricate and cored work naturally absorbing a bigger share of those non-productive costs.

An accountant would quickly and easily advise a foundry as to the percentage necessary to add to the total of these items to cover overheads and a reasonable profit. He had previously expressed the opinion that cost of metal calculation could be simplified by omitting all reference to home scrap (this being made originally from the bought materials). The cost of a charge of pig-iron and bought scrap was readily obtained, and to this cost should be added the cost of fuel and materials per ton of good castings produced, obtained by averaging costs and tonnage of purchases and sales over a year. The furnacemen's wages might be either allowed for or included in the total percentage of non-productive labour. This method, admittedly, was not so accurate, but if reasonable care was taken in establishing the basic figures, the cost on any individual casting, even if only a one-off job, could be very quickly determined. It was most important that a simple system of costing, reasonably accurate, should be introduced into every foundry, and it was then inevitable that ultimately the costing would be made individually more accurate by the more elaborate system outlined in the report of the Sub-Committee.

Mr. E. R. Briggs wrote:—

I would like first to congratulate the Sub-Committee on the way in which they have tackled this difficult and controversial subject. I think they were wise in confining themselves, in the main, to laying down general guiding principles, as experience shows that each business must work out its own method in detail to suit its own work and to conform generally with its own organisation.

There are several points upon which I differ from the findings of the Sub-Committee, but I will confine myself to two of them. The first is the value of the metal. The method of arriving at this value is, I suggest, incorrect, although I agree with the answer obtained. Surely the home scrap has no value at all. It is true that certain charges have been incurred in direct labour and on-costs in melting this scrap, but these charges have been transferred to the account of the good castings, and its value on returning to the cupola is nil. The amount of home scrap produced per ton of good castings must be ascertained over a long enough period to secure average results in order to determine the proportion charged, which must be equal to that returned. The cost of the metal itself is that which is in the good castings plus the metal lost. A simpler and more convenient way of stating the cost of the metal is per ton of good castings, and mixture "A" would be stated thus:—

	s.	d.
10½ cwts. pig-iron (*a*) at 80s. ...	42	0
5¼ cwts. pig-iron (*b*) at 70s. ...	18	4
5¼ cwts. bought scrap at 50s. ...	13	2
21 cwts.	73	6

The lost metal is taken at 5 per cent. of the good castings, and is equivalent to that given in the Report.

The second point upon which I should like to make some comments is that of the on-cost recovery. I must join issue with the Sub-Committee on their statement that the simplest and soundest method is that based on direct labour. This implies that no other method is as simple or as sound, a statement that can hardly be substantiated. The conditions of wages and methods of payments in foundries are such that the nearest approximation to accuracy in the distribution of on-costs is the method of hourly rates. This method provides for the variation in cost of service provided for the different classes of direct workers as well as for the time during which they utilise these services. Every foundry has a limit to the number of productive hours available, and each productive hour has a definite financial value according to the facilities provided for the operation performed; unless these two factors, service and time, are taken into account in distributing the indirect charges, there is the probability that some castings are being overcharged and others undercharged, which would tend to cause unprofitable work to flow into the foundry and keep the more profitable lines away.

WEAR TESTS ON FERROUS ALLOYS

Paper No. 607

By O. W. ELLIS*

[American Exchange Paper]

Introduction

About two years ago, at the Convention of the American Foundrymen's Association in Toronto, Canada, the author, in collaboration with his colleagues, Mr. J. R. Gordon† and Dr. G. S. Farnham,‡ presented a Paper on the wear resistance of white cast iron. The tests described in that Paper were carried out in end-discharge porcelain jars (8.75 in. dia. and 9.60 in. high), which in the individual tests were charged with either nine cylinders ($\frac{3}{4}$ in. high and $\frac{3}{4}$ in. dia.) or nine sand-cast balls ($\frac{3}{4}$ in. dia.), together with 4 lbs. of silicon carbide and $1\frac{1}{4}$ lbs. of water. The jars, loaded and sealed, were rotated at 60 r.p.m. in a motor-driven mill of standard design. The cylinders, or balls, were weighed individually at the beginning and end of each of 10 runs of 160,000 revs. each. At the end of each run the percentage losses in weight of the balls were calculated. The Paper contained curves showing the losses in weight (with time) of various cast irons, as well as tables giving the losses in weight of a number of alloys in mgrms. per sq. cm. of original surface (" wear numbers ") at the end of 800,000 and 1,600,000 revs.

Among the conclusions reached by the author and his collaborators were the following:—

(1) Given a suitable abrading medium, the ball mill can be used to measure the wear resistance of white cast irons.

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(2) The higher the carbon content of white cast iron, the less consistent (under the conditions described) are the results of wear tests on cast balls made from these alloys.

(3) The higher the carbon content of white cast iron, other things being equal, the lower is its wear resistance under the conditions described.

(4) Variations in manganese up to about 1 per cent. have practically no effect on the wear resistance of white cast iron, nor does the addition of this element (up to 6 per cent.) improve white cast iron containing ledeburite.

Effect of Carbon on Resistance to Wear of Iron-Carbon Alloys

Perhaps the most interesting of these conclusions is the third. It was thought important enough to warrant further experiment, and two series of tests were made with 1 in. dia. sand-cast balls. Two balls of each alloy (Table I) were tested in silicon carbide (¼-in. grain) in substantially the way already described. The results of the tests are given in Table I.

TABLE I.—*Wear Numbers for Iron-Carbon Alloys (1¼ pr cent. Si) in Silicon Carbide.*

C. Per cent.	Si. Per cent.	Mn. Per cent.	Relative loss of weight.
0.98	1.21	1.04	100.6
1.41	1.22	1.07	100.0
1.92	1.26	1.09	103.2
2.58	1.41	1.01	110.3*
2.97	1.27	1.01	124.9*

* Mottled.

It was believed that full confirmation of the previous results had been obtained. However, macroscopic examination of the balls made from the 2.58 and 2.97 per cent. carbon melts showed them to be mottled, and therefore unsatisfactory for demonstrating that the wear resistance of white cast iron decreased with rising carbon content. A new series with lower silicon was made, and the analyses of these alloys, also cast as 1-in. dia. balls, are given in Table II, together with their relative losses of weight after test in silicon carbide.

Table II.—*Wear Numbers for Iron-Carbon Alloys (¾ per cent. Si) in Silicon Carbide.*

C. Per cent.	Si. Per cent.	Mn. Per cent.	Relative loss of weight.
0.95	0.72	1.05	102
1.43	0.79	1.07	100
2.02	0.75	1.15	101
2.41	0.72	1.20	104
2.95	0.80	1.05	111

Table III.—*Wear Numbers for Chromium Steels in Silicon Carbide.*

	C. Per cent.	Si. Per cent.	Mn. Per cent.	Cr. Per cent.	Relative loss of weight.
Group 1	2.02	0.75	1.15	—	100
	1.18	1.11	1.01	2.15	99
	0.73	1.24	0.87	4.89	69
	0.45	1.18	0.94	10.20	36
	0.22	1.15	0.90	15.15	45
Group 2	2.02	0.75	1.15	—	100
	1.18	1.11	1.01	2.15	101
	1.05	1.25	0.91	4.94	96
	1.02	1.18	0.90	9.83	68
	0.96	1.18	0.98	13.96	61

Wear Tests on Alloy Steels and Irons in Silicon Carbide

These results fully confirm the view that (under the test conditions described) the wear resistance of white cast iron decreases as the carbon rises. Also, the impression is created that the wear resistance of *steel* falls with decrease of carbon. In short, maximum resistance to wear in silicon carbide obtains in alloys on the borderline between steel and white cast iron—alloys having a structure corresponding to that of the 1.7 per cent. carbon alloy of the pure iron/iron carbide system.

Since the Paper referred to was published, much more work has been carried out under the same test conditions. The results have shown that many alloys of low Brinell hardness number resisted abrasion as well as, and often better than, alloys of high Brinell hardness number. Many pearlitic alloys have been found superior to martensitic alloys, and many austenitic superior to pearlitic. The outstanding feature of the tests as a whole has been the marked superiority of the alloys containing chromium. In this connection, figures in Table III, chosen at random from many, emphasise the points thus far brought out.

Continuous Mill for Testing the Resistance of Balls to Abrasion

While the tests in porcelain jars were being made, results were discussed from time to time with interested persons, among whom was Prof. H. E. T. Haultain, head of the Department of Mining Engineering at the University of Toronto. He brought to the author's attention a continuous mill of his own design, employed in his department to test the grindability of ores. This mill could be readily adapted to wear-resistance tests on alloys in the form of balls, and after preliminary tests had been carried out with the mill as it then was, the necessary minor changes (which require no description here) were made in its design.

Fig. 1 shows the continuous mill, with accessories, in its latest form. The mineral used as the medium of abrasion is fed into the hopper seen at the upper right-hand corner of the illustration, whence it flows on to the continuous rubber belt which moves beneath. Means are provided both for ensuring and for regulating the flow of mineral from the hopper to the belt.

From the belt the stream of mineral falls into a smaller hopper which is connected to a tube extending into the mill. In this tube a rotating cast-steel screw carries the mineral forward into the mill. The screw is cast with a hole running axially throughout its length. Through this hole there extends into the mill a small copper tube by means of which water is supplied during test

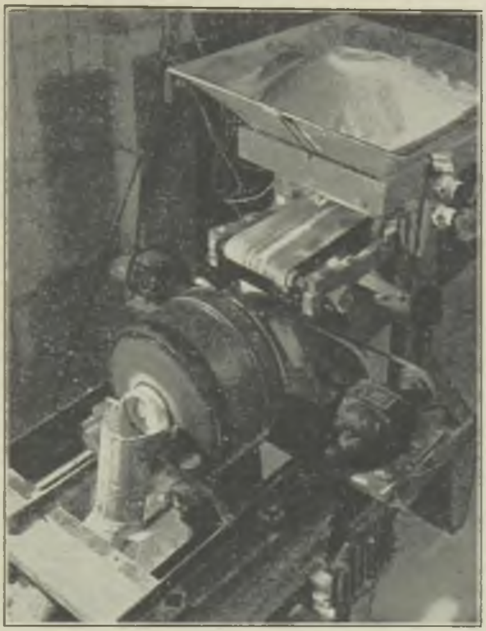

FIG. 1.—CONTINUOUS MILL FOR TESTING THE RESISTANCE OF BALLS TO ABRASION.

in quantities which may be varied at will. The mill itself is rubber-lined and is rotated at from 30 to 60 r.p.m. by means of two shafts supported on suitable bearings, and connected by belting. The mill is divided into two parts:—(1) A front part, consisting of a single casting (lined with rubber), and (2) a back part, consisting of a circular plate (also lined with rubber) firmly attached to the front part by means of bolts to which nuts are fitted. The ground material leaves the mill through a central hole in the front part of the mill. This hole is approximately 1½ in. dia., and is fitted with a screen to prevent the balls from leaving the mill. The sludge is caught in a galvanised iron shute which conveys it to buckets in which it is removed as desired. Means are provided for automatically shutting off the mill if any part of it fails, but troubles have been encountered despite these automatic devices. Experience has made it clear that for continuous operation it is necessary to sieve most minerals so as to eliminate particles smaller than about 40 mesh.

Tests in the Continuous Mill with Kirkland Lake Ore

In the first tests carried out in the continuous mill, primary bowl sands* from Lake Shore Mines, Limited, were used as the abrading medium. These sands, which gave but little trouble in the mill despite their wide range of particle size, varied in this respect within the limits shown in Table IV.

In passing, it is interesting to note that from 83 to 89 per cent. of the sludge leaving the mill was −200 mesh, and that less than 3 per cent. was over 60 mesh.

At the time of starting these tests it was decided to run the mill continuously for a week at

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* The primary bowl sands used as the medium of abrasion in these tests represent the coarse discharge of a classifier after the first ball mill. Practical experience shows that this material is somewhat tougher than the original ore. The ore was ground in ball mills at the mine, and was then classified, so that the — 325-mesh product of the ball mills was removed.

A partial analysis of one sample of these sands is as follows :—Insoluble, 83·2 per cent. ; lime, 3.62 per cent. ; magnesia, 1.85 per cent. ; pyrite, 1.92 per cent. ; and loss on ignition, 5.65 per cent. A complete analysis of the ore of which these sands were a representative sample follows :—Silica, 50.55 per cent. ; alumina, 13.65 per cent. ; sodium and potassium oxides, 10.10 per cent. ; loss on ignition, 6.50 per cent. ; lime, 4.60 per cent. ; iron, 4.25 per cent. ; magnesia, 2.90 per cent. ; sulphur, 1.00 per cent. ; carbon, 0.09 per cent. ; molybdenite, 0.08 per cent. ; lead, 0.02 per cent. ; tellurium; 0.02 per cent. ; copper, 0.01 per cent. ; and gold, 0.59 oz. per ton a time, weighing the balls before and after each week's run. This procedure, once adopted, was used throughout the entire series of tests with the sands. However, owing to difficulties met with in running the mill, the same weight of sands did not pass through the mill each week. In later experiments, the amount of mineral treated has been made the criterion of the length of the run. Generally speaking, 500 lbs. of mineral have been fed to the mill during each run. The ratio of water to sands was kept at 30 per cent. throughout the test.

In Table V are quoted the analyses of the alloys used in making the balls. In all cases the content of sulphur and of phosphorus respectively was less than 0.04 per cent. The balls, suitably marked, were tested and weighed in groups of 10. The number of balls in the mill during each run varied slightly, as is shown in Table VI.

TABLE IV.—*Particle Size of Concentrates Used in Tests in Continuous Mill.*

Particle size.	Per cent.
+ 60	45–60
60 to 80	10–15
80 to 100	9½–10½
100 to 150	Up to 10
150 to 200	1½–9½
– 200	11½–17½

The weight of balls undergoing test also varied from run to run, as might be expected. In Table VII are given the results of the experiments with the sands on a series of sand-cast balls, 1 in. dia., of various compositions, and 1-in. dia. balls of other materials supplied to the author through the courtesy of persons interested in his tests. The Stellite balls were supplied by Dr. C. W. Drury, of the Deloro Smelting & Refining Company, Limited, Toronto, Ontario. The forged steel balls were supplied

TABLE VII.—*Loss in Weight in Mgrms. per Sq. Cm. of Alloys Tested in a Continuous Mill using Lake Shore Concentrate as Abrading Medium.*

RUN NO. -	1	2	3	4	5	6	7	8	9	10	11	12
TOTAL WT. OF MINERAL (IN LB.) FED TO MILL (ALL RUNS)	322	675	1021	1369	1769	2169	2544	2904	3369	3899	4379	4779
TOTAL WT. OF MINERAL (IN LB.) FED TO MILL (LAST FOUR RUNS)									465	995	1475	1875
ALLOY NO.	TOTAL LOSS IN WEIGHT – MG PER SQ CM ORIGINAL SURFACE OF BALL (TOTAL OF 10 BALLS)											
STELLITE	42	80	123	159	189	217	250	284	312 28	337 55	379 95	429 145
NI-HARD	52	101	153	199	238	273	312	353	393 40	429 76	486 133	556 203
A-16	57	113	173	227	273	315	365	411	454 43	491 80	561 150	648 282
A-17	57	120	183	240	289	334	385	436	481 45	519 88	592 156	676 [illegible]
A-14	67	133	197	233	300	344	397	432	404 30	549 93	621 167	726 252
A-8	70	135	197	258	307	354	406	470	524 56	577 107	652 182	741 271
A-13	71	139	205	263	311	356	407	469	523 54	571 102	645 176	732 268
A-15	72	140	206	267	316	363	413	476	533 56	581 106	655 179	745 269
A-11	74	145	212	273	323	367	418	484	544 60	595 111	676 186	753 274
A-12	77	149	217	279	329	376	402	468	524 56	575 107	652 184	743 276
A-19	78	168	244	314	379	424	480					
A-10	80	162	227	289	338	385	437	504	564 60	616 111	693 189	[illegible] 278
A-22	80	159	220	279	328	373	421	485	543 38	581 76	[illegible] 180	754 269
A-18	80	171	240	307	381	414	465					
A-25	81	148	220	285	339	386	440					
A-23	82	161	232	296	349	395	451					
A-24	82	159	232	299	354	404	463					
A-4	85	166	254	302	355	397						

A-7									63	125	206	307
A-9	89	171	234	304	347	396	432	523	588 65	644 121	727 204	814 301
A-5	90	169	237	300	350	397						
A-6	90	172	246	313	371	425	486	551	618 67	676 126	764 216	866 316
A-20	91	173	244	310	364	412	468	557	618 61	671 114	755 198	841 284
A-1	92	175	244	310	367	413						
A-2	94	177	247	319	375	420						
A-27	95	195	277									
A-5	102	192	263	319	365	407						
FORGED STEEL	109	210										
COPPER	232											
GLASS	883											
A-35				64	141	194	246	311	368 64	412 101	461 150	583
A-36				74	130	177	232	294	349 54	397 102	475 180	566 271
A-38				74	133	186	248	318	375 57	426 108	536 218	690 372
A-45							63	134	189 55	241 107	315 181	402 268
A-42							66	143	210 67	267 124	354 211	454 311
A-39							66	155	223 68	287 132	378 223	480 325
A-41							63	170	218 48	297 127	383 213	488 318
A-40							84	157	226 69	286 129	372 215	476 319
A-50								44	85 39	118 72	167 121	239 193
A-51								47	90 43	124 77	192 145	272 225
A-47								46	81 35	120 74	190 144	284 238
A-46								53	94 41	127 74	196 143	287 234
A-49								53	96 43	133 80	199 146	280 227
A-48								57	101 44	141 84	218 161	305 248

TABLE V.—*Chemical Analyses of Alloys Used in Making Balls for Wear Test in Sands.*

Alloy Number.	C. Per cent.	Si. Per cent.	Mn. Per cent.	Cr. Per cent.	Ni. Per cent.	Mo. Per cent.
Ni-Hard	2.72	1.21	0.43	1.58	4.62	
A–16	1.24	1.24	1.14	2.05	3.94	
A–17	1.02	1.32	1.08	3.08	5.95	
A–14	1.00	1.28	0.98	3.18		
A–8	1.56	1.31	1.01		2.89	
A–13	1.18	1.11	1.01	2.15		
A–15	1.43	1.29	0.98	1.12	2.04	
A–11	1.58	1.36	5.85			
A–12	1.39	1.17	1.03	1.06		
A–19	0.62	1.47	5.84			
A–10	1.57	1.30	4.02			
A–22	1.51	1.27	1.24			1.20
A–18	0.68	1.50	3.67			
A–25	0.82	5.48	1.16			
A–23	1.24	3.64	1.23			
A–24	1.03	4.50	1.18			
A–4	2.58	1.41	1.01			
A–21	1.48	1.44	1.25			0.67
A–7	1.47	1.28	0.96		1.97	
A–9	1.55	1.36	2.14			
A–3	1.92	1.26	1.09			
A–6	1.53	1.36	0.95		0.99	
A–20	1.47	1.40	1.32			0.36
A–1	0.98	1.21	1.04			
A–2	1.41	1.22	1.07			
A–27	1.26	0.44	14.83			
A–5	2.97	1.27	1.01			
A–36	1.82	5.05	0.96	2.68		
A–38	0.42	4.89	0.94	2.59		
A–35	1.12	5.24	1.05	2.62		
A–43	2.95	0.80	1.05			
A–42	2.41	0.72	1.20			
A–39	0.95	0.72	1.05			
A–41	2.02	0.75	1.15			
A–40	1.43	0.79	1.07			
A–50	1.02	1.18	0.90	9.83		
A–51	0.96	1.18	0.98	13.96		
A–47	0.45	1.18	0.94	10.20		
A–46	0.73	1.24	0.87	4.89		
A–49	1.05	1.25	0.91	4.94		
A–48	0.22	1.15	0.90	15.15		

by Mr. J. B. Carswell, of Burlington Steel Company, Limited, Hamilton, Ontario. The copper balls were cast at the Foundation, and the glass balls were purchased locally. The methods of manufacture of these alloys were generally similar to those described in the author's previous Paper.

In Table VII are quoted, for the alloys listed in Table V, the total losses of weight in mgrms. per sq. cm. of original surface of ball (surface of ball at commencement of the first run). So that these results may be comparable with others to be given later, the weight of sands treated during each run is quoted at the heads of the columns. A very rough idea of the effect of varying the amount of sands treated can be had by comparing the losses in weight from run to run. The mill was not rotated at the same rate in all the experiments covered by Table VII; in the first ten runs the rate of rotation was 30 r.p.m., whereas in the last two it was 60 r.p.m.

TABLE VI.—*Numbers of Balls Tested in Continuous Mill.*

Run number.	Number of balls in mill .
1	320
2	300
3	290
4	310
5	310
6	310
7	310
8	310
9	310
10	310
11	310
12	310

Comments on Results of Tests in Kirkland Lake Ore

From these results four sets have been chosen for graphical representation in Fig. 2, where the four curves refer to Stellite, Ni-Hard, alloy

A-17, and alloy A-11, respectively. Vertical lines have been drawn to indicate certain stages in this prolonged test, which were felt to be of importance. For example, during the first four runs the feed of sands was fairly constant, during the next four it was changed, during the next two it was changed again, and during the last two the speed of the mill was increased.

It is surprising that, despite these changes in feed and speed, the *relative* losses in weight (as opposed to the *total* losses in weight) of the balls used in the test remained as constant as they did. The relative losses of weight (Stellite = 100) of the alloys listed in Table V are quoted in Table VIII.

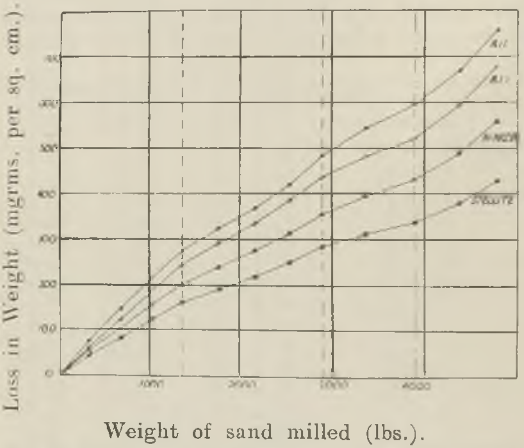

Fig. 2.—Loss in Weight of Various Materials related to the Weight of Sand Milled.

From these results (Table VIII) have been taken at random for graphical representation (Fig. 3), those referring to Ni-Hard, to alloy A-17, to alloy A-11, and to the heat-treated forged steel balls. The relative losses in weight of these alloys during each of the twelve runs are plotted in Fig. 3, together with the average relative loss in weight per run. In this connection, it will be noted that for the heat-treated forged steel balls the maximum variation from the average relative loss of weight (approximately 193) did not exceed 15—or a little less than 8 per cent. This variation from the average, which is high compared with most of the others, is considered remarkably small for experiments of this type.

The order of wear of the first five alloys in Tables VII and VIII was the same throughout the entire test. There was little to choose between the next eight alloys, which constantly jockeyed for position. At the end of the test the difference in weight between the best and the worst of this group of eight was about 6½ per cent. only.

Alloys A-43 to A-40 (Table VII) merit special attention. These were the iron-carbon alloys of which balls were tested in silicon carbide (see Table II). When these alloys are tabulated according to the relative wear in the sands, they reverse their order in Table II, as is shown in Table IX, where the relative losses in weight of the balls, in both sands and silicon carbide, are compared.

Of the straight carbon alloys referred to in Table IX, the 3 per cent. white cast iron is by far the best. It is also superior to the 2 and 3 per cent. chromium steels, alloys A-14 and A-13 (see the smaller values quoted in the last four columns of Table VII).

Tests in Porcelain Jars with Sands, Granite and Silica as Abrasives

The foregoing results were so surprising when compared with those of the tests in silicon carbide that it was decided to find in what order alloys 43-40 (Table VII) would stand when tested in the porcelain jars, but with (1) sands, (2) granite, and (3) silica, in place of silicon carbide. The results of these tests are shown in Table X.

These tests demonstrate the important fact that the order of wear of these alloys, when tested in sands in porcelain jars, is the same as their order when tested in sands in the continuous mill. The chances are good, therefore, that tests in porcelain jars are likely to serve as guides to the behaviour of alloys in larger mills.

These tests also show that the relative losses of weight of these alloys in granite and silica lie in the same order as those in silicon carbide. In this connection it may be well to point out that the order of wear of these alloys, when tested in silica in the porcelain jars, was the same as their order when tested in silica in the continuous mill, as is indicated in the following section. This serves, again, to support the view expressed in the last sentence of the previous paragraph.

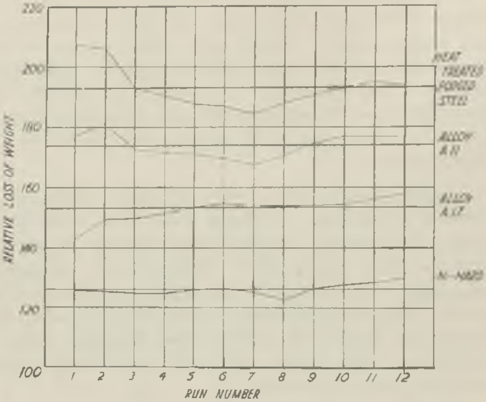

FIG. 3.—LOSS IN WEIGHT OF VARIOUS MATERIALS FOR EACH RUN.

Tests in Continuous Mill with Silica

The question naturally arose whether, if silica, for example, were substituted for sands in the continuous mill, the 3 per cent. carbon alloy, A-43, would stand first in order or last (as it did in the tests referred to in Tables II and X). When so tested, the alloys again reversed their order from that in which they stood after testing in sands (see Table XI).

The Abrading Medium and its Effect on the Resistance of Alloys to Abrasion

It now became clear that the abrading medium was a factor of outstanding importance in determining the relative value of balls to be used in ball mills. Tests were therefore started in the continuous mill with (1) silica, (2) feldspar, (3) marble, and (4) talc. For these tests new balls were cast in series, as follows:—(*a*) Five straight carbon alloys; (*b*) five 2½ per cent. chromium alloys; (*c*) five 7½ per cent. chromium alloys; (*d*) five 15 per cent. chromium alloys; (*e*) five 2½ per cent. nickel alloys. The carbon contents of the five alloys in each group varied from about 1 per cent. to about 3 per cent. The chemical analyses of these alloys are given in Table XII.

The results of these later tests are set out in Table XIII. Under each of the headings in this table—silica, feldspar, marble, and talc—are arranged four columns. In these are given, for ten balls of each alloy:—

(1) The losses of weight which occurred during each of two successive runs.

(2) The sums of the losses of weight which occurred during these runs.

(3) The relative losses of weight which occurred during these runs.

During each run, 500 lbs. of mineral were passed continuously through the mill. The ratio of water to mineral in the feed was approximately 30 per cent. in all cases. The mill was rotated at 60 r.p.m. throughout the tests.

Before testing, the balls (in small groups) were treated in silicon carbide in the porcelain jars, and then were given a preliminary run in the continuous mill, during which 500 lbs. of mineral were passed through. The objects of the treatments in silicon carbide and mineral were to clean the balls and to remove the sharp edges of the identification marks. Thus was eliminated to a large extent, if not entirely, one cause of variation in the results of the tests

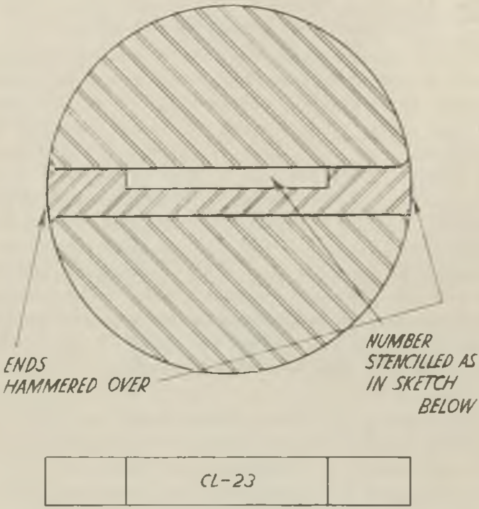

Fig. 4.—Method of Identification.

in the continuous mill—particularly on the more brittle alloys. Quite startling inconsistencies were noted in the loss of weight at the end of the preliminary run in the continuous mill. These, it is believed, were due to the removal of comparatively large chips from the edges of the identification marks, which were cut in all the balls by narrow emery wheels. To obviate the inconsistencies resulting from this method of marking, the author proposes to cast the balls for future tests with a small hole through the centre, into which can be inserted a length of wire suitably marked for purposes of identification, as shown in Fig. 4.

Comments on the Results of Tests in Silica, Feldspar, Marble and Talc

The wear numbers in Table XIII demonstrate, in the first place, the differences in the abrasive effects of the various minerals used in these tests. Consider, for example, one of the less brittle alloys—B-2, a straight carbon steel containing about 1½ per cent. of carbon. In silica (1,000 lbs.) this alloy lost 143 mgrms. per sq. cm. during the second run, and 143 mgrms. per sq. cm. during the third run (the first run was the preliminary one, and is not referred to in Table XIII). The loss of weight during both runs was 290 mgrms. per sq. cm. In feldspar (1,000 lbs.) the corresponding loss of weight was 11.4 per cent. greater. In grinding 1,000 lbs. of marble, the same alloy lost 72 mgrms. per sq. cm.—only one-quarter of its loss in grinding the same weight of silica. In talc this alloy lost 101 mgrms. per sq. cm. during runs 2 and 3. The same general effects are observed in all the alloys.

TABLE IX.—*Comparison of Wear Numbers Obtained in Silicon Carbide and in Sands.*

C. Per cent.	Si. Per cent.	Mn. per cent.	Relative loss of weight.	
			SiC.*	Sands.
0.95	0.72	1.05	102	123
1.43	0.79	1.07	100	120
2.02	0.75	1.15	101	119
2.41	0.72	1.20	104	117
2.95	0.80	1.05	111	100

(The alloy showing the least wear has been taken as the standard—100—in each case.)

* Taken from Table II.

In the second place, the wear numbers in Table XIII bring out an important point which none of the previous tests has elucidated, namely, the marked differences in the relative losses of weight of the alloys in different minerals.

TABLE VIII.—*Relative Loss in Weight of Alloys Tested in Continuous Mill and Using Lake Shore Concentrates as Abrading Medium.*

Run No. ..	1	2	3	4	5	6	7	8	9	10	11	12
Total wt. of mineral (in lbs.) fed to mill	322	675	1,021	1,369	1,769	2,169	2,544	2,904	3,369	3,899	4,379	4,779
SAlloy No.	*Relative Loss in Weight, Taking Stellite as Standard.*											
te-llite ..	100	100	100	100	100	100	100	100	100	100	100	100
NiHard ..	126	125	125	125	126	126	125	123	126	128	128	130
A-16	136	140	141	142	145	145	145	145	146	146	148	150
A-17	142	149	150	151	153	154	154	154	154	154	156	158
A-14	161	166	161	159	159	159	158	160	162	163	164	164
A-8	167	168	161	162	162	163	163	166	169	171	172	173
A-13	170	173	167	165	164	164	163	165	168	170	170	171
A-15	172	174	168	168	167	168	165	168	171	172	173	174
A-11	177	181	173	173	171	169	167	171	174	177	177	177
A-12	185	185	177	175	174	174	161	165	168	171	172	173
A-10	191	201	185	182	179	177	175	178	181	183	183	182
A-22	191	197	179	175	174	172	168	171	174	173	176	176
Heat-treated forged steel	207	206	193	190	188	187	184	188	191	194	194	194
A-7	212	208	195	193	191	191	189	193	196	199	199	199
A-9	214	212	192	190	184	183	181	184	189	191	192	192
A-6	216	214	201	197	196	196	195	194	198	201	201	202
A-20	217	215	199	194	192	190	187	189	192	193	193	192

A study of the results of the tests in silica shows that in this relatively *hard* mineral* the wear numbers of the alloys (B-1 = 100) vary between 96 and 130 only.

TABLE X.—*Wear Numbers of Alloys Tested in Sands Granite and Silica (Porcelain Jars).*

Alloy number.	C. Per cent.	Relative loss of weight.		
		Sands.	Granite.	Silica.
A-39	0.95	100.0	100.0	100.0
A-40	1.43	95.4	107.8	106.4
A-41	2.02	91.4	120.6	118.2
A-42	2.41	91.2	138.6	133.6
A-43	2.95	87.4	167.2	155.0

TABLE XI.—*Wear Numbers of Alloys Tested in Silica in the Continuous Mill* *

Alloy number.	C. Per cent.	Relative loss of weight.
		Silica.
A-39	0.95	102.4
A-40	1.43	100.0
A-41	2.02	107.9
A-42	2.41	111.4
A-43	2.95	116.5

* All the balls tested—310 in number—in run 12 (Table VII) were run in this test.

In feldspar* the spread of relative wear (B-1 = 100) extends from 44 to 131, while in marble,* a still softer material, the spread extends from 32 to 188.

These tests show that, while in the grinding of marble, for example, steel has an undoubted advantage over white iron, in the grinding of silica this advantage, though maintained, is much less significant. The results of the tests on the high-chromium alloys are particularly enlightening. There would seem no justification

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* The approximate numbers (on Moh's scale) of the minerals used in these tests are as follows:—Silica, 7; feldspar, 6; marble, 3; and talc, 1.

for using high-priced chromium alloys in the manufacture of balls for grinding highly siliceous minerals. On the other hand, the use of, say, B-16 in the treatment of materials containing large proportions of feldspar or marble might be quite economical.

The remarkably low relative losses of weight of alloys B-26 and B-27, in both feldspar and marble, merit attention. These alloys are essentially cast irons—not cast steels. Therefore, since alloys containing eutectic wear more rapidly than those free from eutectic (see next paragraph), it seems not improbable that a reduction of carbon to, say, 0.5 per cent. would give to 15 per cent. chromium alloys still greater resistance to abrasion in feldspar, marble, and, possibly, talc, than B-26 and B-27. Whether such low-carbon stainless steels would be of commercial value in the grinding of these minerals could be determined only by actual tests.

In the third place, the wear numbers given in Table XIII confirm the impression created by the results of all the previous tests (with the exception of those in sands), namely, that the higher the carbon content of white cast iron, the lower is its resistance to abrasion. It would seem that the resistance of white cast iron to abrasion is lowered as the amount of eutectic in its structure increases. This appears to be true whatever type of alloy and whatever medium of abrasion are considered.

Of the straight carbon alloys and the 2½ per cent. nickel alloys it can be said that in general the borderline alloys (those corresponding in microstructure to the 1.7 per cent. carbon alloy of the pure iron/iron carbide system) resist abrasion better than those of lower or higher carbon content. Of the other alloys it can be said that the lower their carbon content, the greater is their resistance to wear.

Concluding Remarks

Numerous anomalies in these tests have yet to be explained. It is clear that mineralogical hardness *per se* is not the only property which affects the wear of alloys of different types. Why, if such hardness were an important factor, should the relative loss of weight of alloy B-26, for example, be 107 in silica and 44 in feldspar, where silica and feldspar differ so little in mineralogical hardness? Why, also, should the relative abrasive effects of marble (Moh's hardness, 3) and of talc (Moh's hardness, 1) on the low-carbon, high-chromium alloys, B-26 and B-27, be so similar? The crystal structures of

TABLE XII.—*Analyses of Alloys Used in Tests (see Results in Table XIII) with Silica, Feldspar, Marble and Talc.*

Alloy number.	C. Per cent.	Si. Per cent.	Mn. Per cent.	Ni. Per cent.	Cr. Per cent.
B–1	0.93	0.62	1.10	—	—
B–2	1.48	0.60	1.14	—	—
B–3	1.89	0.80	0.88	—	—
B–4	2.48	0.81	0.95	—	—
B–5	3.10	0.81	1.06	—	—
B–11	0.97	0.80	0.98	2.50	—
B–12	1.43	0.77	1.00	2.60	—
B–13	1.95	0.77	0.91	2.55	—
B–14	2.45	0.79	1.01	2.52	—
B–15	2.77	0.75	1.06	2.58	—
B–16	1.01	1.29	0.92	—	2.42
B–17	1.47	1.50	0.94	—	2.59
B–18	1.97	1.47	0.92	—	2.54
B–19	2.47	1.49	0.99	—	2.46
B–20	3.02	1.32	0.76	—	2.54
B–21	1.00	1.22	0.90	—	7.67
B–22	1.43	1.26	0.91	—	8.05
B–23	2.17	1.17	1.03	—	7.41
B–24	2.63	1.32	0.92	—	7.56
B–25	2.98	1.33	0.98	—	7.52
B–26	1.07	1.29	1.00	—	15.2
B–27	1.56	1.30	1.08	—	14.8
B–28	2.05	1.32	0.95	—	15.1
B–29	2.58	1.30	0.94	—	14.9
B–30	2.98	1.50	0.95	—	15.2

TABLE XIII.—*Wear Numbers (Relative Losses in Weight) of Alloys Tested in Continuous Mill with Various Abrasives.*

Alloy Number.	Silica.				Feldspar.				Marble.				Talc.			
	Loss of Weight (mgrms. per sq. cm.).			Relative Loss of W'ght.	Loss of Weight (mgrms. per sq. cm.).			Relative Loss of W'ght.	Loss of Weight (mgrms. per sq. cm.).			Relative Loss of W'ght.	Loss of Weight (mgrms. per sq. cm.).			Relative Loss of W'ght.
	Run 2.	Run 3.	Runs 2+3.	Runs 2+3.	Run 2.	Run 3.	Runs 2+3.	Runs 2+3.	Run 2.	Run 3.	Runs 2+3.	Runs 2+3.	Run 2.	Run 3.	Runs 2+3.	Runs 2+3.
B1	141	161	302	100	168	141	309	100	32	33	65	100	43	57	100	100
B2	147	143	290	96	179	144	323	105	35	37	72	111	36	65	101	101
B3	162	173	335	111	206	148	354	115	47	45	92	142	60	85	145	145
B4	176	190	366	121	236	169	405	131	45	54	99	152	59	99	158	158
B5	189	205	394	130	209	169	378	122	48	74	122	188	63	114	177	177
B11	173	183	356	118	184	125	309	100	34	35	69	106	75	61	136	136
B12	151	174	325	108	147	117	264	85	32	32	64	98	41	58	99	99
B13	150	177	327	108	163	123	286	93	39	37	76	117	48	70	118	118
B14	168	191	359	119	180	125	305	99	38	41	79	122	52	80	132	132
B15	173	197	370	123	160	160	320	104	49	69	118	182	56	89	145	145
B16	138	162	300	99	138	120	258	84	26	28	54	83	29	38	67	67
B17	145	165	310	103	152	123	275	89	32	36	68	105	33	51	84	84
B18	153	174	327	108	133	124	257	83	36	39	75	115	38	61	99	99
B19	164	185	349	116	159	144	303	98	40	44	84	129	40	74	114	114
B20	178	197	375	124	188	144	332	107	46	55	101	155	54	106	160	160
B21	152	161	313	104	109	52	161	52	25	32	57	88	28	35	63	63
B22	135	151	286	95	104	100	204	66	30	30	60	92	27	41	68	68
B23	146	161	307	102	113	111	224	73	31	35	66	102	27	44	71	71
B24	157	177	334	111	152	124	276	89	35	39	74	114	30	53	83	83
B25	169	188	357	118	165	139	304	98	39	45	84	129	35	69	104	104
B26	153	170	323	107	84	53	137	44	10	11	21	32	21	24	45	45
B27	159	177	336	111	97	52	149	48	13	13	26	40	27	31	58	58
B28	165	185	350	116	110	60	170	55	21	27	48	74	25	29	54	54
B29	159	178	337	112	124	74	198	64	31	35	66	102	24	38	62	62
B30	165	182	347	115	152	126	278	90	35	40	75	115	26	47	73	73

these and other minerals must, of course, be considered in any discussion of their abrasive effects. It is probable that in its influence upon the wear of metals and alloys in mills, the arrangement of the atoms on the crystal lattices is as significant as the mineralogical hardness of abrasive materials. The energy absorbed in grinding a substance of high mineralogical hardness, but with gliding planes along which slip can readily proceed, may quite well be less than that absorbed in the grinding of a substance of low mineralogical hardness, but with a crystal structure more resistant to fracture by cleavage. At the moment, the relationship between crystal structure and abrasive effect cannot be defined.

The acidity or alkalinity of the solution in the mill, produced either by treating the water before admitting it to the mill or by reaction between neutral water and the mineral being ground, is a factor which cannot be overlooked when considering the results of wear tests in mills of all types. Except in certain tests now being made in end-discharge porcelain jars with silicon carbide as the medium of abrasion, the author has thus far left out of consideration the effects of the p_{H} of the solution in the mill upon the wear numbers of the alloys under test. In all instances save the exceptions mentioned, untreated Toronto tap water (p_{H}, 7.5) has been used, and up to the present the p_{H} of the sludge leaving the mill has not been measured at all. Here is a wide field awaiting exploration. For example, the question might well be asked whether the traces of potassium cyanide, which were present in the sands used in the tests the results of which are collated in Tables VII and VIII, determined the order of wear of the straight-carbon alloys. As will be remembered, in these tests alone were the high-carbon alloys shown to be superior to the low-carbon in their resistance to abrasion.

Many other factors, affecting by their variation the outcome of tests in small mills, cannot be referred to here. Nor at the present time does the author claim that the results of these small-mill tests can be used to predict accurately the performance of alloys (as balls) in large mills —though a few commercial tests encourage him to hope that results of tests in small mills may serve as a rough guide to procedure on a larger scale.

Acknowledgments

The author desires to acknowledge his indebtedness to those at the Ontario Research Foundation, who have assisted him in this work, particularly Mr. J. R. Gordon, who until October last was in continual contact with this problem, and Mr. Edwin Nugent, who has been responsible for the manufacture of the alloys and for the operation of the mill. Mention must be made, too, of the assistance rendered by Mr. Geoffrey Coleman and Mr. Gordon Coleman, both members of the Foundation's staff.

The author also gratefully expresses his thanks for the encouragement given him in this work by Dr. H. B. Speakman (director, Ontario Research Foundation), and for the kindness of Mr. A. L. Blomfield (managing director, Lake Shore Mines, Limited, Kirkland Lake, Ont.) who supplied the sands used as grinding material in some of the tests; of Prof. H. E. T. Haultain who loaned the continuous mill used in many of the tests, and of Dr. C. W. Drury and Mr. J. B. Carswell (to whom acknowledgment has already been made). To many others the author tenders his thanks for counsel and criticism, among whom may be mentioned specially Mr. W. H. R. Burrows, President of Canada Electric Castings, Limited, Orillia, Ontario, and to Miss L. L. Blackburn the author is indebted for her assistance in the final preparation of this Paper for publication.

DISCUSSION

Introducing his Paper, Mr. Owen W. Ellis, said he wished to express his appreciation of the honour that was done him and his colleagues of the Ontario Research Foundation in choosing him to present the American Exchange Paper. One point of interest was that he happened to be an Englishman and have been chosen as a Canadian to present the American Foundrymen's Association Exchange Paper. There were two things which had pleased him very much in connection with his visit: one was the occasion of seeing Prof. Turner, his old professor, honoured by the Institute of British Foundrymen. (Hear, hear.) The second was his great pleasure, as one who served his time with the Great Western Railway, in coming to Derby, a railway centre of the first magnitude.

Difficulties in Comparing Results

Mr. J. G. Pearce opened the discussion, and said he would like to say how warmly the Institute welcomed Mr. Ellis, for everybody remembered the work he did in this country, and followed with interest the work he was doing in the distinguished position he now held. He had had the pleasure of seeing the laboratories of the Ontario Research Foundation, and he thought he was right in saying that he gave the first public lecture in the new buildings there. Ontario had put up these buildings in much the same faith as the British showed in this country, and he looked upon this occasion with great pleasure as an opportunity of renewed contact with old friends. Wear results were usually based on a test approximating to service conditions, and it was thus difficult to compare the figures obtained by Mr. Ellis with those from other sources, because the conditions of the test were so different. Thus he found that a higher carbon in white irons lowered wear resistance, a conclusion contrary to that found under other conditions, although the conclusion respecting chromium would be generally accepted. The report, however, as a whole will be welcomed as a painstaking piece of work, which should interest those concerned with grinding problems.

Hardness and Wear Resistance

Mr. F. J. Cook (Past-President) said the Paper was a very good basis for this very interesting problem. He would like to ask if Mr. Ellis had found that hardness was of itself a reliable guide as to the wearing qualities of the metal, and had he found that some of the softer alloys improved by wear hardening?

Mr. Ellis, in reply, said that the most recent work tended to show that in this particular type of abrasion, hardening or wear hardening scarcely entered into it. It might be, of course, in larger mills where balls were falling through greater distances. He had turned his attention to the effect of atmospheres particularly, in small porcelain jars.

Rubber as Wear Preventive

Mr. E. Millington said that whilst it was not his intention to refer to the metals used in this research, on which the author was to be congratulated, he would, however, like to refer to an experiment in which an attempt to solve the wear taking place on the hammers of a coal pulverising machine was made. Various alloys were tried without any marked success. Noting the high resistance to wear of the modern motor tyre, it was thought that hammers coated with rubber might solve the problem. After discussing the proposal with the rubber experts, hammers were " sleeved," but it was found that a few hours' work wore the rubber away, and the experiment failed. He wondered if the author had tried rubber, and, if so, with what results.

Mr. Ellis said the mill referred to was lined with rubber and stood up very well and looked as if it were going to last for a number of years without wearing through. A number of mills in North Canada had been lined with rubber. The difficulty had been binding the rubber to the mill. He thought there was a likelihood that in mills rubber might come into its own when methods of applying the rubber to the steel have been discovered.

Mr. J. H. Cooper said one thing which interested him was the reference to manganese steel. He found in making this steel that the best results were given with about 12½ to 14 per cent.

Mr. Ellis said he chose 14 per cent. as the desirable figure. He thought that the nature of the atmosphere in the testing apparatus was of very great importance.

Martensitic Materials for Wear Resistance

Dr. A. B. Everest, after expressing appreciation of the Paper, stated that Mr. Ellis was carrying out wear tests under ideal conditions. In ball mills, the life in service was generally so short that tests could be carried out on different materials under actual service conditions or under conditions closely related to them, and the results of such tests could usually be given an immediate interpretation. The trouble with most wear testing, as for example in the automobile industry, was that in order to obtain results the rate of wear must be accelerated generally by having insufficient lubrication. Under such conditions a quick result could be obtained, but it was often difficult to interpret this result in terms of life in service.

Dr. Everest thought one of the most important points arising from the present Paper was that there did not seem to be a definite relationship between hardness and wearing quality even under conditions where apparently the wear was purely abrasive, and this emphasised once again the fact that resistance to wear is determined by many factors, amongst which, besides hardness, were toughness, corrosion resistance, heat resistance, and so on. In some of the results shown by the author it would appear that the wear occurring in ball mills showed frequently no relationship to hardness, and undoubtedly toughness was frequently of more importance than hardness in this respect. This fact was brought out in a particularly interesting manner when studying some of the harder martensitic types of cast iron. In this connection some very interesting results have recently been obtained from irons in which the martensitic structure was associated with small quantities of austenite. Such irons were produced, for example, by the addition of about 7 per cent. of nickel, and had given extraordinarily good results. In the case of a pump handling coal washing slurry, in which ordinary steel impellers were lasting only one day, special steels and white cast iron were giving four or five days, whilst the alloy cast iron with the mixed austenite-martensite structure gave some four or five weeks. In such irons there was undoubtedly available improved toughness and corrosion resistance, both of which have undoubtedly an important effect in resisting the corrosion and erosion likely to take place under these working conditions.

Mr. Ellis said that he had had sections of liners from ball mills to examine, and the impression gained was that the amount of wear hardening was very small indeed. Users of ball mills seemed to think it was converted to a martensitic structure.

Austenitic Cast Iron Drilling Machinery

Mr. Frank Hudson said he had been privileged to complete a research into the production of valve materials suitable for use in oilfields for handling drilling mud. In drilling an oil well, mud was forced down the bore to bring up the detrital matter cut away by the drill, and to do this very high pressures were needed, often exceeding 1,000 lbs. per sq. in. It could be readily appreciated that the equipment on this service wears out rapidly and entails high maintenance charges. At the present time the United States probably holds a monopoly in the supply of such equipment, and he was asked if it were not possible to develop improved plant for this service. He set out to conduct wear tests on various metals by mounting specimens on a disc, not unlike the impellor of a centrifugal pump, and rotating this through the mud laden mixtures, and it was perhaps interesting to record that the results obtained tended to follow those given by Mr. Ellis in his Paper. For example, a specimen of nitrogen hardened steel having a hardness of over 900 Brinell, after running 200 hours, showed a wear loss of 84.4 grms. per sq. metre per 24 hrs., whilst austenitic cast iron having a hardness of only 166 under identical conditions only wore at the rate of 16.4 grms. per sq. metre per 24 hrs. Even gunmetals with a Brinell hardness of around 70 gave better results so far as wear was concerned than many of the hardened steels. A whole series of tests embracing over 40 ferrous and and non-ferrous metals clearly indicates that wear in the presence of a corroding agent in many cases is not determined by hardness, but appears to be essentially connected with the corrosion resisting properties of the metal.

Corrosion Fatigue

Mr. Ellis said he had been wondering whether in some of his tests there was not the question of corrosion fatigue. He believed corrosion fatigue merely meant that the material was going to lose weight more rapidly. He thought that in ball mills corrosion fatigue did play a part, and the stresses must be very high during the life of the ball in the mill.

Hardness and Machinability

A Member said the discussion had raised two points upon which he had done work. Using Brinell hardness in relation to wear was one thing, but in his opinion it had no relation to machinability. At one end only of the scale of Brinell hardness one obtained remarkably good wear and machinability. From a machining point of view, he felt Brinell hardness was likely to be more misleading than helpful.

Mr. Ellis, agreeing with what the speaker had said in regard to machinability, said he had always insisted when discussing this point that Brinell hardness numbers were no criterion of machinability.

Vote of Thanks

The Chairman tendered to Mr. Ellis the thanks of the Institute for the preparation of the Paper, and Mr. P. A. Russell, seconding, said that he had read the Paper with very great interest. It was rare to have exchange Papers presented in person, and he was particularly glad to welcome Mr. Ellis.

Mr. Ellis, in acknowledging, said he much appreciated the hospitality shown him at this meeting. He had enjoyed every minute of it.

Paper No. 608

ADDITIONAL DATA ON THE MANUFACTURE OF INGOT MOULDS*

By R. Ballantine (Member)

This continuation of the author's previous Paper, "Recent Developments in the Production of Ingot Mould Castings" will provide greater attention to manufacturing detail and dwell more fully on results of observations in practice.

Alternative Methods

The author has given a great deal of thought to alternative methods of production, and also to the materials used. It is common practice in many works to ram moulds and cores for producing castings up to 10 tons in dry sand, either by hand or pneumatic rammer, but exceeding this weight a transfer to the loam method is generally adopted. In America the trend would appear to be in favour of cement-bonded sands, as instanced by the Valley Mould Company adopting the Randupson process. This system has much to commend it, but it is questionable if a complete change-over would make for greater economies, in speedier production, and the ultimate lives secured.

At the Mossend Works of the Fullwood Foundry Company all moulds and cores are produced in sand, and machines are exclusively used for jolting castings up to 20 tons. In excess of this weight pneumatic rammers are introduced, and in analysing the desirable features in the respective systems, it is the author's opinion that the latter practice has many advantages.

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* The first part of this Paper is omitted as it is a summary of the Paper "Recent Developments in the Production of Ingot Mould Castings" read before the Lancashire Branch and Falkirk Section, and included in this volume. Illustrations of some of the operations referred to will be found in the Paper "Recent Developments, etc."—Ed.

Ramming and Jolting

Hand ramming of cores and mid parts cannot be compared to jolting by machines, either for speed or consistency. Controlled preparation of sand by mechanical means has undoubtedly contributed to the fine results obtained. Jolting treats the mass sand as a unit, whereas hand ramming is a localised movement. The former method ensures a minimum variation in density, and Fig. 1 indicates where these variations occur

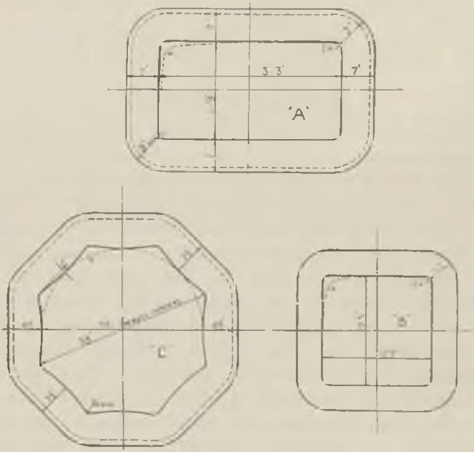

Fig. 1.—Types A, B and C. The Core Hardness is Indicated at Dotted Line X.

in the core sections:—(A) Rectangular, (B) square and (C) which is fluted, may be either octagonal or duodecagonal. All show similar characteristics with the degree of hardness indicated by dotted lines (X).

The slight variations referred to do not affect the resultant casting in any way. There is definite danger, however, if a sand be used which has a low permeability. Whilst, it may be argued, uniformity is not accomplished even by jolting, one can easily bring to mind the many hard and soft ramming oddities which passed under the name of cores or moulds when relying on the human element.

It is frequently said that the skilled artisan will produce a casting second to none when properly rammed, but this is a mechanical age. The advent of the engineer to the foundry has revolutionised practice generally, and to a very great extent in the quantity production of ingot moulds.

Hot Tears

Hot tears in ingot moulds can be definitely traced to two causes:—(1) Fins; and (2) contraction. These two objectionable features have a direct association with each other. Fig. 2 shows an inverted type mould in section; the right hand view shows in detail the effect of both internal (core) fins (A) and external (mid part) fins (B). The placing of a loam stamp (C) which can be limited, but, unfortunately, cannot be eliminated, must be curtailed. Common practice is to place the stamp on the core some distance from the edge. The reason put forward by the practical moulder for this position is that moisture is absorbed by the dried core if placed at the edge; consequently, softening of the core is the result. Naturally, he anticipates crushing when placing the cope in position when closing, and this is quite a reasonable precaution from the moulder's viewpoint, but hopelessly wrong when the casting is examined. Fig. 3 shows part section of what actually happens. Both fins set very rapidly, especially when hematite irons are used. The free movement of the casting is restricted when initial expansion and natural contraction takes place.

The core, being top heavy, allows the casting to ease from the core and settle downwards, but the fins definitely curtail this movement, as Fig. 3 indicates. It is obvious that the heavy body of metal is suspended, and results in the weak points taking the strain and the formation of hot tears. These defects move horizontally, not exactly uniformly, but at distances comparable with fin thicknesses. When it is borne in mind that inverted moulds have head boxes laid on top of them in steelworks practice, as shown in Fig. 4, the problem of internal hot tears becomes serious. Added top pressure makes the steel more searching and the hot tear full of free graphite is attacked, damaging the mould and eventually causing "stickers."

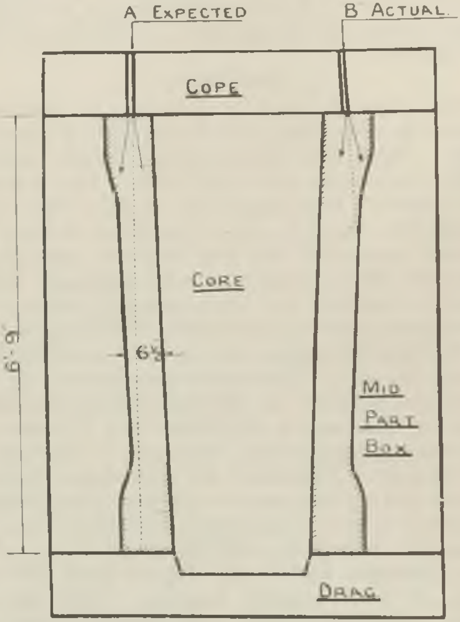

Fig. 2.—Showing Hot Tears, Improper Loam Stamp and Fins.

It is admitted that the machining of these mould castings will ensure freedom from these defects, and various machining allowances, varying from five to ten inches, are recommended, yet is one sure these after operations are essential when it is known that sound castings can be produced without hot tears? The left hand portion of Fig. 2 indicates how internal hot tear defects can be avoided. A loam stamp, restricted in quantity, is placed at the edge of the core. After the cope has been removed, the surplus loam is trimmed off and slightly bevelled. Another loam stamp is placed internally so that any percolation of metal will not enter the ash centre. This ensures a double check. Contraction of the casting is not impeded, because the loam stamp responds to the slight bevel.

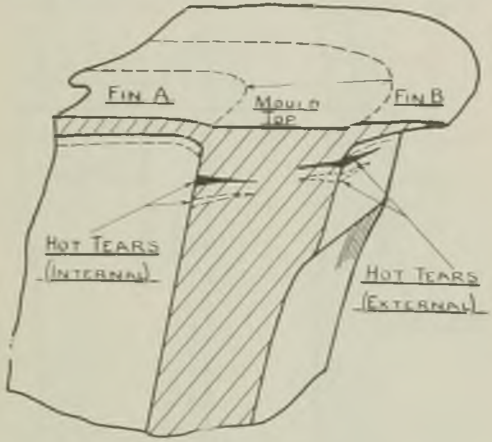

Fig. 3.—Part Section of a Mould Casting after Cooling.

External (mid part) fins B are objectionable. The necessity for under level finishing of sand to avoid crushing can be eliminated when machined boxes are used. Nevertheless, it is surprising how often this moulder's *trait* for safety is encountered despite the provision of machined boxes. A continual source of trouble is loam stamping. At (F) in Fig. 2 the mid part is shown on the drag. The very irregular angle

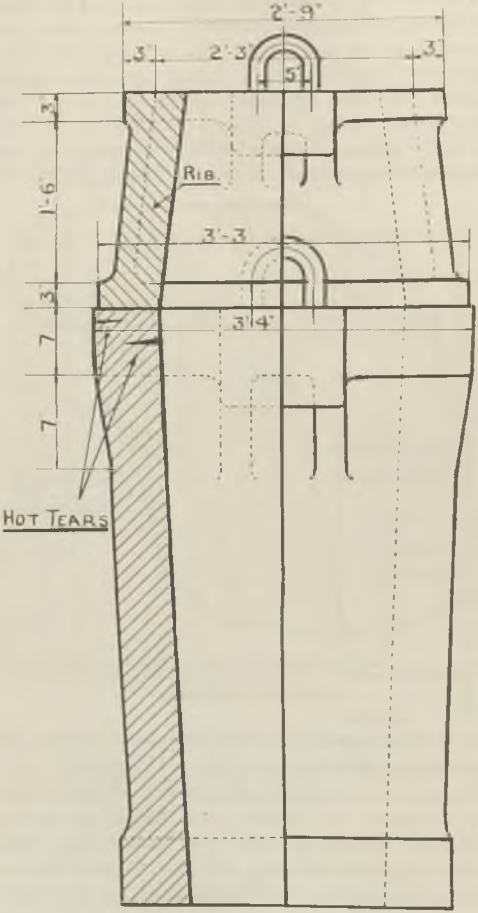

FIG. 4.—INVERTED MOULD WITH HEAD.

plates used for supporting mid part sand, coupled to the black face of the boxes, may mean loam stamping to a depth of over an inch when closing. Steam gathers at X, softening the mould face, and subsequent scabbing occurs. The obvious remedy is machined boxes.

Gating

Investigations on proper gating have revealed many things in the past. What may be accepted practice in certain foundries operating on specialised work may be the very opposite practice in equally efficient foundries engaged on similar work. As stated previously, drop-gates, either of the pencil type or rectangular section, have been eliminated, as much cleaner tops are secured by the down-gate and in-gate arrangements. While Fig. 5 is elementary it shows three down-gates encountred. Type A, which is considered proper, is the type in use. The diameter varies in size, and numbers depend on the casting's weight. Type B is unsatisfactory,

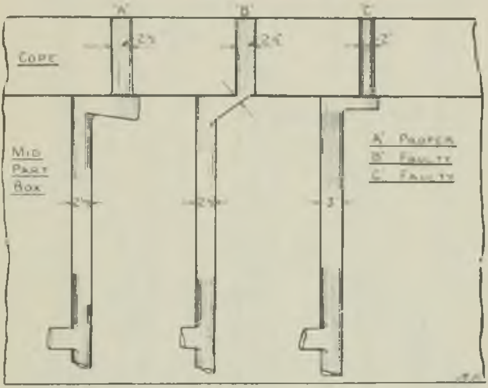

FIG. 5.—DOWN-GATES THROUGH COPE AND MID PART.

but it is amazing how often one sees this type in practice. The flow of metal is governed by the aperture at the cope and mid parting. A time-record of pouring reveals the extended pouring time for filling the ingot mould casting. If the pouring time be unduly prolonged, the sluggish hematite iron churns against the core and mid part walls creating skin defects. An equally bad arrangement is shown at C, and is more commonly used than is credited. The down-gate through the cope determines the pouring rate irrespective of the larger diameter down-gate in the mid part.

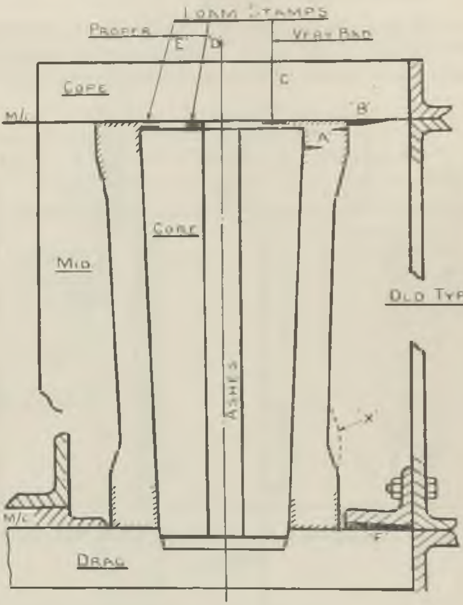

Fig. 6.—Pencil Gates on Inverted Mould.

Fig. 6 indicates the method for top pouring an inverted mould by pencil or rectangular gates.

The gate on the left will spread despite the accuracy of vertical setting, but the one on the right shows what actually occurs in practice. Either an acute angle leading outwards or inwards is obtained. Metal entering the mould impinges either on the core or mid part in its downward travel. This is most objectionable, and, moreover, pellets are formed and never appear to be re-absorbed despite the heavy body of metal in the wall thickness.

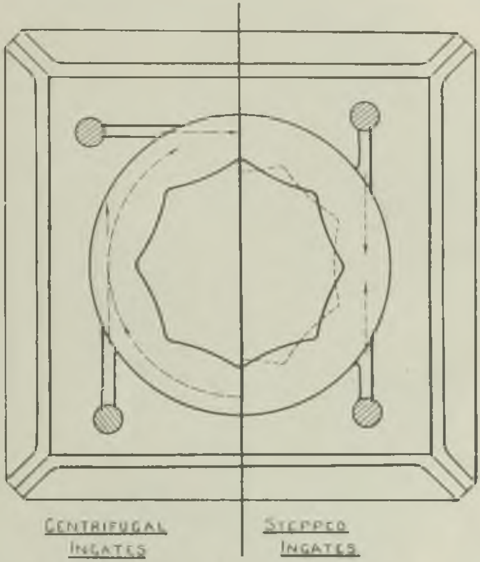

FIG. 7.—TWO METHODS OF GATING.

In-gates are all rectangular. The total cross sectional area of in-gates is equal to the down-gate cross sectional area directly feeding the in-gates. It is good practice to keep the lower in-gate slightly larger than the upper if two be used from the one down-gate. If no attempt be made to regulate the ratio of in-gate to down-

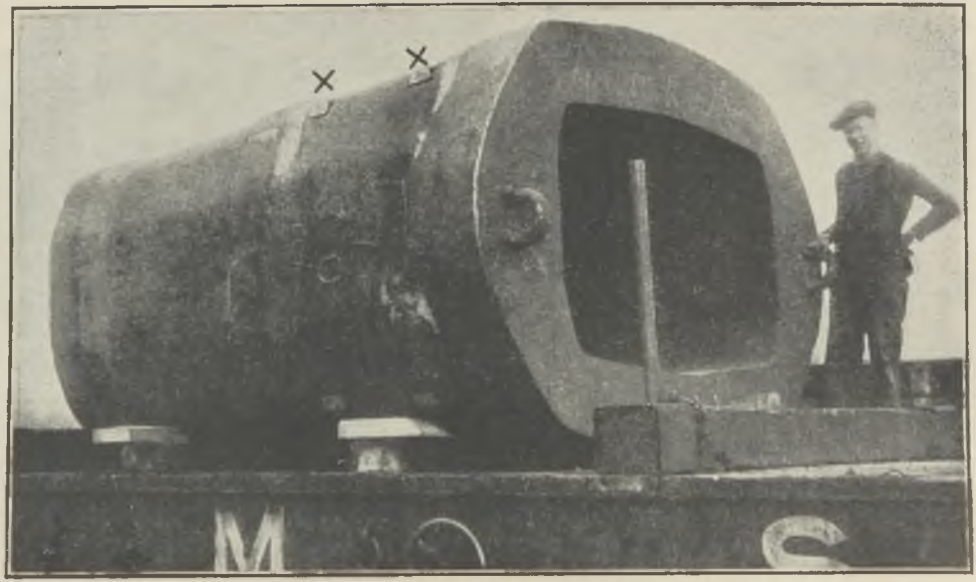

Fig. 8.—A 34-ton Ingot-Mould Casting.

gate, and the former is in excess of the latter, a trickling of metal from the higher gate tends to cause surface blemish in the casting.

The plan view in Fig. 7 is that of an octagonal mould in the mid part box, and alternative methods of gating are shown. The right-hand half gives the impression of gates running against each other, and to a certain extent they do, but the stepped effect for two ladle pouring shown in Fig. 8 demonstrates that disturbance is not severe. Further, if the core be turned and set according to the dotted line in Fig. 7, the fluted part becomes parallel to the in-gate entry, consequently limiting the tendency to disturb the core projections.

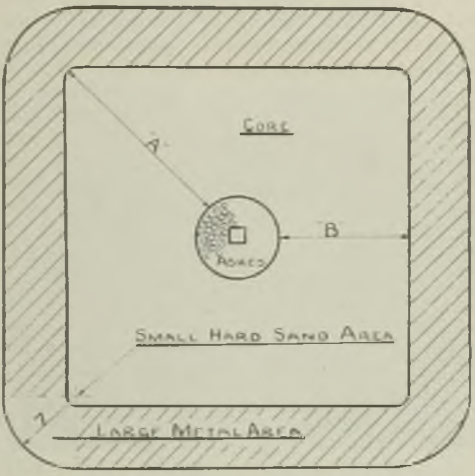

Fig. 9.—Factors Influencing Flaking or Corner Scaling.

Alternatively, the left hand plan, which shows in-gates following each other, would appear in theory to be much more satisfactory for producing fluted octagonal or duodecagonal mould castings. The author does not, however, favour the whirling action of metal entering the mould, especially for cores made in dry sand. There are eight and twelve points of attack in cores of this type. Whirling metal is particularly severe; blackwash scales rapidly and fusion of the sand and casting occurs. If the moulds were cylindrical, this system would be adopted exclusively.

Flaking or Corner Scaling

A disturbing factor in many ingot mould foundries is the flaking or scaling at corners, and many explanations are put forward why this should occur so frequently. There is a feeling in some quarters that the problem is a metallurgical one, and the practical investigator rarely attributes this problem to wrong foundry practice. The author disagrees with both opinions. In Fig. 9 is a cross section of a 10-ton mould and core. The section is square and the ash centre is shown in position. Difficulties are rarely encountered due to flaking of corners on any of the moulds manufactured, but the problem has arisen. It has been frequently asked why this should happen when the same metal has been used, a correct pouring temperature established, and no change made in the system of manufacture. The construction of the core is of vital importance in overcoming this trouble. Fig. 9 reveals a large sand area at A as compared with the amount at B. Added to this, the corners are definitely harder at the fillets.

In view of this, three factors should be borne in mind:—

1. If the body of corner sand be large, thereby increasing the length of travel to the vent of gases evolved, trouble arises.
2. If the sand skin at corners be trowelled extensively, and glazed before blackwashing, the trouble is aggravated.
3. If sand be used which is more suitable for the manufacture of ornamental castings, then flaking or scaling cannot be avoided.

The rare occasions on which this scaling has appeared have been effectively dealt with by limiting the sand area and by having good venting properties in the core sand used. A large grained sand, with a minimum bond, giving high permeability, should be used. The addition of gas-forming materials, such as coal dust, sawdust, etc., is unnecessary. The removal of fines is essential in reconditioned sand and a liberal coating of blackwash as a facing is recommended.

A 34-Ton Inverted Mould Casting

The end view of a 34-ton inverted mould casting shown in Fig. 10 gives a true indication of the core outline, and the very uniform metal thicknesses throughout the casting. Whilst the compensating metal surrounding the lifting handle looks "massive," it is nevertheless uniform. The effect of handle insertion tends to densen the heavy snug part. A pocket core underneath further assists by ensuring uniform cooling.

Fig. 10.—Another View of the 34-ton Inverted Mould Casting shown in Fig. 8.

The angled view showing top and side, as in Fig. 8 clearly demonstrates the minimum fin allowance on the outside of the casting, and the trimmed inside is free from any kish or cold-shut markings. Four in-gates can be seen and these are fed by a second ladle. These, and another six, however, are arranged for two ladle pouring. On the other side of the casting, six in-gates are placed, four below the middle belt and two above. Pouring is timed so that the ladles finish together. Six risers are placed on the broadsides, *i.e.*, three on each side, and the riser basins are so arranged that draining of the pouring heads is assured. Pouring time for this particular casting is 4½ minutes and the second ladle commences pouring two minutes after the first. The influx of fresh metal livens considerably the sluggish tops formed from the first ladle. Feeding is never practised even on castings such as these.

The core weighs approximately 5 tons in the green state. Six rectangular grids of very light section are used and are placed horizontally; and no iron uprights are included. The whole structure which is shown before entering the stove is carried on the core plate. Apart from the venting properties of the ash centre, the lifting rods are accommodated and can move freely and respond to any undue strain set up in the transit of this core. The mid-part is an all-machined box for producing these castings. Cross membering of the broad sides is advantageous, as any tendency to splitting while in service is definitely curtailed by the varied-angled webs shown.

Lives obtained from inverted type moulds give a much smaller average than those obtained from common moulds, and this is only to be expected when types are compared. Some of these 34-ton inverted castings give lives as high as 57 heats.

A 21-Ton Ordinary Mould Casting

In Fig. 11 an end view is given of a 21-ton ordinary mould casting with elongated semi-closed top. The clean outline and sound edges are again evident. The angled view as shown in Fig. 12 conveys a better impression of general structure. When it is pointed out that the core for this casting—quite 9 ft. high—is jolted successfully without upright reinforcements and subsequent sprigging, the job is simplified considerably, and moreover, becomes an ordinary production job.

From castings of this type 70 lives are recorded, with an average well over 60. The pouring time in this instance is slightly over 3½ min., and gating is arranged for one ladle pouring. Two down-gates, placed at one end, feeding two in-gates each, are sufficient. A little latitude can be allowed in the placing of in-gates in this case, and as no bottom belt is incorporated in this design the danger of metal churning against projecting mid part sand is eliminated. The slightly larger bottom in-gates are placed 6 in. from the drag joint, with the smaller ones above, 30 in. apart. The pouring times of the two examples given make for interesting comparisons, for whereas the 34-ton inverted mould is given 4½ min. only, the 21-ton

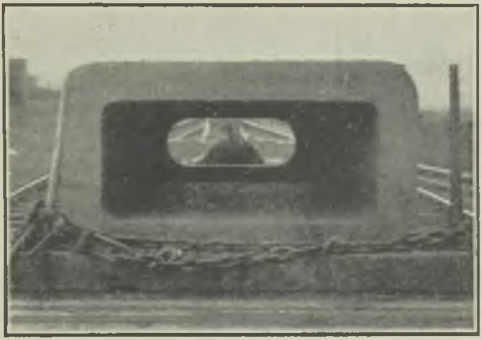

Fig. 11.—A 21-ton Ordinary Mould Casting.

ordinary mould slightly exceeds 3½ min. Condensed, it means there are 13 tons more metal poured, not in slightly under 1 min., but over a period of 4½ min.

From a comparison of the "ordinary" and "inverted" moulds* the reason for altering the pouring speeds is evident; as both are cast with lifting snugs on top, and are gated similarly, yet the metal in rising acts differently in each case. In the inverted mould the metal tends to fall from the top-heavy core face by a churning action when rising, and when nearing the top it becomes slightly chilled, causing internal surface defects, unless filled rapidly.

As a large body of metal is located on top of the 21-ton ordinary mould pouring time can be lessened. The metal in this instance tends to lean on the core when rising in the mould. Obvious conclusions can be drawn from these observations, the most important of which is that pouring time on this type of work is mostly governed by casting design.

In Fig. 13 a group of jolted cores is seen. The one on the left is the core actually used in the making of the 21-ton casting. These cores are all in their green state. Successful jolting can only be accomplished when special provisions are made for the manufacture of the pattern and core box. It is futile to imagine that a pattern and coreboxes built for hand ramming can be transferred to machines for production. Special care must be exercised in construction, apart from weighty timber used, and alternate corner splitting in square and rectangular coreboxes is essential. After jolting, the core is released by undoing the corner bolts, and the slight clearance obtained enables the operator either to take away the corebox in "ordinary" cores, or to remove the core in "inverted" types.

Serious differences can arise in dimensions if

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* See Paper "Recent Developments in the Production of Ingot Mould Castings," Fig. 1.

the coreboxes are constructed in timber, despite heavy iron reinforcements. A definite tendency to bulge arises in this type at approximately the second bottom cross bar. The differences in most cases are trifling, but, nevertheless, it is desirable to maintain a high standard of accuracy. It has been found in practice that working slightly under ordinary rule sizes at the base has materially helped in maintaining the stipulated drawing size. Iron coreboxes do not show the same bulging tendency. A much truer core is obtained from their use, but the sweating effect can " start " sand on the flats which may mean scabbed cores if undetected.

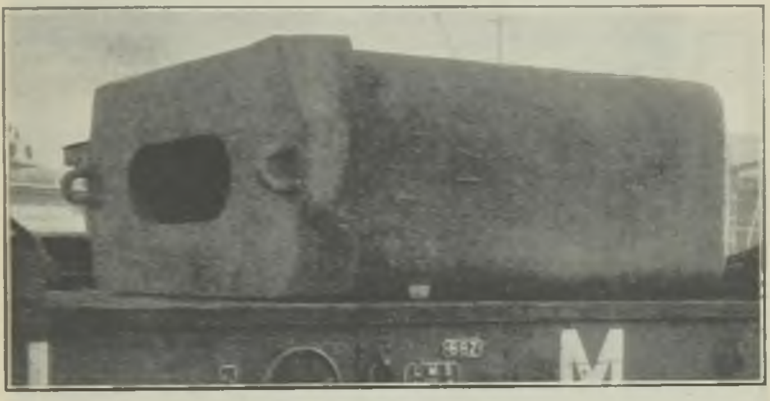
FIG. 12.—ANOTHER VIEW OF THE 21-TON INGOT MOULD SHOWN IN FIG. 11.

Top and bottom mild steel plates put on the pattern should cover the cleading. End bridges will suffer in a short period if this safeguard is omitted. Likewise, the covering steel plates on the corebox should cover the inner cleading and external bars. When cleading both patterns and coreboxes, narrow timber should not be used. Too many joints are objectionable, and these in turn should be extensively dowelled. This precaution limits the "spring" or "elasticity" of narrow timber.

It is not generally appreciated that first-class patterns and coreboxes have a direct bearing on finish and serviceability of ingot mould castings, as in many other castings of ample metal thicknesses, patternshop procedure becomes a secondary consideration. The author's experience is that if one is to manufacture a first-class casting, the prior operations and materials used should be minutely studied. Why talk of moisture content of sand, if a new unvarnished or unpainted pattern be used? It is only reasonable to assume even when first-quality yellow pine is used the wood absorbs the moisture and swells. Is it not much better practice to construct patterns and

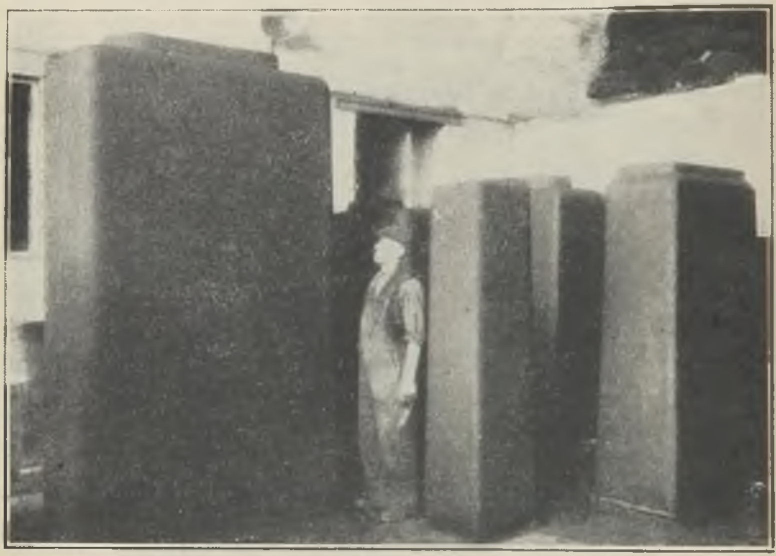

FIG. 13.—ON THE LEFT IS A CORE FOR A 21-TON ORDINARY MOULD AND THOSE ON THE RIGHT ARE JOLTED CORES FOR 8- AND 9-TON CASTINGS.

coreboxes of good quality timber, namely yellow pine, and give a refractory coating of varnish paint to impart skin to the wood and ultimate skin to the casting? The question of proper patterns and coreboxes is equally important as **Pat Dwyer's text-book** on proper gates and risers. A combination of these two subjects appeals to the author more forcibly than metallurgical theorising or sand experimentation.

FIG. 14.—END VIEW OF A 26-TON CASTING.

Core Expansion and Design

A duodecagonal ingot-mould core standing 11 ft. 6 in. high, weighing approximately 3¼ tons, in its green state, and without upright irons for stiffening, looks much more like a fluted column in architecture than a core. An end view of the casting produced from this twelve-pointed core is seen in Fig. 14. The severe test to which these points are subject can be best appreciated by stating that the metal is 13 in. thick and the casting weight 26 tons.

Check measurements on various cores have led to interesting results. Regarding this type, measurements taken before and after drying revealed an increase in height barely $\frac{5}{16}$ in., and a corresponding increase in diameter. Other checks have given similar results, but on the 34-ton inverted core of rectangular section no appreciable difference was noted before and after drying, and these results have been consistently maintained.

It would certainly appear from practical observations on large bodies of sand—as such cores are—that core shape determines to a very great extent the amount of expansion which takes place. In a large slab core, a very slight increase in height was recorded—barely $\frac{1}{16}$ in.—which is negligible on 10 ft. 6 in.

There are, therefore, three core types, a duodecagonal; an inverted rectangular; and an ordinary rectangle, with only a marked difference in the first.

The study of this subject from an everyday angle is well worth continuing, and in ingot mould work, with heavy bodies of metal, and massive bodies of sand, interesting comparison can be made. It is from a study of plain castings that knowledge is gained, and the same principles when adapted to the more involved methods of foundry work will establish a foundation for recording further progress.

The author wishes to express his indebtedness to the directors of the Fullwood Foundry Company, Limited, for their consideration in granting him permission to continue his Papers on the subject of ingot moulds.

DISCUSSION

Mr. Ballantine in introducing his Paper said it was open to discussion whether the lives of ingot mould castings were a true indication of quality. He felt it was an economic question, and bore upon production and relative costs. Mr. C. W. Bigg, in his address, used a phrase "systematisation of effort." He felt that was essential. Founding may be likened to a growing tree, ironfounding being the "trunk." "Branches" were "straggled" and numerous. Some showed the benefits of controlled development, whilst others were "gnarled" with old time "growths." A "grafting" of research and practice, coupled to mature experience and youthful enthusiasm, furthered the "tree" analogy by bearing "fruit." This was essentially a practical Paper, and he would like to appeal to the practical foundrymen present to ask questions.

Influence of Material Shortage

Mr. J. Roxburgh said that there was no doubt that the manufacture of ingot mould castings was a very important part of the industry. The development of ramming the cores in synthetic sand was one which has made the most outstandng contribution to the progress of this particular aspect of the industry. Mr. Ballantine made a remark that the lives obtained from an ingot mould were not altogether indicative of the quality of the casting. Unfortunately, that is the only method by which the quality of an ingot mould can be measured, and to-day, owing to the fact that it was not easy to get hold of hematite pig-iron, he believed the steelworks would extend the use of ingot moulds beyond the limit they were now doing. Also the question of the difficulty of obtaining supplies of hematite pig-iron might result in the specification for ingot moulds being slightly altered, and probably in the next twelve months it might be possible to collect some interesting data on the metallurgical side of ingot moulds. He believed that Mr. Ballantine has already obtained some interesting data on this matter, particularly in regard to manganese and silicon contents. Mr. Ballantine did not cast heads on his ingot mould castings. He contended that if the top surface of his casting were machined, in all probability, he would encounter defects, due to sand, blacking or "drawing." In Sheffield on these larger ingot moulds a point is made of incorporating a head on the castings, which is subsequently machined off, and in that way one saw that the top side was clean and sound, and in actual service that top side was brought to the bottom. The question of runners was also a very controversial one, and Mr. Ballantine had shown two types of runners; what he called the centrifugal ingates and the stepped ingates. On the larger moulds centrifugal ingates had always been used by the speaker with extremely good results. They were used so that a spin was imparted to the metal, and in the case of the larger moulds some of the ingates entered at a higher level to maintain the spinning action of the metal. He did not propose to enlarge on this subject, as he had prepared a Paper on the manufacture of larger ingot moulds, and had dealt with the matter on the practical and technical sides.

Runners and Feeders

Mr. Ballantine said, as regards the question of runners, he could not but believe that with centrifugal ingates there was bound to be a scaling effect. The abrasive action was very severe, particularly with sluggish hematite irons. Moreover the points of attack, in octagonal and duodecagonal cores, were subject to an eddying effect due to core shape. It appeared very strange that hours and hours should be spent on feeding and putting heads on castings of this description.

Mr. A. Sutcliffe pointed out that there were some thirty or forty heads cut from cylinders, callender bowls, and rams in his foundry at the moment, some of them weighing up to a ton.

If any one of these heads were sectioned they would show holes inside, of serious dimensions. Surely this was preferable to having them in the actual casting, which would be the case if no head were used.

Mr. Ballantine said he had examined thousands of ingot moulds, and he could not trace cavities due to lack of feeding.

Mr. A. Marshall asked for more information about the lifting irons for the 5-ton core used for the mould shown in Fig. 10.

Mr. Ballantine said there were no upright irons in the cores for Fig. 10 or Fig. 14. There were two lifters in the former, and three were used for balance in the latter. There was a top covering on the irons which kept the lifters from responding to any movement, and furthermore, they would be cushioned with the ashes surrounding them.

Costs and Mould Life

Mr. A. Campion said that he wished to congratulate Mr. Ballantine upon the Paper which he had presented. He thought that in the author they had an excellent example of the benefits to be derived from the introduction of new blood into a section of the foundry industry. Mr. Ballantine was a comparatively new entrant into the ingot mould business, having previously been engaged in the production of castings of a very different type. He had however set to work to study the possibilities of improving the technique of ingot-mould production and had been successful. It had for long been the custom to value a mould according to the life as represented by the number of heats, a method not altogether satisfactory and one which often led to a good deal of discussion between the steel maker and the foundry. So far as he could gather from the Paper, Mr. Ballantine's idea was to evaluate the mould from the angle of cost of moulds per ton of ingots produced. He considered that if the cost of production of the moulds could be sufficiently reduced a mould with a shorter life might be more economical than one with a longer life. Mr. Campion was inclined to think that Mr. Ballantine was correct in his contention and that he had gone a long way towards achieving his objective. Moulds did not always fail through cracking or crazing during use, many had their useful life reduced by mishandling and maltreatment in the works.

Mr. Ballantine had made what appeared to be somewhat disparaging remarks about what he called metallurgical theorising and sand experimentation, but really the author, like so many others who claimed as he did to be purely practical men, did not actually mean what the sentence appeared to convey. It is merely a difference of language, because the author had in an earlier part of the Paper stressed and rightly stressed the importance of correct sand condition as regards permeability and bond strength. Sand control was a means of giving those properties a quantitative value, which was essential to the maintenance of constant condition of sand.

He thought that Mr. Ballantine had hit the right nail on the head when he stated that half the battle in ingot mould making is to obtain a suitable core centre so as to permit of relief when contraction of the casting occurs. He wished Mr. Ballantine success in the achievement of his ideal in the production of ingot moulds at an economic figure, and looked forward to reading more Papers from him.

Mr. Ballantine, thanking Mr. Campion for his remarks, said that perhaps as a practical man he was falling into some of the failings of his research friends. Some of the sand tests in his previous Paper gave 126 as the number of permeability from A.F.A. apparatus.

Mr. J. C. Jones said he noticed there were difficulties and troubles which were due largely to the foundry itself rather than the materials.

High-Phosphorus Content Moulds

Mr. **Ballantine** said he had occasionally and unknowingly had a very high-phosphorus content iron and the moulds had given splendid lives in the steelworks.

Structural Changes

Mr. **J. Hogg** said what was of interest to him and had caused him to think was that when the ingot mould was cast at the beginning he took it for granted that the metal in the casting had a normal form of carbon content. When the steel-maker had used the ingot mould and had sent it back to the foundry, had it been noticed whether the structure of the metal then compared with the original structure? It had occurred to him that the carbon would be higher and it would be interesting to know what Mr. Ballantine's thoughts were; whether he felt the iron had undergone a transformation and whether he thought it was possible to get it back to its former condition.

Mr. **Ballantine** said he never used discarded ingot moulds, but relied upon the pure hematite. He had examined moulds which had reached lives well over 200 and they show a crocodile surface effect. The open matrix in the wall centre was due to the lack of feeding, and the benefits could be seen in the longer lives obtained. He could only speak of the premature failures and study in these, the probable causes of failures.

Influence of Composition

Mr. **N. L. Evans** said the firm with which he was connected used castings which were fired from the outside, and there had been a suspicion for some little time that a phosphorus content of about 0.3 per cent. was associated with an abnormally short life. Could Mr. Ballantine state the phosphorus content of the "high-phosphorus" ingot mould to which he made reference?

Mr. Ballantine said he traced at one period two moulds with a phosphorus content of about 0.3 per cent. and found that the life in the steelworks was normal. A large factor in the ultimate life secured from these castings was undoubtedly steelworks usage.

Mr. J. H. Cooper asked what would be the percentage of differentiation in the variation of casting temperatures? Also, was it customary to heat treat moulds before using them for the first time? When they had cases of 100 to 120 ingots per mould they made one envious. Had Mr. Ballantine found he obtained a skin on the metal? The metal which was mixed with high manganese iron very often gets a rough surface on the top during pouring which it was nearly impossible to get clear.

Mr. Ballantine admitted that he did get these difficulties in casting. He was fortunate in so far as he supplied common moulds from stock and sent them to different steelworks. As already stated, in two steelworks average lives vary on exactly similar moulds from 62 to 125. Steelworks usage was the greatest factor in mould lives.

Types of Failures

Mr. J. Blakiston said there were two types of failures in ingot moulds. The first, cracking, which was peculiar to plate moulds, and the second, crazing, which afflicts regular shaped moulds. Many ingot mould foundries were attached to steel works and did not exist to make a profit, but solely to produce moulds as cheaply as possible. Therefore, it behoved the ingot mould manufacturer to concentrate on investigating his methods of production. The steel manufacturer generally used the scrapped moulds by melting in his own furnaces. The steel works, therefore, were only concerned with the production moulding cost of that mould, and really this was the sole charge to them, and this should be borne in mind when discussing ingot moulds.

A point that had been raised was the manganese content. Some personal practical experiments showed that up to 1.2 per cent. manganese a satisfactory life was obtained, and above 1.8 per cent. there was an improvement in the life.

He thought there were several iron and steel works in America now producing moulds from basic iron. He did not think phosphorus was such a vital matter to the lives of the moulds. He knew of moulds which have been sent out with phosphorus content as much as 1 per cent. and no complaint had been made.

As an ingot mould must have a perfect skin, he would like Mr. Ballantine's opinion on the method of mixing and of application of blacking. His experience of spraying blacking has not been satisfactory and he found it gave dummy scabs.

Blackings for Ingot Moulds

Mr. Ballantine said good quality blacking was essential and nothing less than one sixteenth of an inch put on with a brush should be used. It should then be washed down with a camel hair brush and water. His foundry was never troubled with scabbing. The scabbing to which Mr. Blakiston referred was not due to the blacking but to the low permeability of the sand used. He was in a fortunate position in Scotland as the deposit of Scotch rotten rock sand seems eminently suitable for the manufacture of ingot moulds.

A Member suggested that when one cast iron on to steel the steel would pick up carbon from the cast iron. Thus when steel was poured into an ingot mould was there transference of carbon from the skin?

Mr. Ballantine said the question seemed to be one of equilibrium of heat in the mould and heat in the steel. The high temperature of the steel when pouring into the mould resulted in sudden shock to the mould casting, despite prior heating. So that it would appear non-feeding of castings has a definite advantage in as much that the open grained wall centre cushioned the initial shock and lessened the tendency to sudden splitting of the mould.

Long Life High-Phosphorus Moulds

Mr. J. Roxburgh, reverting to the subject of the phosphorus content, said that if one mixed, for the sake of argument, a percentage of common iron with hematite, it would mean it would still be necessary to incorporate in that mixture 80 per cent. of low phosphorus iron (to obtain a phosphorus content of 0.3 per cent. in the casting). From personal experience one of the best ingot moulds he had made was about 3 tons in weight, and it actually had about 340 lives with a content of 0.35 per cent. of phosphorus. He felt that, probably due to the shortage of hematite, some interesting results would be obtained.

A member said Dr. Tomlinson and himself had investigated heat resisting iron and had shown that it was neither a desirable nor necessary factor to have low phosphorus.

A vote of thanks was passed to Mr. Ballantine.

Mr. C. W. Bigg, the chairman, apologised for having to leave the meeting, and his place was taken by Mr. F. J. Cook.

COMMUNICATION

The Variations from the Users' Angle

Mr. J. G. Pearce wrote that anyone who had seen ingot moulds produced at the works with which the author was associated would appreciate the care and thought he had devoted to this matter and the excellence of the results obtained. From the point of view of mould production this and the previous Paper were of great value. The author rightly stressed the variations in life obtained on the same type of mould by different steel works, but it must not be forgotten that steel works also find variations in life in moulds from different foundries made to the same design and subjected, as far as possible, to the same conditions of use. When large quantities of moulds were used, the effect of day to day variations in steel works practice could be taken into account. There was, however, now a strong spirit of co-operation between makers and users of ingot moulds which offered the best possible augury of success in securing long-life moulds and better ingot surfaces, in support of which may be quoted the recent report, Section VI of the Seventh Report on the Heterogeneity of Steel Ingots, of the Ingot Mould Sub-Committee of the Iron and Steel Institute.

Paper No. 609

FOUNDRY AND LABORATORY CHARACTERISTICS OF CUPOLA COKE

By H. O'Neill,* M.Met., D.Sc., and J. G. Pearce,† M.Sc., F.Inst.P., M.I.E.E. (Member)

In 1929 and 1933 the British Cast Iron Research Association carried out certain cupola trials on various brands of Durham coke which suggested that further foundry and laboratory experiments would be of interest. During 1934 one of the authors (J. G. P.) and Mr. E. Millington (then chief metallurgist of the L.M.S. Railway Company) drew up a programme for extensive work on a range of cokes, and obtained the co-operation of the Northern Coke Research Committee, the Fuel Research Board and the Chief Mechanical Engineer of the L.M.S. Railway Company. The last mentioned permitted a cupola at Derby Locomotive Works to be used for full scale trials, though, owing to pressure of production, it was decided not to employ cokes which might unduly jeopardise the work of the associated foundry, desirable as it would have been from the experimental point of view to use cokes covering a wider range of quality.

The main object of the research was to examine the extent to which existing laboratory tests give useful indications of the foundry behaviour of cupola cokes. A secondary object was to determine the practical order of merit of these cokes, the price and reputation of which varied considerably.

The work may be considered in three sections as follows:—

Section I.—Foundry trials using a cupola with a daily melt of about 60 tons of a uniform grade of metal, carried out at Derby, as indicated above.

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* Chief Metallurgist, L.M.S. Railway.

† Director, British Cast Iron Research Association.

Section II.—Carbon and sulphur pick-up tests on the B.C.I.R.A. experimental Balanced-Blast cupola using known and uniform charges.

Section III.—Laboratory tests of a physical, chemical and microstructural nature.

I. FOUNDRY TRIALS

Each practical trial consisted of a normal day's run on a cupola engaged in the manufacture of rail chairs, Fig. 1 being a drawing of the furnace used. It was nominally of 8 to 9 tons per hr. capacity and continuous melting throughout the day was possible with the exception of a 1-hr. stoppage at midday. When it was found necessary to retard melting, the blast was cut off completely and a corresponding time allowance made. The weight of patching material required to patch the cupola to standard contour after a run was debited against the coke (Table II) and indicates the extent of the damaging action of the slag.

The melting rate was calculated from the time of blast on to blast off, due allowance being made for all stoppages. Working conditions were standardised as follows:—

(*a*) The cupola was patched to standard dimensions before each test under the supervision of two members of the L.M.S. Research Department.

(*b*) Following the usual procedure in this foundry, the bed was lighted on the previous night and a standard weight of coke was charged. The height from the top of the bed to the charging sill had been taken and the bed was replenished to this height before charging the metal. Air was blown through to bring the bed to a uniform temperature immediately before charging began. The blast was next shut off and the cupola charged to sill level. The blast was then applied and the charges were maintained as far as possible at sill level throughout the day.

(*c*) A metal to charge coke ratio of 16: 1 was used, all metal, coke and flux being weighed The metal consisted of 95 per cent. railway chair scrap and 5 per cent. manganiferous pig-iron (1.5 per cent. Mn min.). The following were the weights employed:—

1st metal charge	20 cwts.
Remaining metal charges ...	16 cwts.

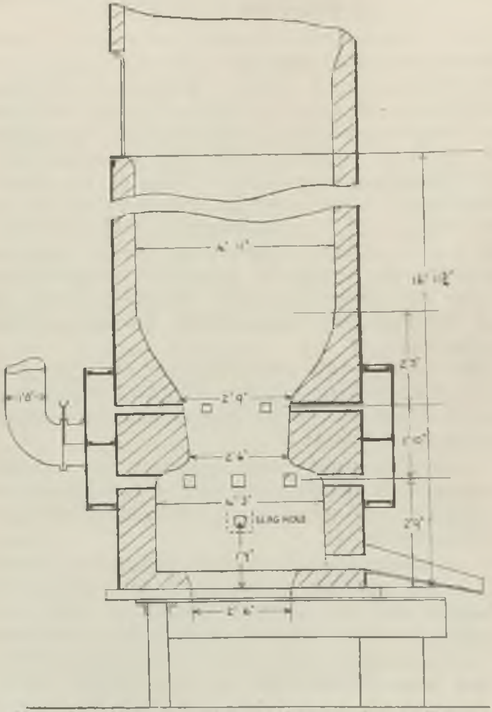

Fig. 1.—Cupola used in Large Scale Tests.

Coke charges throughout ...	1 cwt.
Limestone charges throughout...	20 lbs.

Air Supply and Exit Gases

The air supply was delivered by a fan running at as constant a speed as possible, and any variation from normal in the supply could there-

TABLE I.—*Cupola Combustion Data.*

Coke reference.	Mean metal temp. Deg. C.	Melting rate. Tons per hr.	Mean vol. of air. Cub. ft. per min.	Mean pressure of air. Ins. water.	Atmospheric conditions.			
					Blast temp. Deg. C.	Humidity. Per cent.	Barometric pressure. Ins.	Direction of wind.
L1	1,340	8.3	3,675	16.0	14	43	29.7	S.W.
L2	1,320	8.9	3,725	15.5	24	—	30.0	S.
L3	1,320	9.0	—	—	—	—	—	N.E.
G1	1,320	7.4	3,525	16.5	11	56	28.9	S.
G2*	1,310	9.3	3,900	15.0	21	—	30.1	S.W.
P	1,315	8.9	3,750	15.5	11	47	30.3	N.W.
A	1,310	8.7	3,750	15.5	14	41	30.3	N.W.
F	1,310	8.0	3,700	16.0	9	55	29.95	N.W.
C	1,305	8.4	3,800	15.0	13	75	30.4	N.W.
I	1,305	8.1	3,675	17.0	9	62	29.7	N.N.E.§
H†	1,300	8.4	3,800	16.5	10	77	30.5	N.W.
B	1,300	8.9	3,750	16.5	10	41	30.5	N.
E	1,295	8.2	3,675	17.0	11	47	29.45	W.S.W.
M†	1,295	7.7	3,600	16.5	8	66	28.6	N.
K	1,290	7.9	3,575	17.0	9	66	29.2	N.W.§
D	1,290	7.9	3,650	16.5	10	67	30.05	S.§
J1	1,270	8.5	3,750	16.0	8	75	30.2	S.S.E.
J2	1,295	9.0	3,875	15.5	22	—	30.0	W.
316‡	1,295	8.1	3,800	15.0	10	47	29.9	N.
317‡	1,290	7.7	3,700	17.0	11	60	29.7	S.W. to W

* In this case the cupola throat was patched to a larger size and so the repeat test is not quite comparable.

† Coke of rather small size.

‡ A bed of coke A was used in these tests.

§ Strong wind.

fore be attributed to the coke. The cupola was provided with two separate wind belts having five tuyeres on the upper and eight on the lower. Pressure readings were taken on each belt at frequent intervals by means of water gauges. Volume readings were obtained from a Pitot tube inserted in the blast main supplying both wind belts. Records were also made of blast temperature, humidity of the atmosphere, barometric pressure and wind direction, and these are given in Table I.

Analyses of the cupola gases taken from a side tube situated 3 ft. below the charging sill and halfway in to the centre were obtained each morning and afternoon, and the results averaged. The CO_2 content was generally about 18.5 per cent., with oxygen less than 0.7 per cent.

Slag and Metal

Test-bars and test castings were taken from the first ladle and at 11 a.m., 2 p.m. and 4 p.m. during each trial. The percentage of scrap made was also noted. The make of slag was weighed (see Table II) and its chemical analysis obtained (see Table X), together with that of the castings.

Temperature Measurement

Metal temperature at the spout was taken at frequent noted times throughout each melt by means of an " Optix " optical pyrometer. This is one of the four instruments recommended in the Sixth Report on the Heterogeneity of Steel Ingots (Iron and Steel Institute). The main difficulties to be overcome in obtaining reliable readings of molten cast iron when using an optical pyrometer are, (*a*) calibration of the pyrometer under foundry conditions; (*b*) the presence of an incandescent oxide film which at certain temperatures interferes with the true reading; (*c*) the presence of steam and fumes in the foundry atmosphere.

Frequent calibrations of the pyrometer used were made against a standard Pt/Pt-Rh thermocouple using molten cast iron. The tempera-

TABLE II.—*Slag Formation and Ash Content.* (*For analyses see Table X.*)

25 lbs. limestone and 140 lbs. coke were charged per ton of metal.

Coke reference.	Mean ash content. Per cent.	Patching material used per ton metal melted. Lbs.	Total slag produced. Cwts.	Slag in lbs. per ton metal melted.
L1	6.45	17.2	29.25	64.8
L2	—	13.2	32.75	64.0
G1	8.7	18.8	27.0	63.1
G2	—	—	30.75	60.5
P	8.95	10.6	31.0	64.6
A	6.8	17.7	32.75	68.0
F	4.7	24.6	30.0	65.5
C	8.65	19.1	32.5	65.3
I	5.7	23.9	30.5	67.7
H	3.65	19.6	29.75	62.9
B	8.75	13.4	32.25	66.5
E	7.65	20.1	30.75	67.0
M	8.8	18.0	23.75	56.9
K	9.4	17.0	31.0	70.2
D	5.0	24.0	24.5	54.6
J1	6.45	19.3	38.75	81.4
J2	—	—	33.25	66.3
316	7.15	14.2	31.5	66.5
317	7.0	19.0	33.75	71.4

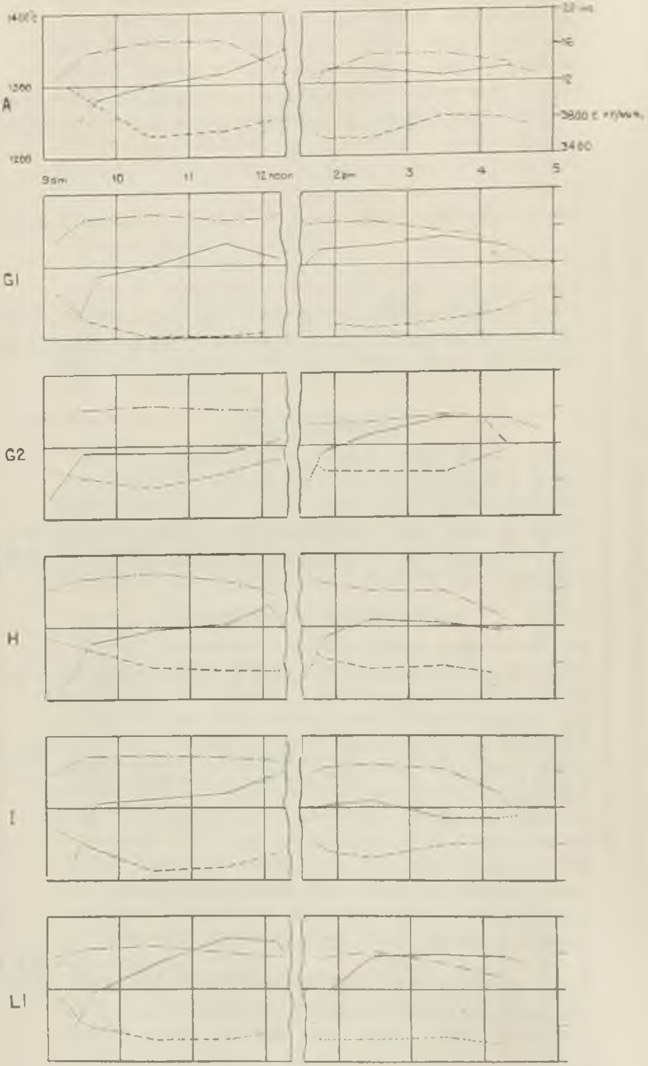

FIG. 2.—(*For explanation of Curves, see p.* 204).

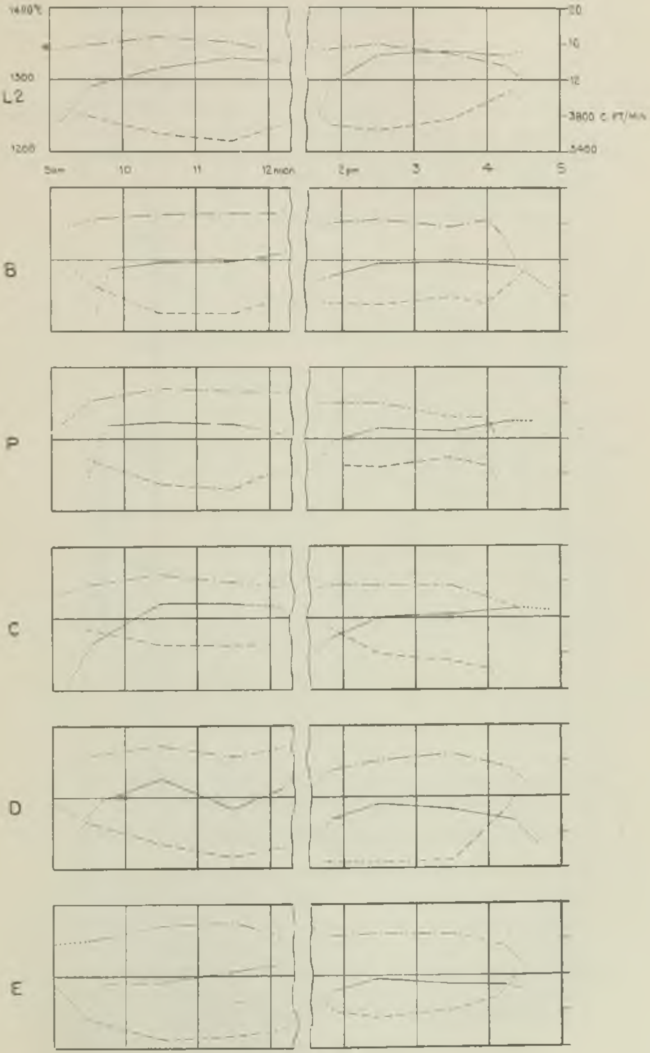
1400°C
1300
1200
L2
9am
10
11
12 noon
2pm
3
4
5
20
16
12
3800 C FT/MIN
3400
B
P
C
D
E

FIG. 2

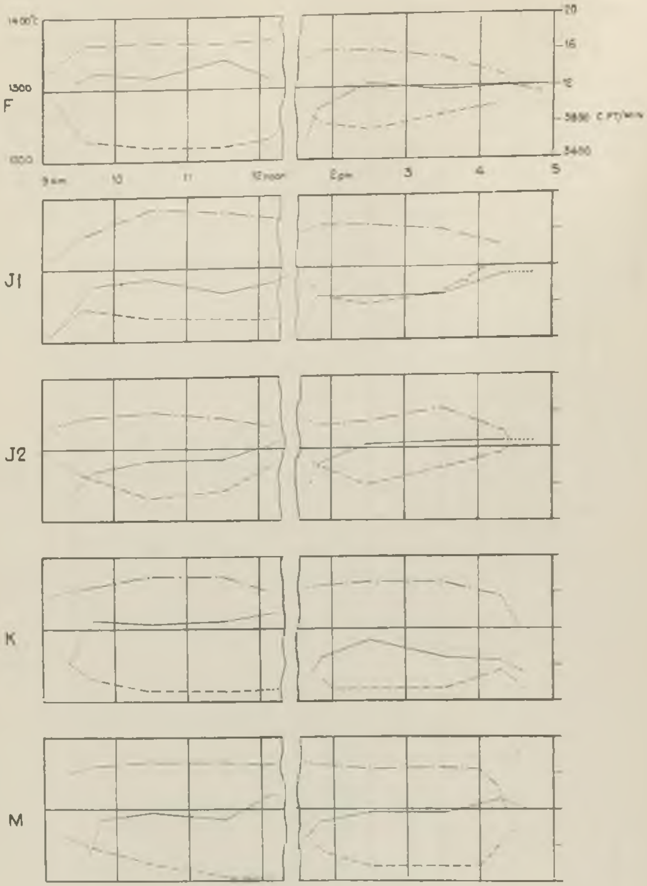

FIG 2. PRESSURE, INCHES OF WATER —·—·—·—

TEMPERATURE OF METAL AT SPOUT, °C ————

VOLUME OF AIR PASSING, C FT/MIN. - - - - - - - - - -

tures recorded can be regarded as being within ± 5 deg. C. of true temperature.

Due to the relatively narrow range of observed temperatures with the different cokes and the fact that the metal throughout the tests was of similar composition, it follows that the surface conditions of the metal remained fairly constant. Care was taken always to focus the pyrometer at the same position on the metal stream, and readings were not taken when foundry operations resulted in the formation of steam fumes in the vicinity of the cupola. The metal temperature never rose sufficiently high for trouble to be experienced with fumes from the metal itself. Readings taken by two operators did not differ by more than ± 5 deg. C.

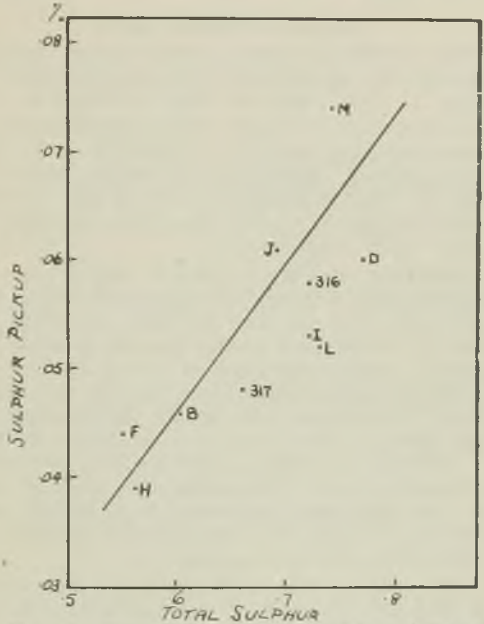

Fig. 3.—Sulphur Pick-up and Total Sulphur.

Sampling

Coke was delivered to the foundry in sheeted wagons which were unloaded into barrows. A small sample was taken from each barrow load and in this way a large representative sample was obtained which was dealt with according to B.S.S. No. 496, entitled " Sampling and Analysis of Coke."

Results of Cupola Tests

The main observations made in the foundry during the practical trials are recorded in Table I. The cokes are there arranged in decreasing order of mean metal temperatures as determined by graphical integration from the mean hourly temperature records given in Fig. 2. The temperatures used in this railway chair foundry are lower than those required in many other foundries.

Referring to Fig. 2, cokes F and K show a marked drop in metal temperature during the afternoon and this can be only attributed to the bed being used faster than it is being replaced. Other cokes such as G and J2 show an increased metal temperature during the afternoon. In the case of coke G2 the diameter of the cupola at the throat was enlarged and this is reflected in lower pressures and increased volumes of air. Naturally the melting rate of the coke was increased, but despite this the curve shows the same general features as observed in the curve of coke G.

The mean of the recorded blast temperatures is 12.6 deg. C., and of the humidities, 58 per cent. Cokes H and J1 were tested with blast temperatures of 10 deg. C. and 8 deg. C. respectively, whilst the humidities were 19 per cent. and 17 per cent. above the average respectively. These testing conditions may tend to lower the metal temperatures for cokes H and J1.

Repeat tests were made on cokes L, G, and J; the first and second tests being designated by the indices 1 and 2. L3 was carried out two years after the others on a current supply of

TABLE III.—*Quality of Metal.*

Av. comp. per cent. at 2 p.m.: Gr. 2.26, C.C 0.76, Si 1.62, Mn 0.33, S 0.12, P 1.38.

Coke reference.	Transverse test (1.2 in. bars as cast). Rupture stress on 18 in. centres. Tons per sq. in.				Tests on chairs (transverse breaking strength. Tons per sq. in.)				Scrap castings, per cent. produced during trial.
	First metal.	11 a.m.	2 p.m.	4 p.m.	First metal.	11 a.m.	2 p.m.	4 p.m.	
L1	19.3	23.9	20.5	20.0†	18.0	26.0	24.5	24.5	6.2
L2	20.3	23.4	16.9	18.8	15.5	22.5	21.5	17.0	6.5
G1	23.0*	21.3	23.0	22.5	21.0	19.0	26.0	24.0	4.1
G2	14.4*	25.2	24.3	21.6	15.0	27.0	17.0	25.5	7.5
P	18.1	19.4	22.2	22.6	21.0	22.0	27.0	24.5	3.9
A	21.1	20.7	21.6	22.2	16.0	18.5	25.0	25.5	5.0
F	17.1	21.1	26.1	20.4	21.5	25.0	24.0	26.0	3.8
C	20.5*	24.3	23.1	18.3*	20.0	23.5	23.0	22.75	5.4
I	18.4	21.9	21.4	24.5	15.75	28.5	27.5	23.5*	3.5
H	19.0*	22.0	25.4	22.3	15.5	27.5	23.0	23.0	4.0
B	19.2	17.9*	21.0	24.2	22.5	26.0	23.0	24.0	3.9
E	20.2	16.5	20.6	18.6*	22.0	22.0	25.5	22.5	4.2
M	16.4*	22.7	22.6	19.2	16.0	17.0	24.5	22.0*	3.3
K	17.9	21.6	22.9	24.7	15.0	25.0	23.0	19.0	4.2
D	17.9	20.1	24.6	24.6	15.0	22.0	26.0	17.0*	5.6
J1	17.1	20.4	21.8	26.8†	15.0	20.0	14.0	24.0	6.3
J2	17.0*	25.2	21.1	24.4	17.0*	21.5	24.0	22.0	5.0
316	19.0*	22.7	21.7	—	15.0	22.0	26.0	18.0*	4.3
317	18.3	23.4	21.2	20.9	19.0	29.0	25.0	24.5	3.3

* Flaw present.

† Broken on 12 in. centres.

coke. During this time the cupola shaft length had been reduced by 1 ft., and the upper wind belt operated with six tuyeres instead of the previous five. The results for coke L agree fairly satisfactorily, whilst the high melting rate and lower temperature for G2, as compared with G1, may be ascribed to the increased cupola patching size. J1 and J2 do not agree well, and the values for the laboratory tests reported in Tables IX and XIV show correspondingly differences. This points to irregularities in the supply of material and does not commend coke J.

TABLE IV.—*Blast Pressures and Volumes.*

Coke reference.	Mean blast pressure in wind belt. Ins. W.G.	Mean volume of air. Cub. ft. per min.
B	9.65	1,130
D	9.15	1,120
F	9.70	1,135
J	8.55	1,140
L	10.20	1,285
I	9.60	1,245
H	10.40	1,085
316	6.30	1,175
317	9.80	1,180
M	9.30	1,235

Criterion of Merit

If the adopted working conditions for the cupola be accepted as an equitable compromise it follows that the best coke from the thermal point of view is the one giving the highest metal temperature, provided that the melting rates of all the cokes are equal. Alternatively for a given satisfactory metal temperature the coke with the highest melting rate is thermally the best. A high melting rate tends to penalise the temperature owing to decreased time of preheating in the cupola shaft. It can otherwise be a disadvantage, and inquiry shows that economy generally results from cokes giving high temperatures with relatively low melting rates.

The order of merit given in Table I is free from ambiguity, since the better cokes all have good melting rates. Before deciding that it represents the practical order of merit, slag behaviour and metal quality must be examined.

Slag Formation

In Table II are given the patching requirements and slag yields obtained during the trials, the cokes having been placed in the table in the previous order of metal temperatures. Analyses of the ashes and slags were made, and it was observed that cokes from the same coalfield had similar ash compositions as regards silica-alumina ratio and SO_3 content.

The ash contents reported by two different laboratories working on the same sample have been averaged. The maximum ash in the series is about 9.5 per cent. (coke K) and the minimum 3.5 per cent. (coke H).

The maximum amount of patching material per ton of metal was required for cokes F, D, I and E, and this was consistent with the chemical analysis of their ash and slag. Cokes J1 and K produced the highest yield of slag and the latter is high in ash. This is consistent with the high FeO content, 25.2 per cent., of the slag from Coke J1 caused by the low working temperature.

It is evident that the hotter cokes have not consistently caused greater damage to the cupola, and so slag formation does not call for a reconsideration of the order of merit given in Table I.

Metal Quality

The quality of the castings made from the different cokes may be judged from Table III. The corresponding chemical analyses from each cast have been obtained and may be consulted at the Institute's office.

The mechanical tests show no evidence of inferior metal for the hotter cokes, but the percentage of scrap chairs is high in L1, L2 and G2. The scrap figure is not a reliable criterion in the present case, however, as the conditions of moulding and fettling varied a great deal.

TABLE V.—*Charge Analyses.*

Element.	Pig-iron specification. Per cent.	Mean analysis per cent. of		
		Pig-iron.	Steel fishplates.	50 : 50 charge.
T.C	4.0	3.70	0.41	2.06
Si	3.5—4.0	—	—	—
Mn	1.0	—	—	—
S	0.04 max.	0.012	0.059	0.036
P	0.04	—	—	—

Chemical analysis showed a sulphur content of about 0.12 per cent. in the castings from all of the cokes except M, and this value is not unsuitable for rail chairs. The first metal of each trial was highest in silicon and manganese, and lowest in sulphur and phosphorus, because the first charge consisted of 10 cwt. of chair scrap and 10 cwt. of manganiferous pig-iron (1.5 per cent. Mn min.). Owing to its lower temperature the first metal gave inferior mechanical properties.

The carbon and sulphur figures obtained on the test castings have been plotted with the tapping temperatures of tho metal from which these castings were poured. When the actual carbon figures of the castings were considered, it was found that due to differences in silicon and phosphorus content, especially on the metal from the first tap, comparative results were not obtained. It was therefore decided to adjust the carbon contents of the castings to a uniform silicon and phosphorus content, using a factor of 0.3 per cent. carbon for each 1 per cent. silicon or phosphorus present. A mean silicon + phosphorus content of 2.95 per cent. was taken as standard and assuming that the silicon + phosphorus of a certain casting was only 1.95 per cent., then 0.3 per cent. carbon was deducted from the actual total carbon figure.

It was thus found that in almost every case, as the total carbon rose, the sulphur content fell, and *vice versa.* The sulphur content generally increased with temperature and in some cases, for example, cokes H, F and K, the curves for temperature and sulphur show marked similarity.

II. CARBON AND SULPHUR PICK-UP TESTS

In the practical trials on cupola cokes carried out at Derby, the metal charge consisted chiefly of scrap rail chairs. Although this material yielded metal of sufficiently uniform composition for the purpose of the tests already described, it was thought that little useful data would be

Table VI.—*Carbon and Sulphur Contents of Metal. Per cent.*

Coke reference.	1st tap.		2nd tap.		3rd tap.		4th tap.		5th tap.		6th tap.	
	T.C.	S.	T.C.	S.	T.C.	S.	T.C.	S.	T.C.	S.	T.C.	S.
B	3.03	0.103	3.11	0.085	3.12	0.084	2.93	0.073	2.81	0.070	3.03	0.072
D	3.24	0.112	3.15	0.105	3.06	0.095	3.12	0.091	3.13	0.081	3.09	0.084
F	3.24	0.104	3.29	0.082	3.17	0.075	3.15	0.076	3.19	0.072	3.20	0.067
J	3.31	0.125	3.37	0.114	3.02	0.097	3.05	0.079	3.00	0.079	2.78	0.084
L	3.07	0.083	2.87	0.117	3.14	0.090	3.05	0.076	3.00	0.079	3.07	0.079
I	3.00	0.123	3.11	0.094	3.05	0.082	2.95	0.082	2.97	0.078	2.96	0.075
H	3.21	0.086	3.06	0.082	3.12	0.076	3.04	0.015	3.12	0.067	3.09	0.068
316	3.32	0.122	3.26	0.103	3.06	0.086	3.07	0.083	2.99	0.082	2.94	0.082
317	3.02	0.112	3.13	0.096	2.84	0.080	2.91	0.072	2.97	0.067	2.99	0.069
M	2.90	0.138	3.02	0.115	3.10	0.108	3.08	0.105	2.86	0.099	2.89	0.093

obtained on the carbon and sulphur pick-up from the cokes, owing to the slight variations in the composition of the metal known to occur from the character of the scrap used. It was therefore decided to examine this property of the cokes in the experimental Balanced-Blast cupola of the British Cast Iron Research Association. It was not possible to carry out these trials on the whole series of cokes tested at Derby, as in some cases insufficient material was available.

Experimental Cupola Conditions

The experimental Balanced-Blast cupola has an internal diameter of 24 in. in the main tuyere zone and well, and is flared out at a level 10 in. above the centres of the main tuyeres to 32 in. diameter. During the tests the main valves were set with a port opening of 1 in. and the bottom and middle rows of auxiliary tuyeres were fully open. The auxiliary tuyeres in the top row were closed. The bed was made up to the level of the top row of auxiliary tuyeres and burned through by the use of the kindling tuyeres. The method of kindling was standardised so that, as far as possible, the condition of the bed was similar for each test. The cupola was also patched to a standard size after each test. The presence of fumes prevented reliable

Table VII.—*Carbon and Sulphur Pick-Ups.*

Coke ref.	Mean carbon pick-up. Per cent.	Mean sulphur pick-up. Per cent.	Sulphur per cent. in coke.		
			Total.	Combustible.	Fixed.
B	0.94	0.046	0.59	0.25	0.34
D	1.07	0.060	0.77	0.66	0.11
F	1.15	0.044	0.55	0.51	0.04
J1	1.03	0.061	0.69	0.67	0.02
L1	0.97	0.052	0.73	0.68	0.05
I	0.93	0.053	0.72	0.68	0.04
H	1.03	0.039	0.56	0.55	0.01
316	1.07	0.058	0.72	0.63	0.09
317	0.92	0.048	0.66	0.55	0.11
M	0.87	0.074	0.75	0.65	0.08

metal temperatures from being taken with the Optix pyrometer, but they were higher than those required from the larger cupola.

Air Supply

The settings of the tuyeres and the speed of the motor driving the fan was the same for each test, but blast pressure and volume readings showed that the amount of air supplied was not constant, due, no doubt, to the way in which the different cokes packed in the bed. The materials charged into the furnace were, of course, similar in each test, and Table IV gives the mean figures for pressure and volume of air.

TABLE VIII.—*Order of Merit from Cupola Trials when Making Rail Chairs.*

Order of merit.	Coke reference.	Coalfield of origin.	
1	L	Durham	
2	G	Durham	
3	P†	Lancashire	
4	A	Durham (blended)	
5	F	S. Wales	
6	C	S. Yorkshire	
7	I	Durham	
8	H*‡	Durham	
9	B†‡	Lancashire	
10	E	S. Wales	
11	M	(Blended)	
12	K	Scotch	
13	D	S. Yorkshire	
14	J‡	Scotch	
15	316‡	Durham	Special experiment.
16	317‡	Durham	

* Conditions of humidity and blast temperature during test may have slightly penalised this coke.

† P and B are from the same pit.

‡ Small size, tending to give lower temperatures.

Charges

Since low carbon content charges, when melted in the cupola, tend to pick up more carbon than medium or high carbon charges, it was decided

TABLE IX.—*Chemical Analyses and Calorific Value of Cokes.*

Coke reference.	Moisture per cent. (105deg.C.)	Sulphur Per cent.			Proximate analysis calculated to dry coke.			Gross calorific value. B.Th.U. per lb.	
		Combustible.	Fixed.	Total.	Mean ash. Per cent.	Vol. Matter. Per cent.	Fixed carbon. Per cent.	By calculation.	Determined.
L1	0.5	0.68	0.05	0.73	6.4	0.9	92.7	13,350	13,220
L2	0.4	—	—	0.78	6.9	0.6	92.5	13,300	—
G1	0.9	0.69	0.04	0.73	8.7	0.8	90.5	13,000	12,930
G2	0.6	—	—	0.78	7.4	0.6	92.0	13,200	—
P	0.6	0.31	0.29	0.60	8.9	1.7	89.4	13,000	12,990
A	0.7	0.65	0.05	0.70	6.8	1.2	92.0	13,300	13,230
F	0.4	0.51	0.04	0.55	4.7	0.8	94.5	13,600	13,530
C	1.7	0.48	0.24	0.72	8.6	1.0	90.4	13,000	12,790
I	2.6	0.68	0.04	0.72	5.7	0.9	93.4	13,450	13,465
H	1.3	0.55	0.01	0.56	3.6	0.8	95.6	13,750	13,675
B	0.9	0.25	0.34	0.59	8.7	1.8	89.5	13,000	13,020
E	0.5	0.62	0.05	0.67	7.6	0.9	91.5	13,150	13,160
M	0.9	0.65	0.08	0.73	8.8	1.1	90.1	13,000	12,800
K	5.0	0.53	0.05	0.58	9.4	0.5	90.1	12,900	12,820
D	2.1	0.66	0.11	0.77	5.0	0.9	94.1	13,550	13,440
J1	3.6	0.67	0.02	0.69	6.4	0.9	92.7	13,350	13,260
J2	0.3	—	—	0.74	8.9	0.4	90.7	13,000	—
316	0.7	0.63	0.09	0.72	7.9	1.3	90.8	13,100	13,260
317	1.1	0.55	0.11	0.66	7.0	1.7	91.3	13,250	13,100

to employ a 50 per cent. steel mixture for these tests. Hematite pig-iron (broken into quarter pigs) was used, the whole consignment being delivered at one time, and by careful sampling 32 pigs were selected for analysis. Steel in the form of fishplates was sampled in the same way, twenty plates being selected for analysis. The mean compositions of the materials and of the 50 : 50 mixture are given in Table V.

Owing to the relatively small amount of coke available and also owing to the difficulty of handling larger quantities of metal with the staff available, it was necessary to limit these trials to a melt of 35 cwt. The following charges were used:—

Metal charges ..	5 cwt.	Ratio 10 : 1
Coke charges ..	56 lbs.	
Limestone ..	21 lbs.	

The charges were applied by hand, care being taken to see that they were evenly distributed and kept level. The steel was put on first, followed by the hematite, the coke and limestone being charged together.

Tap Sampling

As far as possible an attempt was made to tap each charge as soon as it was melted, and in every case six full taps of approximately 5 cwt. were obtained. The metal was cast into pigs, a test block being poured when half the tap had been pigged. The test block was sampled for analysis by drilling completely through from top to bottom with a ½-in. diameter drill.

Results of Tests—Sulphur Pick-up

The total carbon and sulphur contents of each individual tap are given in Table VI.

It will be seen that with the exception of coke L the sulphur content of the metal, as would be expected, is highest in the first tap. Speaking broadly, the sulphur content then falls progressively during the remainder of the melt. Table

VII shows the mean pick-up figures for sulphur and carbon, together with the sulphur contents of the cokes from Table IX. There is a slight tendency for high carbon pick-ups to be associated with low sulphur pick-ups.

The total sulphur in coke is determined by the usual laboratory method described in B.S. Specification 496-1933, Sampling and Analysis of Coke. Sulphur in the ash can also be determined and the difference is known as the combustible sulphur. The 1933 tests referred to above suggested that sulphur pick-up is more closely related to the combustible sulphur content than to the total sulphur content, but the number of cokes then tried was too limited to permit a definite conclusion. It is a matter of common experience that sulphur pick-up does not depend entirely on total sulphur, which cannot, in consequence, be regarded as a guide to sulphur pick-up. The present tests, however, do not give the conclusive evidence that was anticipated on the relationships between sulphur pick-up and combustible or total sulphurs.

The total sulphur figures plotted against mean sulphur pick-up are shown in Fig. 3. Speaking broadly, the higher the total and combustible sulphur in the coke, the higher the sulphur pick-up obtained. Apart from the result on B, there appears to be a rather closer connection between sulphur pick-up and combustible sulphur than between sulphur pick-up and total sulphur.

Carbon Pick-up

Examining the carbon pick-up in the individual taps, it is seen that with the exception of cokes D and 316, the carbon content is highest in the second tap. A possible explanation of this is that the metal is not sufficiently hot in the first tap to show a high carbon increase, but during the melting of the second charge the bed is still high and at a high temperature. Coke M gave the lowest and coke F the highest pick-up, and it will be found that the increase

TABLE X.—*Ash and Slag Analyses.*

Coke reference.	Analysis of ash. Per cent.										
	SiO_2.	Al_2O_3.	Fe_2O_3.	Fe.	TiO_2.	MnO.	CaO.	MgO.	P_2O_5.	SO_3.	Alk. and Undet.
L1	47.4	32.8	12.6	—	1.3	0.1	2.9	1.0	0.2	1.5	0.2
G1	49.0	35.4	8.8	—	1.5	0.1	2.4	1.1	0.1	0.8	0.8
P	33.9	17.6	21.0	—	0.8	1.2	10.7	3.6	0.4	7.6	3.2
A	44.8	35.3	8.7	—	2.0	Tr.	4.7	0.6	0.5	2.4	1.0
F	34.9	30.4	25.1	—	0.9	0.3	4.3	0.5	1.5	1.8	0.3
C	44.9	26.9	7.3	—	1.6	Tr.	10.1	1.7	0.1	6.7	0.7
I	47.3	37.0	7.2	—	1.2	Tr.	3.8	1.0	0.2	1.5	0.8
H	48.7	35.1	8.4	—	1.8	Tr.	3.3	1.1	Tr.	1.0	0.6
B	39.2	19.5	14.3	1.9	1.1	0.3	11.9	2.6	0.8	6.1	2.3
E	44.4	39.4	6.6	—	1.4	0.2	2.3	1.2	0.1	1.5	2.9
M	46.9	32.0	8.0	—	1.4	0.3	4.6	0.2	0.1	2.1	4.4
K	50.7	37.7	5.8	—	2.3	Tr.	1.7	1.2	Tr.	0.2	0.4
D	44.2	29.1	12.5	—	1.0	0.2	5.5	0.9	0.7	5.2	0.7
J1	46.5	36.1	11.0	—	0.4	0.1	2.5	1.1	0.4	0.6	1.3
316	47.4	31.3	9.7	—	1.2	0.2	5.6	1.3	0.2	2.6	0.5
317	46.3	31.2	10.0	—	1.3	0.1	5.2	1.6	0.2	3.3	0.8

Analysis of slag. Per cent.

			FeO.							CaS.	
L1	52.3	9.4	10.9	1.3	2.4	4.7	18.1	0.6	0.2	Tr.	0.1
G1	49.5	10.9	12.5	1.2	2.4	4.6	17.3	0.9	0.1	0.2	0.4
P	51.9	7.8	11.8	0.8	2.3	4.5	10.3	5.4	0.7	Tr.	4.5
A	50.6	8.1	14.8	1.5	2.6	4.3	17.2	0.7	0.1	0.1	—
F	51.7	0.8	19.9	0.5	2.7	4.7	17.8	0.6	0.7	Tr.	0.6
C	48.5	10.1	13.5*	—	1.4	4.5	19.0	1.1	0.4	0.2	1.3
I	50.0	8.2	14.9	1.2	1.7	4.9	18.0	0.7	0.3	0.1	—
H	49.6	7.7	15.0	1.3	2.3	5.1	17.6	0.7	0.3	0.1	0.3
B	48.3	7.6	13.6	1.1	2.8	3.0	19.0	1.3	1.8	0.3	1.2
E	47.9	8.8	14.4	1.5	2.0	4.4	18.0	1.2	0.1	0.2	1.5
M	48.2	11.0	11.5	1.4	2.6	4.3	16.7	0.5	0.6	0.2	3.0
K	47.6	9.5	15.5	1.0	2.9	4.5	16.9	1.3	0.5	0.2	0.1
D	50.0	5.1	18.5	—	2.0	3.6	17.9	0.3	1.7	0.1	0.8
J1	44.7	10.8	25.2	—	2.0	1.3	14.2	0.6	0.8	0.2	0.2
J2	—	—	12.6	—	—	5.0	—	—	—	—	—
316	50.3	8.7	14.8	0.7	1.5	4.4	17.6	0.8	0.4	0.1	0.7
317	49.7	11.7	14.9	1.1	2.5	1.9	16.8	0.8	0.4	0.1	0.1

* Individual FeO contents of slag: (1) 10.45 a.m., 16.4; (2) 11.50 a.m., 14.7; (3) 2.25 p.m., 6.9; (4) 3.45 p.m. 12.0; and (5) 4.45 p.m., 12.5 per cent.

in carbon of the metal melted with this coke remained consistently high. Most of the cokes tested showed a more or less rapid fall in carbon in successive taps after the second tap. Cokes I and H gave a metal of fairly uniform carbon content, but a lower carbon increase than coke F.

Conclusions from the Cupola Tests

From consideration of the previous Tables it may be concluded that since none of the cokes gave metal of inferior metallurgical properties, the thermal values—and the metal temperature in particular—will suffice to appreciate the merits of the fuels. In Table VIII the order of merit is recorded against the coke reference letter and the coalfield of origin.

The authors have every confidence in this order of merit and the trials have modified the views hitherto adopted by some of the L.M.S. foundries. The best cokes in this list were quoted at the ovens in 1934 as about 30 per cent. cheaper than a certain popular coke, and 43 per cent. cheaper than another coke in Table VIII. The satisfactory use of cheaper brands in various L.M.S. cupolas employed on general foundry work indicates that the research results obtained above were not peculiar to the cupola employed for the trial.

It should be explained that samples 316 and 317 refer to pieces of the same Durham coke chosen for trial from different positions of the charge in the oven. Thus:—

No. 316 was the "outer ends," *i.e.*, the portions adjacent to the oven wall; whilst

No. 317 was the "inner ends," *i.e.*, the portions at the core of the charge.

These trials were made at the suggestion of Professor H. L. Riley, and as the weights available were small a bed of coke A had to be used. The results are therefore not strictly comparable with those on the other samples.

III. LABORATORY TESTS

To obtain correlations between cupola and laboratory results the cokes were next examined by the following procedures:—

Chemical ..	*Analysis (cokes and slags)*	*Tables IX, X*
	Wet oxidation test ..	*XI*
	Combustibility ,,	*XI*
	Reactivity ,,	*XI*
Physical ..	*Shatter* ,,	*XIV*
	Calorific Value	*IX*
	Porosity	*XV*
	Compression Strength	*XV*
	Abradability	*XV*
Structural ..	*Macrostructure (Rose's Method)*	*XIV*
	Microstructure	*XVI*

Most of these tests are well known, but the following brief descriptions of some of them may be useful:—

Wet Oxidation Test.[1]—The rate of oxidation of carbon in the coke by a solution of chromic and phosphoric acids is determined. Graphite is oxidised more rapidly than "amorphous" carbon by these reagents, and so a high value of CO_2 as reported in the test results indicates a relatively large amount of graphite present in the sample. It has been suggested that high graphite is a desirable property in a metallurgical coke.

Shatter Test.—Coke is allowed to fall four times through 6 ft. on to a steel plate according to the procedure outlined in B.S.S. No. 496/1933. The shatter index was determined by sieving through both 2-in. and 1½-in. screens. A high shatter index means a high resistance to breakage both in transport and in the cupola stack, and frequently indicates good thermal properties. The index is expressed as the percentage weight remaining on 2-in. and 1½-in. screens.

Combustibility Test.—This is a measurement of the capacity of the coke to react with air. Coke

TABLE XI.—*Reactivity Tests.*

Coke reference.	Wet oxidation test. Mg. CO_2 per 2.5 hrs.	Combustibility test " A."							Reactivity test.	
		Ignition temp. Deg. C.	Max. steady temp. Deg. C.	Combined gas analysis.			Consumption. Gm. per hr.		RI.	RIII.
				CO_2.	CO.	CO_2:CO.	Carbon.	Coke.		
L1	204†	565	1,181	14.2	10.1	1.40	44.8	49.2	104	59
G1	201	559	1,175	14.7	9.6	1.53	45.2	49.6	90.5	47.5
P	141†	519	1,129	12.7	12.8	0.99	48.4	53.4	190.5	124
A	194	545	1,177	14.6	9.6	1.52	45.2	48.3	89	55
F	217	586	1,192	15.3	8.4	1.86	43.9	45.8	77.5	43
C	161	570	1,161	13.2	11.1	1.19	47.0	51.2	144.5	157
I	189	530	1,200	14.4	10.0	1.44	45.6	48.5	74	42
H	208	566	1,170	15.1	9.1	1.66	44.7	46.3	63.5	46
B	133†	528	1,164	13.8	10.5	1.31	46.3	50.2	100.5	118
E	230	561	1,163	15.0	8.9	1.69	44.5	48.3	68	38.5
M	186	522	1,188	14.4	10.0	1.44	45.6	49.9	126.5	64
K	167	566	1,112*	13.5	11.2	1.21	46.9	51.7	58.5	54
D	150	584	1,195	15.0	8.7	1.72	44.4	46.8	88.5	55
J1	144	550	1,174	14.5	9.8	1.48	45.4	49.3	14.5	27
316	218	560	1,190	14.2	10.1	1.41	45.8	49.1	107	70
317	178	490	1,160	14.4	10.1	1.43	45.6	49.4	132	61

* Falling temperature.

† Similar tests made in the B.C.I.R.A. laboratory gave L1 = 164, P = 119, B = 125.

is heated in a current of air or oxygen and its ignition temperature noted. This ignition temperature depends upon the apparatus used, and so the latter must be standardised. The rate of combustion is determined, as well as the maximum steady temperature obtained.

Reactivity Test.—This is a measurement of the extent of the reaction of coke with carbon dioxide. In the Fuel Research Board method[3] the volume of carbon monoxide obtained from 100 mls. of carbon dioxide gas when passed in a stream over cokes maintained at an arbitrarily selected temperature of 950 deg. C. under standard conditions is measured.

The "*RI value*" is the primary reactivity value of the coke as obtained above for the first 100 mls. of carbon dioxide, and has a theoretical maximum value of 200.

The "*RIII value*" is obtained by continuing the experiment until the volume of gas obtained from successive determinations is substantially constant. Reactivity values can be considered from three aspects, (*a*) the magnitude of RI and RIII, (*b*) the difference between RI and RIII, and (*c*) the smoothness of the curve obtained for the change from RI to RIII.

Macrostructure by Rose's Method.—A typical piece of coke is coated with a mixture of plaster of Paris and magnesia, and is sectioned longitudinally with a hack saw after the coating has set. The sawn face is soaked in water and more coating material applied. After this has set the section is rubbed down with emery on a glass plate, and may be photographed to show the amount of fissuring in the coke. The latter is likely to bear some relation to the shatter index.

Chemical Analysis

The results of chemical analysis are given in Table IX, the cokes being arranged as before in descending order of thermal merit. From the proximate analysis it is possible to calculate the approximate calorific value by means of an empirical formula dependent on the ash and volatile contents of the coke. The actual calorific power as determined in a bomb calorimeter is given alongside for comparison, and it will be observed that the agreement is good. The carbon content is perhaps the most important item in the chemical analysis of a coke, but is of no great utility in the present tests.

Cokes H and F are high in fixed carbon and low in volatiles, but they do not stand particularly high in the authors' practical order of merit. Coke F gave the highest carbon pick-up (see Table VII) and there is fair correlation between this quantity and the percentage of fixed carbon.

The compositions of the coke ashes are given in Table X together with those of the corresponding cupola slags.

After consideration of these chemical results it must be concluded that none of them determines sufficiently well the melting merits of the cokes.

Thermo-Chemical Laboratory Tests

The results of various reactivity tests are given in Table XI.

Detailed study of Table XI does not show that any of these laboratory results taken singly will indicate the melting merits of the cokes.

It emerges that by placing the specimens in the order of their wet oxidation test results they become segregated into groups of the appropriate coalfields. The indicated order of decreasing graphite content is as follows:—South Wales, Durham, Scotch, South Yorkshire and Lancashire. This method of coalfield grouping will be considered later.

Macrostructure

The preparation of sections of coke by Rose's method presents no difficulties, but the question arises as to whether a selected piece can legitimately serve as a sample for a given brand. The authors have not seen this point dealt with

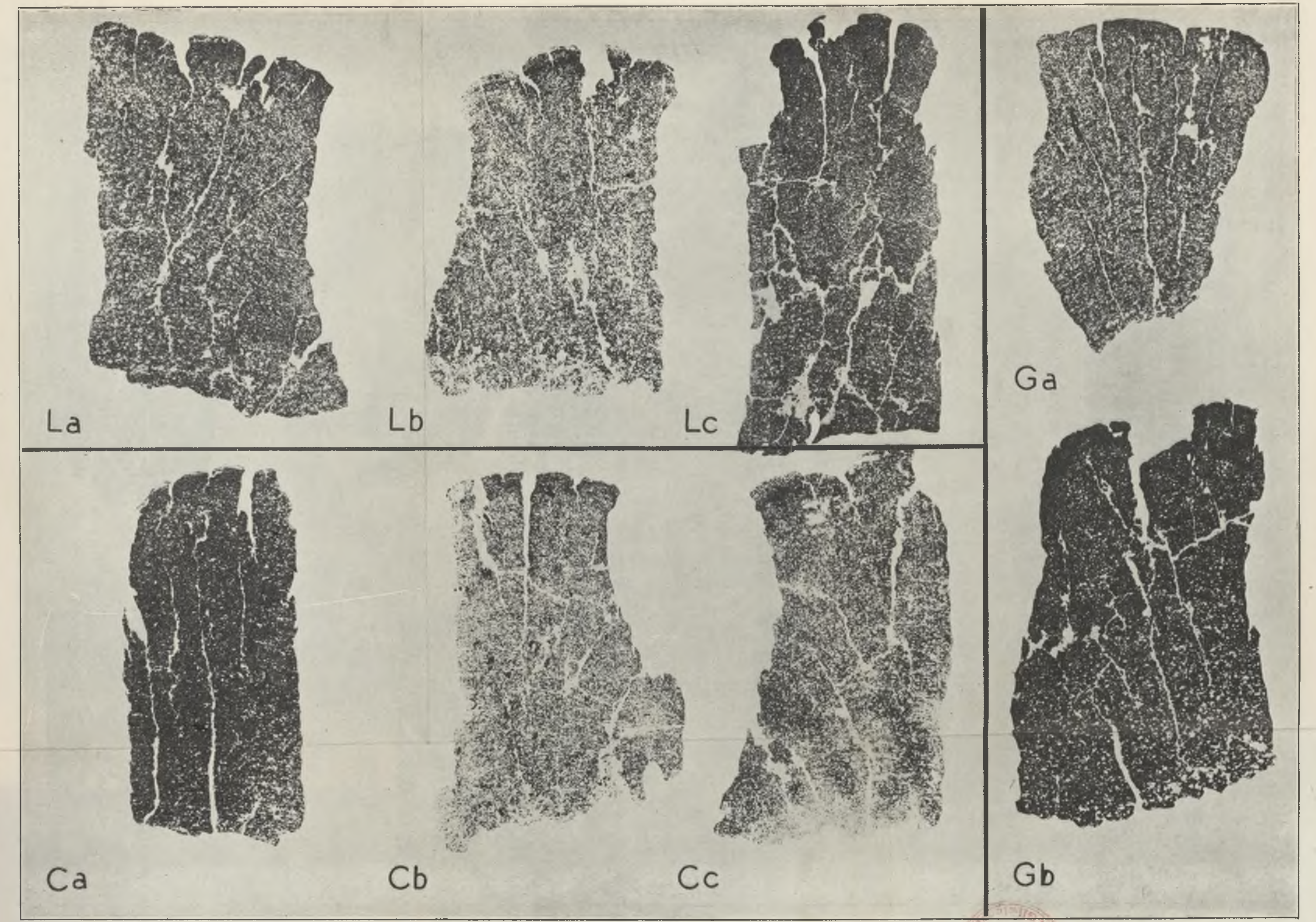

Fig. 4.—Rose's Test on the Macrostructure of Coke.

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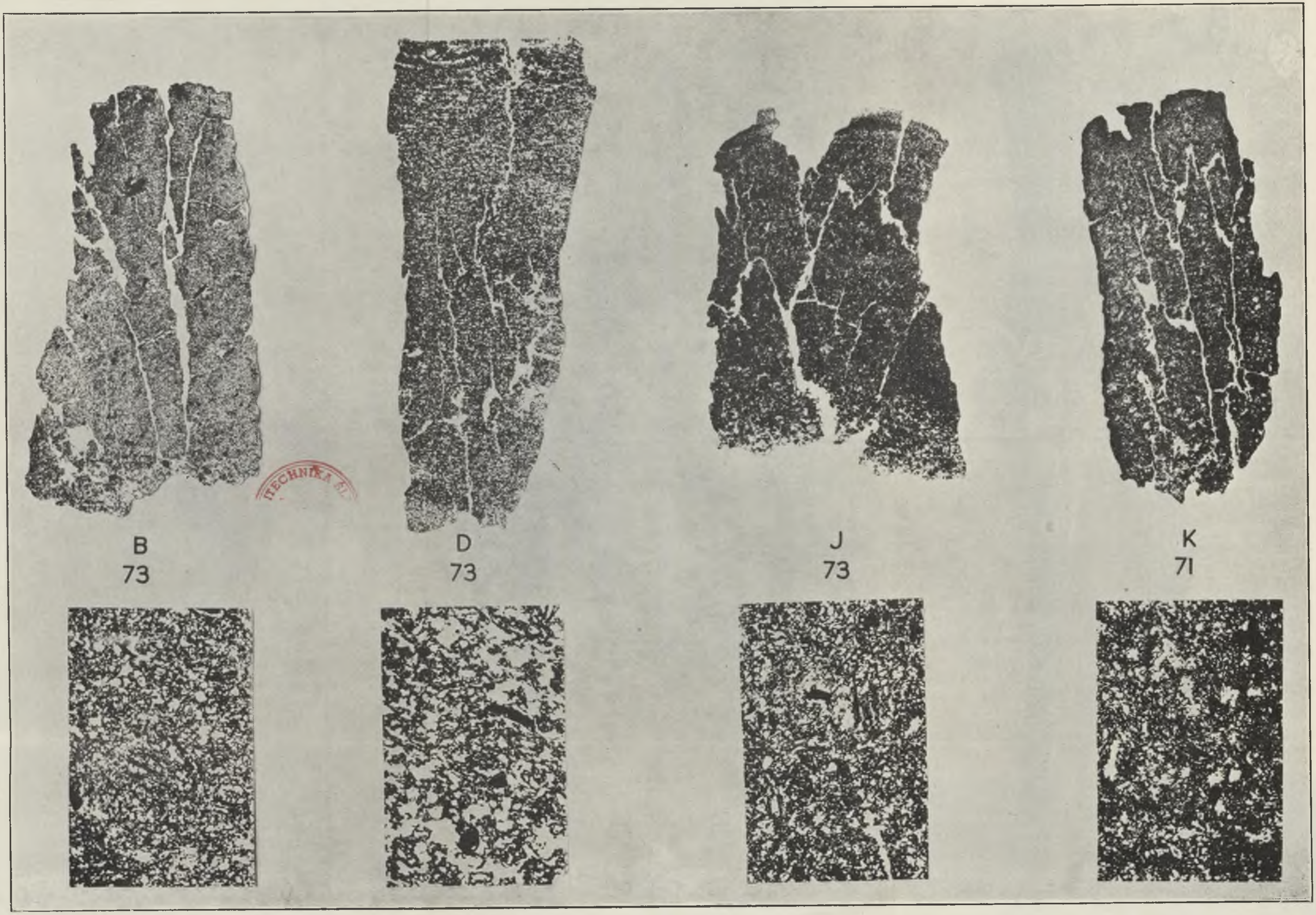

Fig. 7.—Macrostructures and Microstructures of Cokes B, D, J, and K.

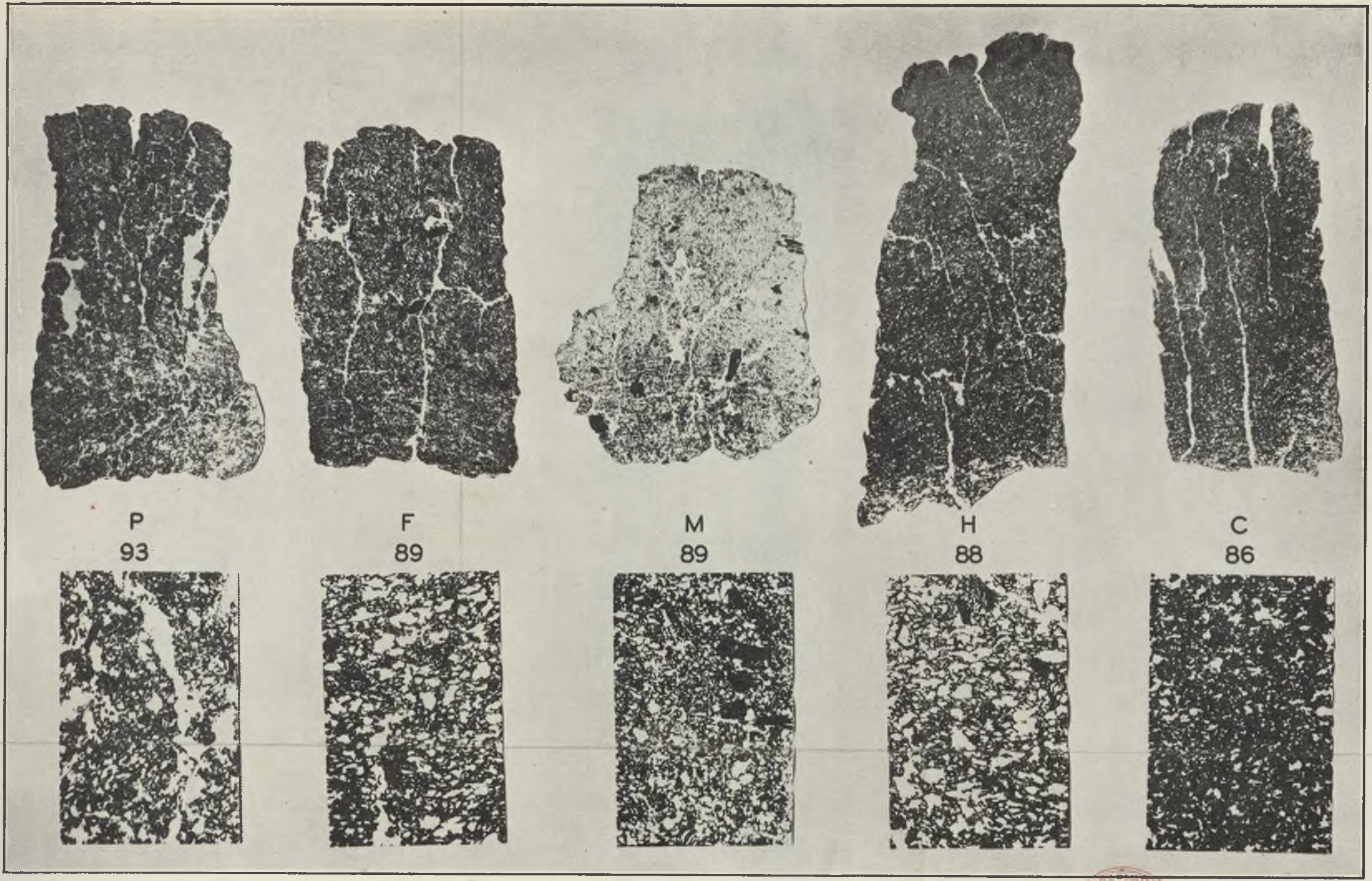

Fig. 5.—Macrostructures and Microstructures of Cokes, P, FF, M, H, and C.

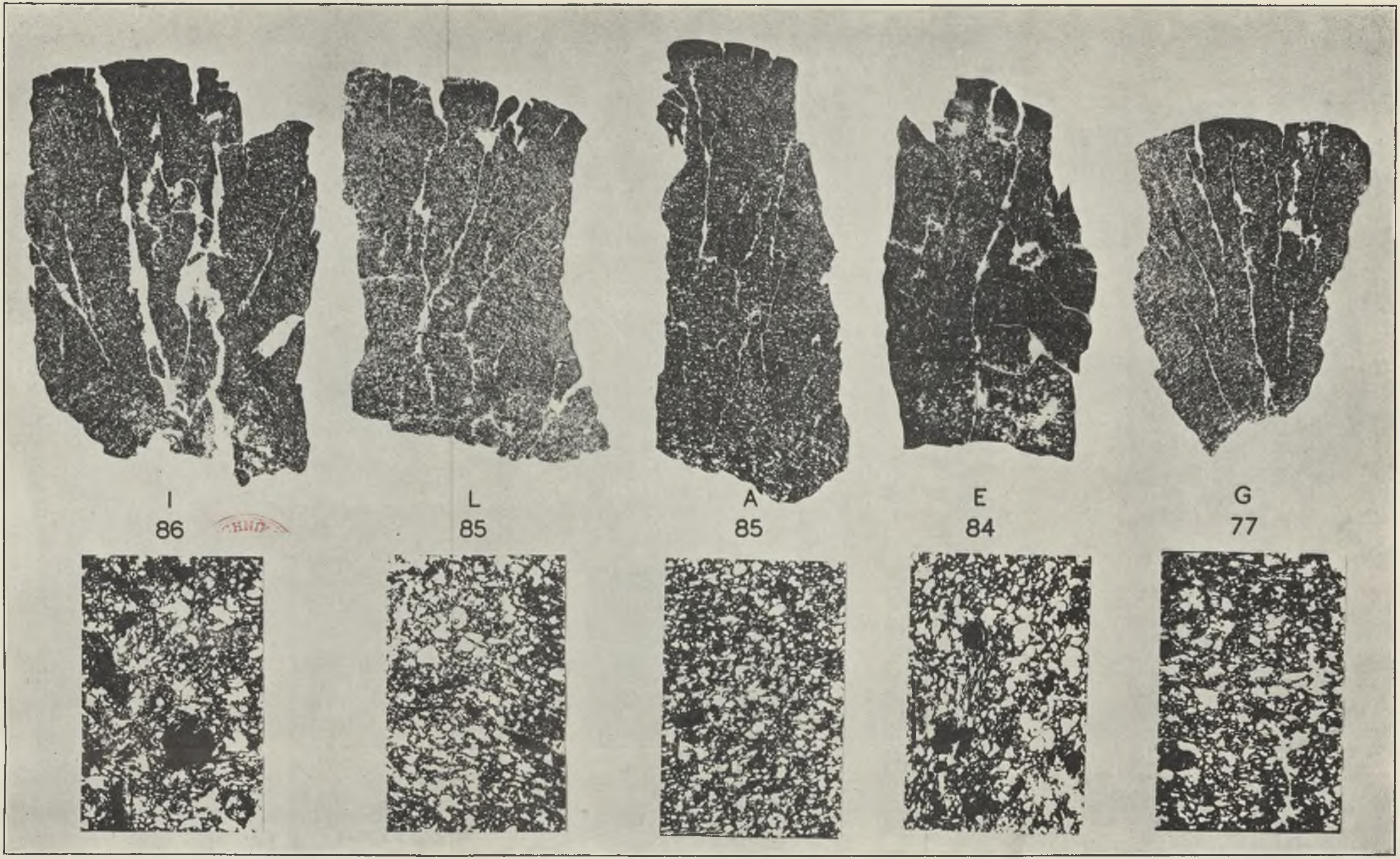

Fig. 6.—Macrostructures and Microstructures of Cokes I, L, A, E, and G.

very fully, and their own examination of it has only been slight.

In selecting a sample for macrostructure the aim was to obtain an average piece showing both the "cauliflower end" (*i.e.*, portion adjacent to oven wall) and the inner coke. Fig. 4 illustrates the appearance of sections of brands L, C and G sampled from different deliveries over periods of time as reported in Table XII.

Besides the macrostructure, the cell formation has also been examined in the way described later in this Paper. The authors are of the opinion that cokes L and G have maintained a structural consistency during the time period mentioned, and that a selected macrospecimen has given a reliable indication of structure. Coke C, however, has changed, for whilst Cb and Cc duplicate quite well, they differ greatly from Ca. From quite an independent source the authors have heard that coke C is variable in quality for cupola work. The general form of the cokes and the points to be noticed in the macrostructure have been described according to the scheme set out in Table XIII.

TABLE XII.—*Repeat Rose's Tests.*

Ref. on Fig. 4.	Batch period of sample.	Microstructure. Black cell wall. Linear per cent.		
		Traverse 1.	Traverse 2.	Mean.
La	Original (1934) ..	47	53	50
Lb	1 year later ..	44	41	43
Lc	2 years ,, ..	46	43	45
Ca	Original (1934) ..	66	70	68
Cb	1 year later ..	30	43	37
Cc	13 months later ..	31	41	36
Ga	Original (1934) ..	54	56	55
Gb	2 years later ..	59	45	52

The upper portions of Figs. 5, 6 and 7 are reduced photographs of the longitudinally sectioned cokes arranged from left to right in decreasing order of shatter index (2-in. screen). A description of the structures is attempted in Table XIV.

Shatter Properties

The results for the shatter test will be found in Table XIV, and since the 2-in. screen values give a more open scale than the $1\frac{1}{2}$-in., the former have been adopted for purposes of reference. There is a suggestion that cokes of small original size sometimes yield shatter values rather higher than the average. Results obtained several months before the present research commenced are also given and indicate reasonable regularity of values for the various brands.

There is a slight indication from Table XIV that the shatter indices are decreasing as the cupola merit of the coke decreases. Fig. 8 shows this effect graphically, and whilst the generalisation is to be taken very broadly, the authors find that shatter index is a more consistent guide to the merit of cokes from *any* coalfield than any other single laboratory test result examined in the present investigation. *Cokes with a shatter index (2 in.) of less than* 80 *have not given the best results in these trials and might always be viewed as doubtful for cupola purposes.*

It is difficult to establish a precise correlation between macrostructure and shatter value, but if the longitudinal fissures are distinct, long and clearly connected to a distinct system of transverse fissures enclosing only small prismatic areas of coke, then the shatter test result will be low. Thus it will not be surprising that coke K is the most easily shattered of the series.

The External Size

The external size and shape of the specimen also merit consideration, for if large pieces have

TABLE XIII.—*Nomenclature for Describing Macrostructure.*

	Descriptive terms employed (in order).
(1) *Form of pieces :*	
(*a*) Size	"Large," "medium," "small."
(*b*) Outline	"Roughly rectangular," "irregular," "segmental," "bent."
(*c*) Ratio of length to section—"prismatic index"	"Blocky," "fingery" or "prismatic."
(2) *Appearance of fissures in longitudinal section :*	
(*a*) Width	"Indistinct," "fine," "coarse."
(*b*) Extent	"Short," "long."
(*c*) Form	"Wavy," "straight."
(*d*) Spacing	"Widely spaced," "closely spaced."
(*e*) Degree of connection between different systems of fissures.	"Communicating," "disconnected."

TABLE XIV.—*Shatter Index and Form.*

Coke reference.	Average form of pieces.	Shatter index.			Fissuring in longitudinal macrostructure.	
		2-in. screen.	1½-in. screen.	Previous 2-in. screen values.	Transverse.	Longitudinal system.
L1	Large, roughly rectangular, blocky	85	92	85—88	Indistinct	Fine, wavy.
L2	Medium, do.	87	94	—	—	—
L3	Medium, do.	86	94	—	—	—
G1	Large, segmental, blocky	77*	88	84—85	Indistinct	Fine, long, disconnected.
G2	Medium, do.	85	93	—	—	—
P	Large, roughly rectangular, prismatic	93	95	87	Indistinct, short, wavy	Indistinct, short, wavy.
A	Large, prismatic	85†	93	85—87	Indistinct, short	Fine, f. long.
F	Large, roughly rectangular, blocky	89	95	—	Fine, widely spaced	Fine, long, wavy widely spaced.

C	Medium, roughly rectangular	86	93	79—83	Indistinct	Fine, long, diconnected.
I	Large, irregular, blocky	86	95	—	Indistinct	Coarse, wavy, disconnected.
H	Small, prismatic ..	88	95	—	Indistinct	Fine, short, wavy.
B	Small, prismatic ..	73	87	73	Fine, communicating ..	Coarse, long, straght.
E	Medium, blocky ..	84	93	81	Fine	Fine.
M	Small, irregular, blocky	89†	94	—	Indistinct	Indistinct, wavy.
K	Medium, prismatic ..	71	87	—	Fine, communicating, closely spaced	F. coarse, long, straight, closely spaced.
D	Large, prismatic ..	73	88	—	Indistinct	Fine, long, closely spaced.
J1	Small, irregular blocky	73	89	—	Coarse, communicating, wavy	Coarse, wavy, long.
J2	Medium, do	81	92	—	—	—
316	Small	87	94	—	Indistinct	Fine, disconnected.
317	Small	91	95	—	Indistinct	Fine, disconnected.

* This value is evidently low, and 84 would be more representative.
† Blended coke and not strictly comparable.

survived quenching at the oven and transport therefrom, the shatter resistance is likely to be good. In this respect it has been found that small pieces resulting from the shatter testing of large pieces have the same prismatic index as the latter.[3] Specimen I (index 86) (Fig. 6) is badly fissured but its shape is more promising than that of specimen J (index 73) (Fig. 7), and it is almost devoid of transverse fissuring. A quantitative system might aim at awarding marks to each coke for the various macrostructural features suggested above as contributing to shatter resistance, or alternatively a set of standard macrographs could be employed. If the average size of the coke is small it will tend to reduce the cupola temperature.

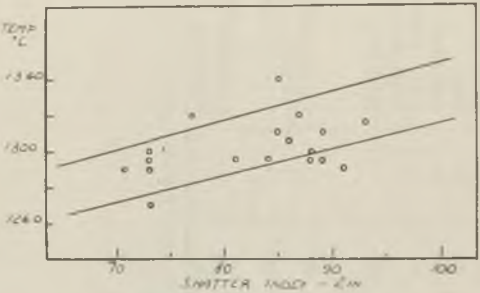

Fig. 8.—Shatter Index and Melting Quality.

Microstructure and Cell Hardness

Cokes with a high degree of combustibility are said[4] to have a high resistance to abrasion and a pronounced cell structure displaying continuity in the distribution of the cells and a large proportion of minute pores in the cell walls. Beilby[5] has similarly outlined the microstructural features favouring reactivity as (1) large area of reactive surface, (2) minute cells with thin cell walls and (3) accessibility of reacting gases to the interior of the coke. The authors have attempted to determine the cell size distribution and cell space ratio of the present samples.

Photomicrographs of Rose's sections × 6 (Figs. 5, 6 and 7) were traversed over an actual coke length of 1.66 cm. and the intercepts of black cell wall and white cell space determined. Fissures or black patches of mineral matter were avoided as much as possible in these measurements. The readings of two traverses were averaged, and the frequency-cell size curves obtained are shown in Fig. 9. The cokes have thus been divided into three groups according to cell size distribution, and whilst the division was readily made for most specimens, cokes **H**, **P** and **M** proved to be rather special cases. The results are summarised in Table XVI.

A method is now being tried for the rapid determination of cell space ratio similar to that used by Barkas[6] for wood. A photoelectric cell is fitted in place of the eyepiece of the Vickers projection microscope and the Rose's macro-section is placed on the specimen stage. In this way the ratio between black and white on the object can be determined.

A few experiments have also been made regarding the mechanical properties of the coke material when free from major fissures. It was felt that the static compressive strength and the abradability of *small* test-pieces were more likely to be associated with constitution and combustibility than mechanical tests on large specimens. Cubical pieces fractured in compression after their top and bottom surfaces had been bedded in the test machine with *ciment fondu* gave the results recorded in Table XV.

Grinding tests were made in an $11\frac{5}{8}$-in. by $4\frac{3}{4}$-in. dia. steel cylinder containing three $\frac{5}{8}$ in. dia. steel rods and rotated for a standard time of 2 hrs. at 30 r.p.m. The initial coke charge of 100 grms. was screened to be between B.S. sieves 8 and 16, *i.e.*, 0.081 in. and 0.0395 in. apertures, and the material was afterwards given sieving analysis up to B.S.S. 300. The increase of surface area or grindability index (C) was determined by Cross's method,[7] and for purposes of comparison the reciprocal of this may be considered as the resistance to abrasion.

TABLE XV.—*Properties of Cellular Structure.*

Coke Ref. in order of melting temp.	Apparent porosity.* Per cent.	Compressive breaking stress. Lbs. per sq. in.			Abrasion tests.	
		$\frac{7}{8}$-in. cube.	$\frac{3}{4}$-in. cube.	Representative value.	L.M.S. resistance index (10^6/C.).	N.C.R.C. resistance index‡ per cent. on 72 B.S.S.
L	46	1,670	1,560	1,610	65.5	66.0
G	45	—	3,050 1,469 1,555 1,665	1,560	—	65.5
P	48	—	1,158 1,220	1,190	—	57.0
A	48	1,210	1,295 1,270	1,280	64.5	61.5
F	48	—	—	—	—	—
C	46	1,760 2,280	1,040	2,020	75.5	68.0
I	47	—	2,800 1,553 1,665	1,610	—	61.0

H	50	1,560	1,210	1,560	—	63.5
B	43	—	—	—	—	55.5
E	45	—	1,610 1,610 1,360	1,530	74.0	66.5
M	46	—	1,550 1,700 1,665	1,640	—	57.5
K	40	—	3,610 5,410	4,510	57.5	59.5
D	48	1,870	2,480 2,380	2,430	65.5	62.0
J	46	—	1,610 1,760 2,060	1,810	61.0†	55.5
316	44	—	—	—	—	61.5
317	53	—	—	—	—	57.0

* Average of four "cage" tests. † Repeat gave 60.5: the others are single tests. ‡ Mean of three tests.

Prof. Riley (Northern Coke Research Committee) has kindly carried out micro-impact tests on the cokes by a method which he will shortly publish. Two grams of properly sampled material graded between B.S. sieves 14 and 25 are impacted with steel balls for 800 revs. in a tube rotating about its transverse axis. The breakage is determined by sieving analysis and the " micro-impact index " or resistance to abrasion is expressed as the percentage of original material remaining on B.S. sieves 25 and 72. The authors have taken the liberty of referring to the percentage on 72 B.S.S. alone as a simplified abrasion index. Results are given in Table XV, and it will be observed that the L.M.S. and N.C.R.C. abrasion tests agree quite well.

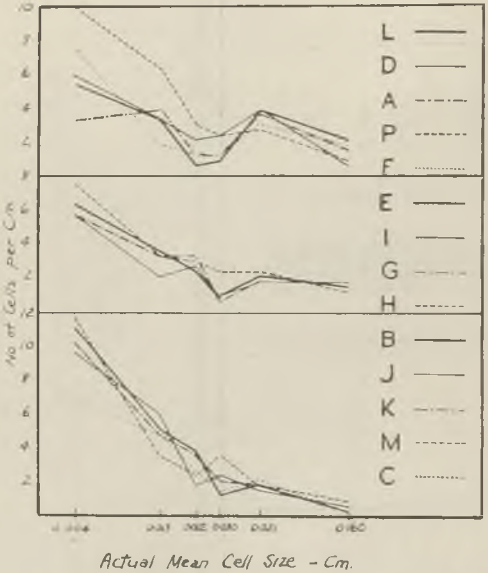

FIG. 9.—GROUPING COKES BY CELL SIZE.

TABLE XVI.—*Correlation of Tests.*

Coke reference.	Structural.			Thermal.		Mechanical.		
	Cell structure group (see Fig. 9).	No. of cells per cm.	Black cell wall. Linear per cent.	Cupola melting temp. Deg. C.	RI–RIII reactivity values.	Shatter Index. (2 ins.)	Compression strength. Lbs. per sq. in.	N.C.R.C. abrasion resistance. Per cent. on 72 B.S.S.
L	Rather open ..	16	50	1,330	45.0	85	1,610	66.0
F		17	52	1,310	35.0	89	—	—
A		15	54	1,310	34.0	85	1,280	61.5
G	Mixed	17	55	1,320	43.0	84	1,560	65.5
I		15	60‡	1,305	32.0	86	1,610	61.0
E		17	53	1,295	30.0	84	1,530	66.5
H		20	52	1,300*	17.5	88	1,560	63.5
C	Dense and uniform	18	68	1,305	−12.5	86†	2,020	68.0
J		22	67	1,270–95	−12.5	73	1,810	55.5
K		23	65	1,290	4.5	71	4,510	59.5
B		24	64	1,300	−17.5	73	—	55.5
P	Rather open ..	25	51	1,315	66.5	93	1,190	57.0
D	Do. (Beehive)	18	51	1,290	33.5	73	2,430	62.0
M	Dense	24	58	1,295*	62.5	89	1,640	57.5
316	—	25	51	1,295*	37.0	87	—	61.5
317	—	19	63	1,290*	71.0	91	—	57.0

* Coke was of small size and temperatures are liable to be low.

† Previous values for this coke are 79 to 83 (see Table XIV), and it is said to be variable.

‡ Unduly high value caused by large amount of black mineral matter in section.

TABLE XVII.—*H = high, L = low.*

Coke reference.	Cupola temp. H ≮ 1,305 deg. C.	Shatter index (2 ins.). H ≮ 80.	Wet oxidation test. H ≮ 187.	Openness of microstructure (per cent. black cell wall). H ≯ 60.	N.C.R.C. resistance to abrasion. H ≮ 60.	Reactivity test (RI–RIII). H ≮ 30.
L	H	H	H	H	H	H
F	,,	,,	,,	,,	,,	,,
A	,,	,,	,,	,,	,,	,,
G	,,	,,	,,	,,	,,	,,
I	,,	,,	,,	,,	,,	,,
H	M†	,,	,,	,,	,,	L
E	L	,,	,,	,,	,,	H
P	H	,,	L	,,	L	,,
C	,,	,,	,,	L	H	L
M	L	,,	,,	H	L	H
D*	,,	L	,,	,,	H	,,
B	,,	,,	,,	L	L	L
K	,,	,,	,,	,,	,,	,,
J	,,	,,	,,	,,	,,	,,

* Beehive coke.

† M = medium (see Table VIII).

Discussion of the Results

Table XVI has been drawn up largely on the basis of microstructural observations for comparison purposes. In an endeavour to obtain a hint as to where generalisations might be made, Table XVII has been prepared by arbitrarily selecting a division in the values of certain suitable tests below which the result is called " low " and above which it is " high."

It can be said fairly definitely that the three cold cupola cokes B, K and J gave low results for the five tests reported in Table XVII, and the converse tendency is noticeable for the hot cokes.

The negative and very low (RI—RIII) reactivity values for the dense uniform cokes, C, B, K and J are interesting, and indicate that the fuel becomes more reactive as it burns away. This suggests a relative increase of the surface area of the cell walls as combustion proceeds, possibly by pitting, in the manner suggested by Burrage,[8] during the activation of charcoal. The degree to which such pitting or surface enlargement occurs might well be affected by the micro-constitution of the bituminous conglomerate which was the source of the coke. A negative (RI—RIII) value is said to be abnormal and has previously been associated with beehive cokes by the Fuel Research Board.[2] From the same source has come the suggestion that low reactivity cokes are metallurgically desirable, and that low RIII values correspond with high shatter results. The present work within its own narrow limits does not confirm this suggestion. Mott[13] has reported that low reactivity gives high coke bed temperatures, but considers that the fuel size may be of greater importance than reactivity. A probable difficulty regarding the reactivity test is the selection of an arbitrary combustion temperature of 950 deg. C., for whilst it probably places cokes in the correct order of reactivity at this temperature, the order might be different at 1,300 deg. C.[9]. In this respect Riley[10] states that whilst below

TABLE XVIII.—*Test Results arranged According to Coalfields.*

Coalfield.	Coke ref.	Cupola metal temp. Deg. C.	Wet oxidation test.	Reactivity test.		Combustibility test. CO : CO$_2$ ratio.	Shatter index. 2-in. screen.
				RIII.	RI–RIII.		
Durham ..	316	†	218	70	37	0·71	87
	317	†	178	61	71	0·70	91
	L1	1,340	204	59	45	0.71	85
	G1	1,320	201	47.5	43	0.65	84
	A	1,310	194	55	34	0.66	85
	I	1,305	189 ↓	42	32	0.69	86
	H	1,300 ↓	208	46 ↓	17.5 ↓	0.60 ↓	88
Lancs ..	P	1,315	141	124	+66.5	1.01	93
	B	1,300 ↓	133 ↓	118 ↓	−17.5 ↓	0.76 ↓	73 ↓
S. Yorks ..	C	1,305	161	157	−12.5	0.84	86
	D*	1,290 ↓	150 ↓	55 ↓	+33.5*	0.58 ↓	73 ↓
S. Wales ..	F	1,310	217	43	35	0.55	89
	E	1,295 ↓	230	39	30	0.59	84 ↓
Scotch ..	K	1,290	167	54	4.5	0.83	71
	J1	1,270† ↓	144 ↓	27 ↓	−12.5 ↓	0.68 ↓	73

* Beehive coke, reactivity generally abnormal. † Results not representative.

1,000 deg. C. "amorphous" carbon is more reactive to oxygen than graphite, above 1,000 deg. C. the reverse is probably true.

As regards the combustibility test, the only observed point of interest was that the rate of combustion (and the $CO:CO_2$ ratio) appeared greatest with cokes P, C, M, J1, K and B, and these are fuels with the greatest number of cells per cm. (Table XVI). Support is not provided for the view[14] that a high rate of combustion corresponds with a low shatter index and a low apparent porosity test result (Table XV).

By considering the cokes on a basis of their native coalfields, certain tendencies have been isolated which are indicated in Table XVIII.

In a given group the cupola temperature decreased with decrease of wet oxidation, reactivity, combustibility, $CO:CO_2$ ratio, and shatter result. The carbon pick-up of the Durham cokes increased with their wet oxidation test results.

The fact remains that in spite of all the laboratory tests the safest method of judging an unknown coke of the present series is by means of a controlled practical trial. This view is supported by the results of the work of the Midland, Northern and Scottish Coke Research Committees, operating in conjunction with the Iron and Steel Industrial Research Council. Since this Report was prepared, a Paper summarising the work of these Committees has been presented to the Iron and Steel Institute by Evans and Ridgion.[11] The authors state ". . . it is frequently a matter of considerable difficulty to express quantitatively the difference between cokes by methods of testing at present available." They add that "the shatter test has proved a useful tool, but is not in itself completely satisfactory as a measure of the strength of the coke," and that "if anything, the information available suggests that cokes of high specific reactivity to gases are not desirable for cupola or blast furnace practice," and finally "Whilst laboratory tests have their value, the ultimate effective method of testing coke is in actual service." The same view is confirmed by recent German work.[12]

Quite apart from the conclusions to be drawn, it is thought that the data presented for a wide variety of tests will be useful in showing values obtained from a group of cokes from the principal coalfields for the period 1934-36, and the variations to be expected.

Summary

(1) Cupola results of the behaviour of fourteen different foundry cokes are given. A very complete laboratory examination of the cokes is also reported, special attention having been devoted to macrostructure and microstructure.

(2) Coke merit for a cupola charge ratio of 16:1 has been assessed on a basis of metal temperature. Certain cokes were proved to be as good as more famous brands of higher price.

(3) Determinations of the sulphur and carbon pick-ups from eight of the cokes were made in a small experimental cupola. Broadly speaking, the sulphur pick-up of the metal was directly proportional to the total, and to the combustible sulphur contents of the fuels. The carbon pick-up tended to increase with (*a*) the cell-structure openness; (*b*) the combustibility test rate, and (*c*) the fixed carbon content. Incidentally the fixed sulphur decreased as the wet oxidation test value increased.

(4) Cupola metal temperatures were determined to within about ±0.5 per cent., but the results for the best and worst cokes only differed by about 5 per cent. The field for correlating cupola and laboratory tests therefore proved unfortunately to be very narrow. Under these circumstances none of the tests can yet be relied upon to predict the practical cupola properties of a coke of unknown origin, but the most helpful in this respect was the shatter test.

(5) Correlations between the various tests themselves and the cupola results hint at the

following generalisations for these particular samples:—

Cokes giving *low* metal temperatures are *low* in:

(*a*) Shatter index.
(*b*) Rate of wet oxidation.
(*c*) (RI – RIII) reactivity value.
(*d*) Resistance to abrasion.

and *high* in:

(*a*) Density of cell structure.
(*b*) Resistance to static compression.

(6) If these few cokes are considered in groups of their native coalfields, the following generalisations suggest themselves:—

A *decrease* of cupola metal temperature is associated with a *decrease* in:

(*a*) Shatter index.
(*b*) Rate of wet oxidation.
(*c*) (RI – RIII) reactivity value.
(*d*) CO : CO_2 ratio in the combustibility test.

Acknowledgments

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DISCUSSION

The **Chairman** (Mr. F. J. Cook) said that this was a Paper the industry had been seeking for many years and one which perhaps had not carried the subject as far as one would have wished, but Mr. Millington, the originator of the research, was present, and he invited him to speak.

Wet Oxidation and Reactivity Factors

Mr. E. Millington said that, as Mr. Cook had referred to his having been responsible for this research in the first place, and although now retired from active service, it was with pleasure that he would make a few observations. He congratulated Dr. O'Neill and Mr. Pearce on the excellence of their report, which he characterised as a complete subject presented in masterly fashion. The origin of the report was based on previous work carried out by the L.M. & S. Railway Company, in which valuable, but inconclusive, results had been obtained. Since it was his duty to advise the buying department on the quality desired, this had to be based largely on the experience of the various foundries, with uneconomical results.

In view of his own work and that of others, such as the Fuel Research Stations, and the Northern Coke Committee, it was felt that a comprehensive research would be justified having for its object the formulation of a specification for the purchase of foundry coke having the desired properties. This proposal was discussed with Mr. Pearce, who welcomed the scheme with enthusiasm. All the known available tests as given in the Paper were brought in so as to cover the ground as far as possible. As to the results obtained, it was clearly shown that, apart from the physical side, such as the shatter, macro- and microscopic tests, little was to be gained from what might be described as the purely chemical side. But this was not known, and the research was justified in that it had at least cleared the ground for the time being. This did not dismiss from further study the ultimate service of the now rejected tests; on the other hand, it might intensify a closer study of these methods, such as wet oxidation, reactivity, etc. On reflection, it was perhaps not surprising that the chemical tests, and in a measure the physical ones also, had failed in their object. For, after all, it was the properties and the behaviour of the coke while in an incandescent state supporting a heavy burden, that one desired to know, and what might be satisfactory in the relative cold might be altogether different in the hot state. It was now possible to divide cokes into groups identifying their district origin, and by grouping the methods of testing to formulate a restricted specification. Up to the present, however, the ultimate tests rested with the cupola.

Finally, he would like to congratulate the members of his old staff for the excellence of their work, and to extend these to his friends of the British Cast Iron Research Association.

Routine Acceptance Tests

Mr. Pearce said he would like to say with what pleasure he looked back on his early contact with Mr. Millington on this research. The Paper proved that coke was just as complicated as pig-iron and cast iron. The Paper raised the question of the position of chemical tests, because he thought that analyses were the most common tests applied to coke. It could be stated that their value was that, when one bought coke, one wished to buy carbon, and if these tests were made, it could be stated how much of the outlay was being expended on that constituent. Also, chemical tests were very good checks on regularity from delivery to delivery. How far were these results applicable to the purchase of foundry coke? The answer was that in a limited degree, they were applicable. If one was compelled for transport reasons to buy coke wholly from one coalfield, these tests could definitely be used to sort out one coke from another. These results, of course, would not apply to blended cokes, and the future might provide further light on correlating the different fields. In a general way, the tests as a whole showed up the good cokes as the best, although an isolated bad result of one test on a coke would not justify its condemnation.

Melting Practice as Controlling Factor

Mr. Ben Hird said this subject was important, and no doubt all foundrymen would agree that bad coke would spoil the best of iron. Thus coke was a fundamental factor in producing good iron. It might be possible to use inferior coke for railway chairs, but the economy was very limited. To obtain good results, the best coke was necessary, especially if the castings were to be machined and subjected to pressure tests, and it would certainly prove to be the most economical.

He agreed with Mr. Millington that the future research in this subject would be in the direction of a close study of the reactions in the cupola during melting. One line of investigation suggested was the effect of the ash content. Was there a possibility that a high percentage of ash formed a slag when the coke burnt and covered the carbon particles, thus preventing proper combustion?

The most reliable test available was the shatter test. If a coke would not carry the burden of iron, and withstand the abrasion of the descending charges, it became disintegrated, and created bad melting conditions; this was especially important when mechanical charging of the cupola was used.

Cheap Coke May Give Satisfaction

Mr. Pearce said there was much to be said for the point that the best coke was the cheapest, but the L.M.S. foundries were now using cokes, the recommendations of which were based on this work, and, so far as he could say, no complaint had been recorded. The present situation with regard to coke must be considered, because foundries may be forced to use coke of a different or inferior brand from that to which they were accustomed. The situation was not as bad as during the coal strike, but all metallurgical assistance should be made use of in burning coke of a different kind from that obtainable under normal conditions. He did not think, with regard to the ash content, that the coating of slag on the coke would seriously interfere with combustion. It had been found in the blast furnaces that increase in the ash content of the coke had a much bigger effect than would be expected from the mere increase in the ash. The shatter test, too, had to be taken with some little reserve. On cupola coke it turned out to be the best available test, but the shatter test was not accepted by all experts as absolutely reliable on all cokes. The Committee which concerned itself with the Durham fields thought it very good, but the Committee concerned with the Midland fields was not so satisfied, and for that reason attention was being called to the Cochrane or drum test.

Influence of Coke Size

MR. J. ROXBURGH said that, as a foundry manager engaged on high-class engineering castings, it appeared to him that a great deal of the success of cupola coke, apart from the coke itself, depended on the efficiency of the cupola practice. Obviously, there must be a certain bed of coke, a certain separating charge, a definite volume of air, blast pressure and so forth, and he had definitely proved and always maintained in personal practice that the use of a good quality coke was essential. It was also necessary to have white hot metal, apart from the cost. There was no mention in the Paper with regard to the size of coke, and he felt that whether the coke was large or small or whether it was uniform in size, either uniformly large or small, had something to do with the successful use of coke. The authors of this Paper were to be congratulated on the work they had carried out, and if, as a result of the research, it had been proved that certain tests were of no commercial value, he still felt the work had been worth while, and if in the future, due to further research, tests were made which could be applied usefully in a foundry, he thought foundry managers would be only too pleased to have the knowledge of those tests.

Influence of Cupola Design

Mr. J. H. Cooper said he had personally given this subject great consideration and for many years he had carried out much research work on it. The point which had given him much concern in this Paper was the shape of the cupola in which the test has been carried out. In practice he found that to have a cupola to work well it was necessary to have at least a height equal to the diameter running straight above tuyeres. He found that gave the best conditions. He could not see how it followed that there was a difference in the analyses of the slag from 25 to about 6 per cent. FeO. There must be some reason for this variation. The sole idea, he thought, was to try and keep the tuyeres from becoming blocked. He did not think he had ever seen a cupola made in the form outlined in the Paper. Perhaps it was made for the test. Would the authors recommend in actual practice a cupola made to a design of this description?

The coke ratio was not much better than one had in Scotland. Some cokes were distilled to destruction, so there was not the same calorific value. Many foundrymen had adopted cupolas to work with square tuyeres which had given excellent results. He thought when using a cupola the chief points were to burn the coke to CO_2, reduce oxidation to a minimum and try to keep the tuyeres clean.

Mr. F. J. Cook said the primary object of the research was to see if the L.M.S. Railway could find a coke cheaper than the very high priced one they had previously used, and to see if they got value for money from the dearer material. This work afforded a very good opportunity to carry out a full research on the cokes being tried with a view to extending the knowledge of coke and its behaviour under standard working conditions.

Routine Testing

Mr. P. A. Russell said he had been extremely interested to see the results of this research, and he was particularly interested in the conclusion that there was nothing like a practical trial. Fortunately, it was not difficult for the average foundry to conduct this.

He endorsed the views expressed in the discussion that cupola control was more important than coke control, and his experience was that many complaints originally attributed to coke ultimately proved to be due to faulty cupola operation. There were instances when the coke was at fault, and for this reason he would like to know whether the authors had been able to evolve, as a result of these experiments, any improved method of "truck to truck" checking of coke supplies.

With reference to coke size, to which the authors referred, he agreed that large coke was preferable to small coke, even if the large coke had to be broken for use. He understood this to be because coke with good shatter value did not break up very much in transit. Another rough check on the strength of coke was to examine the dump at the end of the melt. This gave an indication of how the coke had stood up to the cupola conditions.

Mr. Pearce said it was very difficult to arrive at a definite figure for cokes and Table XIV gave the best possible statement with regard to the average form of the individual pieces. One of the earlier pieces of work referred to in the introduction was concerned with coke size and the authors did arrive at a conclusion. For a given size of cupola there was an optimum size of coke, but practically speaking it was difficult for foundrymen to control the size of coke. If bad, it got smaller in transit, and, if large, it was probably good, and it was doubtful whether it would break up in transit.

Continuing, Mr. Pearce said Dr. O'Neill had told him that the L.M.S.R. had not altered its procedure with regard to truck to truck checking. Mr. Russell's question was a pertinent one and the best result could be got out of this Paper by finding the best way of checking coke as deliveries were received. It was practically impossible to apply Rose's test as a routine test. The cokes which caused bad reports from the foundry were those which showed the variability of structure from sample to sample, under that test. The time distance from Ca to Cc was about two years and showed variability in coal and process of carbonisation.

Mr. Russell pointed out that the journey which the coke had to undergo was in itself a form of shatter test.

Shatter Testing

Mr. Bradley said that in the shatter test which he had found to be most consistent, the size of the coke definitely did affect the result, and small coke contents tended to give a high result and in that way the test was not too satisfactory. It was quite true that the shatter index, speaking generally, was the best test. He thought if he had a shatter index of not less than 80 on a 2-in. screen and not less than 90 per cent. fixed carbon, one could generally assume the cupola would run quite satisfactorily.

Small Coke and Loss of Melting Efficiency

Mr. J. Hird said a recent personal experience was rather interesting. He had trouble with cold iron and iron in the tuyeres. Finding that in the coke there was a lot of small pieces he tried a run the next day, but eliminated the small coke. He had exceptionally hot metal and no sign of iron in the tuyeres.

Mr. Pearce asked whether the coke was screened or hand-picked.

Mr. Hird said it was hand-picked, eliminating pieces below 3 in. by 3 in.

Mr. Pearce thought that was a very important point and actually bore upon blast-furnace practice, where the temperature rose if the fines were eliminated. He was indebted to Mr. Hird for making that point. Mr. Bradley's suggestion of 80 per cent. on a 2-in. screen for a shatter test formed a good working basis for coke without involving too much time in testing.

Mr. J. K. Smithson said some years ago he screened several trucks of blast-furnace coke and analysed the smalls separately, finding them to be very considerably higher in ash than the large coke. This factor no doubt explained to some extent the improvement in cupola working to which Mr. J. Hird referred when he had separated the smalls from his coke.

Mr. Smithson in a written communication gave figures (Table XIX) for three makes of average quality Durham Patent blast-furnace coke, showing the proportions of material under ½ in., over ½ in. and under 1½ in., and over 1½ in., together with the complete analysis of each size. The higher ash content of the smaller material is very marked, and it would seem that the value of this material in the cupola is very small, and taking into consideration the probable detrimental effects it seems that it will be well worth while to discard the smalls, which can be generally used for drying stoves, etc.

The higher ash content of the small coke seems to indicate or suggest that the tendency to breaking in handling and service may be in some degree connected with the size and distribution of the ash particles, and that this is a field for future investigation. Possibly the practical man who is not in a position to make chemical and physical tests of his coke will find that a record of the small coke from various makes will provide him with a fairly reliable criterion of their comparative merits.

Table XIX.—*Tabulated Results of Three Durham Blast-Furnace*

	Coke A.			Coke B.			Coke C.		
Size ..	Over 1½ in. 94.5 per cent.	1½ to ½ in. 2.5 per cent.	Under ½ in. 3.0 per cent.	Over 1½ in. 95.5 per cent.	1½ to ½ in. 2.9 per cent.	Under ½ in. 1.6 per cent.	Over 1½ in. 95.6 per cent.	1½ to ½ in. 2.2 per cent.	Under ½ in. 1.8 per cent.
Ash. Dried ..	12.30	13.40	31.60	10.00	11.70	19.80	10.40	13.00	23.30
Sulphur ,, ..	0.85	0.96	1.02	1.30	1.51	1.57	0.85	0.96	0.91
Volatile ,, ..	1.15	1.50	5.50	2.30	2.30	4.00	0.95	2.50	3.00
F.C. ,, ..	85.70	84.14	61.88	86.40	84.49	74.63	87.80	83.54	72.79
Moisture ..	6.50	10.50	12.50	2.00	7.10	10.20	4.90	8.95	23.00

Mr. Pearce said these figures were very valuable. It was obvious that screening could be applied to many foundries without wasting any of the consignment, because the small coke could be used up elsewhere.

A Member said if slag were covering coke, it would have the result of improving the combustion of coke, and he asked if the different types of coke could be screened and the different effects given.

Mr. Pearce suggested that Mr. Smithson's figures indicated what would be expected if this were done, in the light of Mr. J. Hirds' experience.

A Member raised the question of taking gas analyses at different levels in the furnaces, and **Mr. Pearce** said that had never been done, although it has been suggested and considered. In dealing with gas from a cupola, one was faced with not having the same conditions from point to point either horizontally or vertically. The furnace never seemed to arrive at the condition of equilibrium. Not only from point to point in the stack, but from instant to instant, there were changes in the analyses of the gas, and at present a personal view was that one could not attach much importance to cupola gas analyses. Done on a sufficient scale it would be justified.

Cupola Gas Analysis

Mr. Cooper said a method adopted in Germany was to take an ordinary sleeve brick and insert it at 45 degrees in the cupola approximately 4 ft. above the top tuyere. When the CO_2 was ranging from 16 to 18 per cent. and after the cupola has been blown in the test for gas was made, and it was so run until the cupola was blown down. A sleeve brick was used in conjunction with an ordinary iron tube and the gas could be taken through to the CO_2 recorder or gas apparatus. This was a most satisfactory method and quite reliable.

A vote of thanks was passed to the authors on the proposition of **Mr. Cook**.

THE ELIMINATION OF GASEOUS IMPURITIES IN ALUMINIUM

Paper No. 610

By Professor Georges Chaudron

[French Exchange Paper]

It is, indeed, a great personal honour to have been chosen to submit to the Conference an Exchange Paper, but at the same time it is a very heavy responsibility, because the author has devoted the whole of his activities up to the present to problems of chemistry, and he would be greatly at a loss if he had to deal with a question of direct interest to foundry practice. He has assumed that the Institute would be interested in some observations of a chemical or physico-chemical nature which the author has recently made, and which might have some more or less remote application to the very complicated practice associated with the foundry industry.

In the course of the last two years, there has been perfected in the author's laboratory a new method for the degasification of metals, by means of which it is possible in particular to effect the complete determination of the gases of aluminium.[1] [2] It was therefore considered that it would be possible to attack with new and more powerful means an important problem, which is that of the gases in aluminium. This problem may be divided into two parts:—

(1) To ascertain the value of the usual methods for the degasification of aluminium; and

(2) To provide the conditions enabling this metal to be remelted without recharging it with gases.

Actually, the foundry industry can procure aluminium of a very high degree of purity, but it must be pointed out at once that neither the hydrides, the carbonyls, nor even the nitrides are determined. In many foundry operations, however, gases may give rise to blow-holes which render the castings useless. It is a well-known fact that these gases are chiefly liberated at the moment of solidification, and it has rightly been said that in many cases it may be quite deceptive to have a purity corresponding to 99.99 if the last hundredth part consisted of gases.

The New Discharge Method of Degasification

Before describing this new method of degassing metals, it is desirable to recapitulate some experiments on the extraction of gases *in vacuo*. It has been clearly proved by numerous authors[3] that extraction in the solid or liquid state, even in very high vacua, has always been an extremely lengthy and incomplete operation.

A. Villachon[4] has studied this question with aluminium, and has shown that it is possible to remove the maximum amount of gas by heating in the solid state, but that, even after experiments lasting several months, extraction is still very incomplete. A discussion on the causes of this failure would seem profitable. The extreme slowness of the removal of the gases has been explained by attributing it to the low rate of diffusion of the gases in the interior of the sample, especially when the metal cannot be raised to a very high temperature. There is, however, an observation which contradicts this hypothesis and which indicates that the diffusion is appreciable even at the ordinary temperature. For instance, a sample of aluminium may be heated in a very high vacuum at a temperature of 550 deg. C., the gases being removed as fast as they are liberated. This experiment can be continued until a point is reached where no further appreciable removal of gases is observed. It is then found that each time the sample is left for some hours at the ordinary temperature, the extraction being arrested, a fresh liberation of gas is observed on subsequently reheating the sample. This experiment may be repeated a very large number of times, which obviously proves the existence of an appreciable diffusion at the ordinary temperature.

It was therefore thought that the liberation of gases was particularly difficult when the gases were leaving the boundary of the metallic lattice, and that, in short, a mass of metal could be imagined as being surrounded by a skin which is not very permeable to gases. Physicists explain that at the boundary of the metallic lattice there exists a potential barrier which would play the part of this skin exactly.

The author has advanced the hypothesis that if this potential barrier could be disturbed, it would be possible to extract rapidly the gases enclosed in the metal, and to do this he has employed the bombardment in a discharge tube where the projectiles were ions and electrons. The sample to be degassed is made the cathode in a discharge tube. For many reasons, which it would not be of interest to enlarge upon here, a bulb of rather large diameter and of very definite dimensions was selected (Fig. 1). This bulb is connected to a mercury vapour pump which delivers into a cascade of mercury enabling the gases removed to be collected. The electric discharge passes at a very low intensity —a few milliampères—and at a tension which may be as high as 130,000 volts. It is important to note that under these conditions the bombardment of the sample does not produce any appreciable rise in temperature. This cold extraction is of the greatest interest because it is thus possible to investigate the part played by the gases in the metal; for example, their influence on the electrical conductivity, the mechanical properties and the dimensions of the lattice, but that has been studied by others,[5] and it would be digressing to discuss it further.

It is necessary to point out that in order to effect the degasification, it is by no means necessary to bombard the whole of the surface of the sample. On the contrary, it is possible, for instance, to extract all the gases from a long

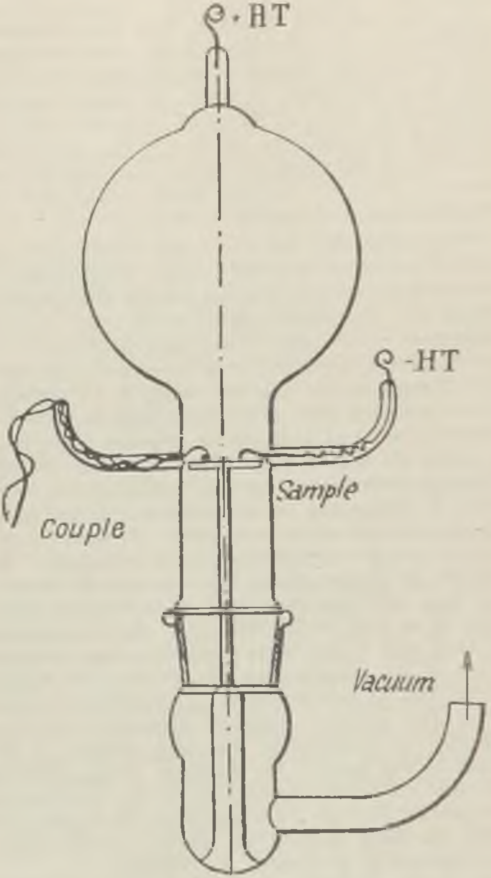

Fig. 1.—Discharge Tube for the Extraction of Gases.

aluminium wire by introducing a very short length into the tube, or, again, it is possible to effect the degasification of a long aluminium strip by coiling it and then placing it in the discharge tube. These experiments show clearly that diffusion may take place in the cold. Finally, this method enables much greater quantities of gases to be extracted from aluminium than the amounts obtained by previous investigators in this field.

TABLE I.—*Comparison of Gas Extraction Results obtained by Various Processes.*

Method of extraction.	Volume liberated per 100 grams. Ml.
Heating at 600 deg. C. for 1 month in a vacuum higher than $\frac{1}{100}$ mm. of mercury	12.5
Fusion and extraction in a vacuum higher than $\frac{1}{100}$ mm. of mercury ..	20
Discharge tube	192

Comparison of the Volumes of Gas Extracted by Heating *in vacuo*, by Fusion *in vacuo* and by the New Method

Table I summarises the author's results on the same sample.[6]

The nitrogen which is combined with the aluminium in the form of nitrides may be estimated by the following well-known method:—The metal is dissolved in caustic soda the solution is boiled and the ammoniacal vapour is collected in a titrated liquid. It was of interest to ascertain whether the new method of extraction gave the same results as the chemical method. It will be seen from Table II, which summarises some experiments, that the relationship A + B = C is substantially confirmed.

The results given in Table I confirm that heating *in vacuo*, either in the liquid or solid state, does not allow of a complete degasification of aluminium, in fact, it may be said that this is far from being the case.

Comparison of Industrial Methods of Degasification

It is now proposed to consider the simple methods which have very often given practical results, namely, those in which an inert gas is bubbled through the liquid metal, and the methods in which the liquid metal is stirred with fluxes. Table III summarises the results obtained.

None of these methods produces a metal freed from its gases, but there is obviously an appreciable reduction in the contents, the nitrogen figure having decreased by about 50 per cent. Practice has shown, however, that metals thus treated and therefore only partly degasified have given every satisfaction.

TABLE II.—*Gas Extraction results from Diverse Processes.*

	The nitrogen is calculated in ml. per 100 grams of metal.		
	A.*	B.	C.
Aluminium, 99.99 per cent. pure	7.2	3.1	10
Commercial aluminium, 99.7 per cent. pure ..	12.5	2.8	13
Calcium (99 per cent. pure, sublimed)	45	55	118

* A denotes the nitrogen extracted by new method. B the nitrogen determined chemically after extraction, this being therefore the residual nitrogen, because in these experiments which were carried out at the commencement of the investigations, degasification was not carried to completion. C denotes the nitrogen determined chemically on the initial metal.

It is found in fact that these partly degasified metals no longer exhibit any blow-holes after solidification, even if the latter is effected *in vacuo* (" Rochage "* *in vacuo*). This test is, in fact, extremely sensitive, solidification takes place in a vacuum of the order of one millimetre of mercury, and therefore under these

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* " Rochage " is the quantity of gas liberated on solidification It is sometimes accompanied by spitting, as in the case of oxidised silver.—V.C.F.

Table III.—*Gas Evolutions under Diverse Conditions.*

No. of test.	Metal tested.	" Rochage," *in vacuo.*	Degasification by discharge.					Nitrogen by chemical method. Ml.
			Nature of gases—ml. per 100 grams of metal					
			Total gas.	CO_2.	CO.	H_2.	N_2.	
1	Original metal, Al 99.5 per cent.	Gas evolved ..	231	14.5	42.25	152	17.75	11.8
2	Metal stirred with a flux ..	No gas evolved	175	4.9	35.0	128.9	6.0	4.9
3	Metal chlorinated by bubbling chlorine through ..	No gas evolved	175	5.6	38.0	123.35	8.05	5.6
1	Original metal, Al 99.7 per cent.	Gas evolved ..	205	5.0	53.7	130.3	16.0	12.0
2	Metal stirred with a flux ..	No gas evolved	165	4.1	33.9	119.6	7.4	6.5
3	Metal chlorinated by bubbling chlorine through ..	No gas evolved	173	4.8	45.3	115.0	7.5	5.2

conditions any bubbles which would tend to form would occupy a volume several hundred times greater than at atmospheric pressure—theoretically almost 760 times greater (Figs. 2 and 3).

For the practical details of this test, ("Rochage" *in vacuo*), reference should be made to an article by the author's collaborator Moreau.[7] Reverting to the nitrogen determinations indicated in Table III, it should be noted that, in the first place, there is a fairly good agreement between the results found by the discharge method and the results found by the chemical method. It should be noted, however, that the nitrogen estimated chemically is always smaller in quantity than the total nitrogen as determined by the discharge method, whence it may be concluded that very probably some of the nitrogen is occluded in the metal and is not combined with the aluminium. Finally, these nitrogen determinations show that the content of 5 ml. per 100 grams appears to be a limit of solubility. Above this content, it would seem that the nitrides are free in the liquid metal, because they can be removed from the aluminium by filtration. The same observation has been made in the case of magnesium.[8]

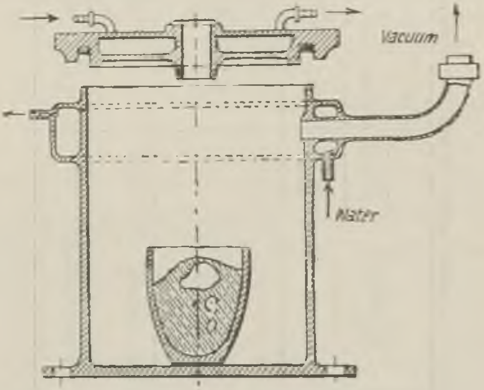

FIG. 2.—VESSEL FOR CARRYING OUT THE "ROCHAGE" TEST *in Vacuo*.

TABLE IV.—*Influence on " Rochage " of Bubbling Various Gases through Liquid Aluminium.*

No. of test.	Metal investigated, electric furnace method.	" Rochage," *in vacuo.*	Gas extracted by discharge degasification. Ml. per 100 grams metal.					Nitrogen evolved by chemical method. Ml.
			Total gas.	CO_2.	Co.	H_2.	N_2.	
1	Original metal, Al 99.7 per cent.	Very slight gas evolved	137	2.8	30.2	98.0	6.0	*6.4*
2	The same, treated with flux	No gas evolved	124	3.2	27.0	90.5	3.4	2.8
3	Bubbling H_2 at 950 deg. C.	Gas evolved	167	3.0	33.0	*127.0*	3.9	3.2
4	Bubbling CO at 90 deg. C.	Gas evolved	167	3.0	33.0	*127.0*	3.9	3.2
5	Bubbling CO_2 at 950 deg. C.	No gas evolved	127	3.0	32.0	88.0	4.2	3.9
6	Bubbling dry N_2 at 950 deg. C.	No gas evolved	127	3.0	32.0	88.0	4.2	3.2
7	Bubbling moist N_2 at 950 deg. C.	No gas evolved	127	3.0	32.0	88.0	4.2	3.4
8	Bubbling N_2 at 1,200 deg. C.	Gas evolved	127	3.0	32.0	88.0	4.2	*18.6*
9	Bubbling NH_3 at 900 deg. C.	Gas evolved	127	3.0	32.0	88.0	4.2	*40.0*
10	Aluminium nitrided with NH_3	Gas evolved	128	3.0	29.0	80.0	15.4	*17.6*

It certainly seems that the nitrogen content may suffice to indicate whether a metal is unsafe to employ in the foundry, and, as will be shown later, will clearly demonstrate that the other gases in excess may act in the same way. Above certain contents, which are comparatively high, of carbon monoxide and hydrogen, the metal may likewise spit.

Influence of the Composition of the Gaseous Atmosphere and the Melting Temperature on the Gas Content and on the "Rochage" of the Metal

In these experiments, two factors were varied in succession:—

(1) The metal was melted in an electric furnace and, while the temperature was maintained constant, a given gas was introduced, and

(2) For a given gas bubbled through, the temperature was varied.

Fig. 3.—Section of Aluminium Ingots after the "Rochage" Test *in Vacuo.*

This programme of work has not yet been completed, but it is considered that there are sufficient facts already available to enable several conclusions to be drawn from them. Table IV summarises these experiments. It may be said that below 900 deg. C., employing temperatures between 800 and 850 deg. C., it has not been possible appreciably to charge the metal with gas, but above 900 deg. C. the mere fusion in a blower-operated gas furnace of a sample of aluminium which originally did not exhibit any "Rochage" is sufficient to render it gassy. It has, on the contrary, been possible to effect several successive fusions in the electric furnace without observing any charging with gas provided 950 deg. C. was not exceeded. These experiments are summarised in Table V.

These experiments clearly show the advantage of heating in the electric furnace. An electric furnace was used having a nichrome resistance, whilst the atmosphere above the crucible was air which could only be renewed with difficulty because the refractory tube employed as a muffle was carefully closed with an asbestos plug. From the figures in the second column of Table V, it will be seen that a very slight formation of nitride occurs between 900 and 950 deg. C., but the action of the nitrogen (molecular nitrogen) is only rapid well above 1,000 deg. C., as may be seen from experiment 8 of Table IV. Hydrogen and carbon monoxide combine much more rapidly with aluminium even at 950 deg. C., as shown by experiments 3 and 4 of Table IV. Nitrogen, or more exactly nitrides, are therefore not the only cause of the spitting of aluminium.

TABLE V.—*Showing Influence of Temperature.*

Nature of the metal and treatment.	N_2 ml. per 100 grams.	" Bell-jar " test.
Original metal	4.8	No gas evolved.
Same metal melted in the gas furnace (T. 900 to 950 deg. C.)	10.3	Gas evolved.
Same metal melted in the electric furnace (T. 900 to 950 deg. C.)—		
1st melting	4.8	No gas evolved.
2nd ,, ...	5.2	,, ,,
3rd	5.2	,, ,,
4th ,, ...	5.6	,, ,,

These experiments clearly show that the solubility of the hydrides, carbonyls and nitrides of aluminium increases with the temperature, but that this solubility is still very high in the liquid state in the vicinity of the melting point, and even in the solid state. The sole effect of practical methods of degasification is therefore to destroy the supersaturation acquired at high temperatures. It would certainly appear that the foundryman has nothing to fear from gases properly dissolved in the metal (that is to say, in equilibrium with the latter). The author will not give any advice from the practical point of view, but certain conclusions follow from these experiments:—(1) Overheating of the aluminium is the first enemy of the foundryman; and (2) gases of combustion must not come in contact with the metal.

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COMMUNICATIONS

Mr. F. Hudson wrote that all foundry metallurgists should be particularly indebted to Prof. Chaudron for his most interesting Paper. The problem of the gaseous impurities present in metal was a most important one, having a considerable bearing upon practical production problems, and it was a problem for which the average metallurgist had usually little facilities available for developing in the manner it deserved. In the foundry it was being increasingly recognised that gases played a large part in the successful production of castings, and whilst the practical worker would do as much as possible to counteract their effect, he must look to men like Prof. Chaudron to supply knowledge on the various fundamental factors entailed.

In this present Paper perhaps one of the most important facts brought to light was the doubtful value of tests conducted in vacuum, and one sincerely hoped that the discharge tube method might in the future be extended to the investigation of metals other than aluminium. If this could be done it would be of infinite value to the practical worker, particularly with respect to alloys containing nickel such as the straight nickel-copper alloys, which were extremely susceptible to the effects of gas absorption and furnace atmosphere.

Mr. A. Dunlop wrote that he had read Prof. Chaudron's Paper with very great interest, and was sure this contribution to the knowledge of gaseous impurities in aluminium would help towards the overcoming of this problem. He was particularly interested in the methods described for the determination of the gaseous content of aluminium. As pointed out in the Paper, the amount of damage done by the presence of gases in the metal was out of all proportion to the amount present, taken on a percentage basis.

With the "spark" method of degasification, used in conjunction with the bell jar test, much information regarding the efficiency of the practical methods used in the foundry for the removal and protection of the molten metal from gaseous impurities could be obtained. He would be very pleased if Prof. Chaudron would give a few more details of the bell jar test, and if he would say if he considered that this test could be applied to other alloys such as high nickel-content bronzes.

Mr. J. S. G. Primrose wrote that he considered the principal idea in the Paper showed clearly that there was usually much more gas content in cast aluminium than was generally shown by the ordinary method of analysis. The very interesting method of electron bombardment might seem fantastic to a foundryman, but the results quoted in the several tables given in the Paper brought to light a fact which could not be ignored in practical founding. That there was nearly ten times as much gas remaining in the solidified metal as was formerly estimated, made the present methods of partial degasification in the endeavour to eliminate pin holes appear almost futile, and the success in producing sound castings must therefore appear to be mainly due to careful melting practice, such as was recommended at the close of the Paper. Undoubtedly the care taken not to overheat the melt was very important, and the second claim that gases of combustion must not come in contact with the metal was much more difficult of accomplishment except in the case of the ideal electric furnace melting. Once the damage was done and the gases, which appeared to be chiefly carbon monoxide and hydrogen, were in solution in the molten metal, it would be a very useful application of the "spark" method of showing their presence, if it could be devised to extract them thoroughly from the metal before pouring it into the casting. Perhaps the author could state if the application of electron bombardment to molten metal in a crucible contained in a high vacuum would have the same desirable effect in extracting the dissolved gases as his results in Table I showed that it had on the solid metal.

Author's Reply

Prof. G. Chaudron wrote that he was extremely interested in the remarks following the presentation of his Paper. He wished to emphasise that the method of determining of gases called the "spark test" had already been utilised in his laboratory for metals other than aluminium, and especially by his collaborator, Mr. Moreau, who had used this process for the determination of hydrogen absorbed by iron in the course of cutting-off runners and risers by the oxygen blowpipe. Mr. Moreau's work had also covered the gas contained in magnesium, gold, copper, silver, palladium, platinum, etc. All these results would be printed in his thesis for his doctorate, to be published next month.

In reply to Mr. Dunlop, who asked if the bell-jar method of testing could be generally applied, it was possible to state that this method had given good service in the laboratory for the practical testing of magnesium and its alloys, as well as for copper and certain of its alloys. Every time, however, there was a new adjustment to make, it was necessary to choose a suitable crucible which did not react with the metal and also to determine the temperature at which the vacuum had to be created. Mr. L. Moreau had carefully set out the conditions for the list so far as aluminium was concerned.

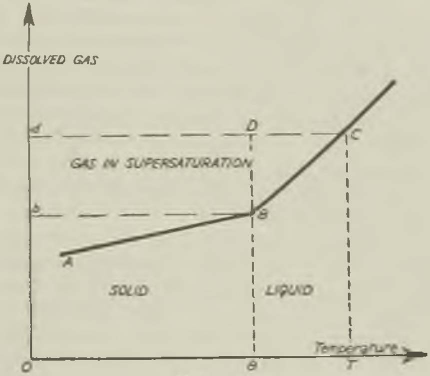

FIG. A.

The "spark" method of gas extraction did not apply only to metals in the solid state. It could serve equally well for degassing metals in the form of very thin sheets or small diameter wires. This method was completely different from that which consisted of bombarding metal with electrons and of thus heating it to a very high temperature *in vacuo* (degassing by wireless valves). For the spark method the metal remained virtually at room temperature.

Finally, the author stressed again the cardinal conclusion of his researches, *i.e.*, that the "spark" method allowed the determination of the gas content in aluminium, but in comparing the results obtained with those given by the bell-jar method, it was shown that all gases did not play the same part in the foundry. Those which appeared to enter into the category of "supersaturated" left the metal at the moment of solidification and gave rise to blowholes. The others remained in solution in the solid state and had no appreciable influence on the properties. The classical diagram which showed the solubility of hydrogen in the solid and liquid states in aluminium was well known. Such a diagram showed a distinct discontinuity at the melting point of aluminium. It was not thought that this discontinuity was of great importance, but that the "rochage" (evolution of gas at solidification) was simply due to the evolution of dissolved gas at high temperature, that was to say, by supersaturation.

The diagram, Fig. A, was therefore put forward, and on it were shown sections of the curve AB and BC which met at the point B, the melting point of aluminium. The curve BC, which corresponded to the liquid state, showed that the solubility of the gas increased very rapidly with the temperature. Metal taken to the temperature T absorbed a volume of gas corresponding to the ordinate of the point C. By rapidly cooling and without stirring (or churning), one could arrive at the point shown at D. During solidification the gas in supersaturation corresponding to *d b* was evolved. That was the "rochage" of aluminium. The metal, however, retained a quantity of gas of which the value was given by the ordinate of point B.

It should be pointed out that for other metal, the "rochage" could be due to other causes, as, for example, in the case of copper. Here there was a reduction of the oxide by hydrogen dissolved in the metal and in the case of silver by a brusque change in the solubility of silver oxide.

REMELTING ALUMINIUM IN THE FOUNDRY

Paper No. 611

By H. Röhrig

[German Exchange Paper]

Metals are valuable materials, and aluminium, which can only be converted into the metallic state at the expenditure of considerable quantities of electrical energy, is indubitably one of the most valuable metals employed in industry. The remelting of aluminium therefore signifies the preservation of values, and this object will be accomplished more completely the more the losses are reduced in quantity and the better the quality of the original metal can be preserved or restored.

The principal objects to be achieved in remelting are accordingly:—(1) Preventing loss of substance; and (2) preserving or restoring the quality. Before proceeding to discuss the factors which are materially responsible for attaining these objects, some of the features wherein aluminium and its alloys differ from the heavy metals with regard to remelting will be considered.

Whenever any of the heavy metals that are of importance in foundry practice have been rendered unfit for normal remelting by impurities or by additions made for alloying purposes, they can be refined by reducing processes to give a metal of restored value. At some moment, therefore, they disappear from the scrap-metal market. In the case of aluminium, such a possibility does not exist if one excepts the method, so far only considered theoretically, of reconverting this metal into virgin metal by electrolytic refining, employing the Hoopes process. In the case of this light metal, therefore, the supply of scrap metal must necessarily increase as the production of new metal increases. Thus, in the United States of America, where the collection and remelting of scrap aluminium would appear to be organised better than in any other country, the proportion of remelted aluminium during the last few years has been 46 per cent. of the total production.

New Difficulties

A factor which is also characteristic of the light metals concerns the variability of the composition of the scrap metal. During the first decades of the use of aluminium, the scrap metal substantially contained as alloying components either copper or zinc, or both these heavy metals together. Iron also occurred as an impurity, this being partly due to the application of inappropriate remelting conditions. With the extended use of Silumin or Alpax, silicon appeared in addition to copper and zinc. Foil constituted an important source of lead and zinc as impurities in scrap aluminium, since aluminium foil mixed with tin or lead foil is often melted. Nickel appeared in the remelted aluminium alloys, particularly after the introduction of Y-alloy and the RR-alloys, and magnesium is becoming increasingly noticeable as an impurity of scrap aluminium now that alloys of the type of Magnalium and Birmabright have gained importance. This development has occurred in the space of a few decades and is still continuing. An example of this is the scrap with an oxide film produced anodically. The rapid development of new types of alloys thus produces fluctuations in the nature of the scrap metal, while a further consequence is that the scrap metal alloys often do not correspond, even fundamentally, in their composition with the new alloys, but lag behind them.

A factor which increases the difficulty of collecting and sorting scrap consisting of aluminium and aluminium alloys, unlike heavy metal scrap, is that the colour of the various kinds is the same or only differs slightly. Copper and brass and the numerous kinds of brass and bronze are easily distinguished, but to differentiate aluminium alloy scrap containing zinc or silicon, especially when the pieces of scrap metal are oily and dirty, is only possible with the aid of expert knowledge, and even then not without certain expedients, such as chemical spot tests.

A further difficulty, which is not of importance in the case of either copper, brass or bronze, is that aluminium alloy scrap often has a coating of paint, which not only gives rise to difficulties in sorting, but is a source of trouble during melting and favours the absorption of gases.

Finally, it may be mentioned that in the case of light metals, it is necessary to take into consideration the fact that it is almost impossible to eliminate unwanted alloy components during remelting. It must therefore generally be expected that any metallic components contained in the charge will reappear in the ultimate melt. If necessary, they may be diluted by the addition of pure aluminium, and the proportion in which they are to exist together may be predetermined by suitable mixing of different portions of the scrap metal. For this purpose, however, it is indispensable to know exactly the composition of the individual portions melted, and this can only be attained if careful analyses are first made by skilled chemists. It is necessary to add that, as far as the author is aware, there is one exception to this. Magnesium may be eliminated from an aluminium alloy by two different methods even under normal melting conditions, that is to say, without superheating the melt and without diminishing the air pressure. It may be converted into magnesium sulphide by introducing copper sulphide into the melt and thence may be caused to pass into the slag, or it may be caused to react with a heavy metal chloride, for example, manganese chloride, volatile magnesium chloride being formed. In both cases, the removal of the magnesium is secured at the expense of introducing another metal into the melt. In certain cases, however, this substituent metal may be less troublesome than the substituted metal, while in addition the conversion of manganese chloride to manganese is accompanied by an effective degasification and purification of the melt.

A Complex Proposition

The enumeration of the factors which make the remelting of aluminium and aluminium alloys more difficult than the remelting of heavy metals could be continued a good deal further. Mention may be made of the pronounced tendency of aluminium to oxidation and the readiness with which it absorbs gases, particularly hydrogen. But even apart from this, no one can deny that, more than in any other fields of remelting, the remelting of aluminium alloys is a job which only the really experienced expert is capable of performing satisfactorily, and that any mistakes which may be made have their repercussions more so than in other fields. It is not intended to deal here with the wide field of remelted aluminium in its entire breadth and scope, that is to say, the various sources of scrap, dross and ash, their sorting, purchase, evaluation, and so forth. These are problems to which special firms devote their attention and which furthermore have already been dealt with excellently in the pertinent literature.* It is thus preferable to confine the subject to cases where alloys are melted and made into castings from the works' own scrap or other scrap of known composition and nature. The alloys offered for sale by the remelting works, if their use in the foundry is not to give rise to difficulties, should be supplied with reliable analyses, and they should also have passed through a carefully conducted process of purification in order to free them from gas and oxide. Of course, the composition of such alloys put on the market by remelting works can only be checked, if necessary, with the assistance of a chemical laboratory, while the gas content may be checked by close observation of a carefully machined and

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* "Secondary Aluminium," by R. J. Anderson, D.Sc., Cleveland, Ohio. 1931.

polished section of the ingots. The gas content may also be estimated by observing the surface of a slowly freezing sample of metal, *i.e.*, one cast in a mould made of non-metallic material, such as sand or carbon, or finally by applying a test in which the metal is allowed to freeze in a heated mould *in vacuo*. Each test in which the metal under investigation is melted is, of course, only reliable if the melting operation itself has been carried out with the necessary care; in other words, if the melting temperature was not too high and the furnace atmosphere was satis factory, and in particular was free from wate vapour or hydrogen.

Standardisation Would Help

The selection and handling of remelted alumi nium would be facilitated very considerably if standardisation of the composition were to be introduced on a wider scale than up to the present in many countries. In doing this, it is not sufficient merely to fix the minimum and maximum values of the desired alloy constituents, such as copper, zinc, silicon, manganese or others, but, on the contrary, it is also desirable to fix a reliable upper limit for the unwanted metallic impurities, such as tin, lead, iron and others. For a long time, no method was available for the reliable determination of the oxide content of aluminium alloys, but it is probable that the method recently described by G. B. Brook and A. G. Waddington* enables the oxide content to be determined in a dependable manner.

PRINCIPAL OBJECTS IN REMELTING

Preventing Metallic Losses

Oxidation is the principal source of the loss of metal. The lower the melting temperature and the purer the metal, the less the oxidation. Under normal conditions, aluminium and its alloys should not be heated above from 730 deg.

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* "The Determination of Alumina in the Presence of Metallic Aluminium," by G. B. Brook and A. G. Waddington. J. Inst. of Metals, Vol. 4, Part 4, April, 1937, 772.

C. to 750 deg. C. It seems that certain impurities, such as sodium, calcium and even magnesium increase the tendency of aluminium to oxidation. When a melt was maintained at constant temperature and vigorously stirred from time to time, it was observed that the thickness of the oxide film newly formed on the surface gradually diminished, the longer the melt was allowed to stand, and it was also found that the sodium content of the melt gradually fell. The sodium was found again in the oxide films removed from the melt.

Oxidation of aluminium occurs to an undesirable extent even before melting if, through unsuitable storage, aluminium scrap is exposed to the action of moisture. Since the resulting corrosion products contain water, the absorption of hydrogen by the melt will also be considerably promoted in this case. Metal containing hydrogen, in other words gassy metal, can only be made fit for use again if it is kept in the molten condition for a long time at the lowest possible temperature and in a satisfactory furnace atmosphere. This prolonged melting period in its turn again results in oxidation to a certain degree.

Loss of metal through oxidation also occurs when sheet, turnings, wire and so forth are melted direct, *i.e.*, when they are not placed in an already existing bath of molten metal. There is no need to comment specially on the fact that the numerous tough oxide films formed on sheet metal scrap under the action of the furnace atmosphere, when the scrap remains exposed to the air until it melts, remain very stubbornly in the melt.

Use of Fluxes

Despite the fact that the oxygen in the furnace atmosphere contributes to the oxidation of the metal, it is generally inadvisable to melt with a reducing flame, because the absorption of gas by the melt is thereby promoted. As a general rule, a slightly oxidising furnace atmosphere is to be preferred. The loss of metal is mainly due not so much to direct oxidation as to the fact that the oxide films enclose particles of metal and prevent them from coalescing. Suitable fluxes are employed for liberating these enclosed droplets of metal. Such fluxes should be capable of dissolving and slagging the oxide films—any reduction is, of course, out of the question. For this purpose, they must have a sufficiently low melting point. Fluxes which only melt above 750 deg. C. are usually just as useless as those which vaporise below 600 deg. C. Cryolite possesses a high solvent action for oxide, and really useful fluxes are produced by mixing it with common salt and potassium chloride for lowering its melting point. The use of calcium chloride is only advisable if there is certainty that this hygroscopic salt will not introduce any moisture into the melting furnace, which would cause the metal to be gassy. Zinc chloride is frequently employed as flux for light metal melts, probably not least of all on account of its cheapness, but it should be remembered that its effect may be impaired by a water content, since this salt tends to absorb water from the air during storage, while, furthermore, it should be borne in mind that zinc chloride reacts with the molten aluminium and that zinc is absorbed by the metal treated with this salt.

In this connection, it should also be mentioned that treatment of the melt with halides which react with it, resulting in reduction of the salt, also appears to effect a diminution in the sodium content of the melt. This is indicated by the fact that a melt of the modified eutectic Al-Si alloys (Alpax) rapidly loses its improved properties by treatment with a certain quantity of a heavy metal chloride, so that the castings subsequently exhibit the coarse fracture of unimproved Al-Si alloys.

Phenomenon of Dross Incandescence

Melters of aluminium are all acquainted with the incandescence of the dross floating on the bath of metal which occurs when the hot dross comes into contact with the air. Various attempts have been made to explain this phenomenon of incandescence, the existence of a suboxide of aluminium having even been suggested. Probably the most obvious explanation of the phenomenon is that metallic aluminium dispersed in the dross in a very fine state of division burns when it comes into contact with the air. The occurrence of this phenomenon in the melting furnace should therefore be regarded as a sign that the furnace atmosphere contains too much oxygen. A further consideration possibly connected with this phenomenon is the following. In the reaction which is accompanied by incandescence, the oxide is converted into a corundum-like modification of high specific gravity and considerable hardness. The high specific gravity causes these portions to sink into the interior of the molten bath, and it is no longer possible to remove them by skimming the bath. The extreme hardness is noticeable when castings made from such melts are machined with cutting tools. Probably nobody would attribute to normal inclusions of oxide films the fact that the cutting tools lose their edge, such films being far too soft and thin to damage the cutting edge of a chisel or drill, but this would, on the contrary, require the compact inclusions of the corundum-like oxide.

Oil Contamination

In addition to oxidation, a further cause of melting losses which ought not to be overlooked is the contamination of the scrap by oil. Old engine casings are coated with oil and the oil results in the accumulation of dust, sand and other particles of dirt which considerably contaminate the melt. Any impurity unnecessarily introduced into the melting furnace implies, however, a loss of metal, and it is consequently disadvantageous to charge the furnace with such scrap without the latter having previously been degreased. Fine lathe turnings often contain even larger amounts of oil and proportions of oil amounting to 15 or 20 per cent. of the weight of the metal are by no means uncommon. The heavy clouds of soot which are produced when such quantities of oil are burnt and which permeate the melting shop may be avoided by deoiling the turnings in suitable apparatus by means of substances which dissolve the oil. Both the oil and the solvent may be recovered without trouble.

Furnace Design

Unsuitable melting furnaces are to be regarded as a further source of loss of metal. It has already been pointed out that thin pieces of metal should be immersed in an already existing bath of metal, and this can only take place effectively if the melting furnace is of suitable construction. Consequently, small crucible furnaces will not be so suitable for this method of remelting. The risk of overheating the melt can only be effectively countered if means for regulating the furnace temperature are actually provided. Despite the higher cost per calorie, the electric resistance furnace is therefore very advantageous in many cases for the remelting of aluminium. Town's gas contains no small quantities of hydrogen and is often the cause of the absorption of gas. Coke should be quite dry because, as already stated, steam is decomposed by the molten aluminium. The hydrogen passes into the metal and the oxygen oxidises some of the metal. It has been repeatedly observed that the gas-content of the melt is higher in summer than in winter. This is not due to the position of the moon or to a depression over Iceland, but to the fact that the combustion air passing through the furnace contains 4 or 5 times more moisture in summer than in the dry winter.

Virgin Metal Additions

One of the most effective means of minimising the remelting losses is the addition of virgin metal. It is preferable not to employ the remelted pure aluminium, but the metal from the electrolysis works, since the latter metal still contains effective quantities of flux, unlike the remelted pure aluminium which is "shorter" on casting. The extent to which the casting properties of a melt which is "dry," in consequence of its content of oxide films, may be improved by the addition of 10 to 20 per cent. of electrolytic aluminium is often surprising.

Losses caused by the splashing of metal during transfer or transport of the latter are easy to avoid and therefore too often overlooked. In the same way, losses of metal due to confusion of the different kinds of alloys in the foundry and workshop may be reduced merely by means of a suitable organisation. In both cases, considerable sums may be saved.

Quality Preservation

This important problem has already been touched upon here and there in the discussion of the prevention of losses. The excellent machining properties of aluminium alloys when worked with cutting tools is one of the great advantages of the light metal, but it becomes questionable if the casting is permeated by hard oxide inclusions. As already mentioned, such inclusions are caused by the combustion of fine particles of metal interspersed in the slag. There is yet another way by which they may pass into the melt. The application of anodic oxidation of aluminium has recently become increasingly important. The oxide films produced on aluminium in this way are 5 to 20 μ thick, and the film is considerably harder than the oxide film produced naturally. The loss which occurs on melting scrap coated with anodically produced oxide films is considerably greater than that occurring with normal scrap. It is, of course, possible to pickle the parts with caustic soda solution and to dry them before melting, but while this method prevents the thick oxide film residues from passing into the remelted material, it is necessary to take into account the rather considerable loss due to metal dissolved in the alkali solution. Both disadvantages may be obviated by adding one or two per cent. of a suitable flux when melting the scrap.

Corrosion Resistance

The question of the resistance to corrosion and the gas content of the remelted aluminium is closely connected to the oxide film content. It is a well-known fact that places lacking in homogeneity always exhibit a tendency to corrosion. Oxide inclusions cannot be removed by any mechanical or heat-treatment, and therefore they always form places at which the attacking agents can gain access to the interior of the parts. This danger is enhanced by the fact that gas residues are occluded with particular stubbornness on the oxide film inclusions, and their presence very considerably increases the number of places of open structure. All founders are acquainted with the small or large spongy places which are often so large as to render the soundness of the casting doubtful. In such cases, unless the other conditions of melting render all skill unavailing, only the treatment of the melt with an efficient flux will remedy matters. In carrying out such treatment, the flux should not be merely scattered on the surface or stirred below the surface, but should actually be submerged as far as the bottom. It is often more effective to add portions of flux in succession rather than excessive amounts all at once. For submerging the flux, wide bell-shaped appliances, open at the bottom, are not as suitable as appliances which are provided with cast-in slots and taper downwards to a point. It has already been indicated that fluxes containing adequate quantities of cryolite are particularly serviceable. A reliable mixture consists of

2 parts of cryolite,
2 ,, ,, common salt,
4 ,, ,, potassium chloride,
1.5 ,, ,, alkali sulphate.

Its action may be assisted by adding a sufficient quantity of virgin metal during the melting operation.

The oxide content of remelted metal should be kept as low as possible particularly from the point of view of the ability of the surface to take a polish and also because even the smallest defective places, such as those produced by oxide inclusions, show up when the parts are subjected to anodic oxidation. There is hardly a method of improving the surface of aluminium alloys which brings out the defects in the structure more prominently than anodic oxidation. All attempts to prevent costly waste are illusory if these oxide inclusions cannot be successfully removed.

Degasifying Molten Baths

A large number of methods have been recommended for degasifying the molten baths. In Germany, the introduction of chlorine gas or chlorides has been successfully urged. These methods are more suitable for remelted aluminium, the simpler and cheaper their application, and the desired object is often attained even by stirring in a heavy metal chloride which reacts in contact with the molten aluminium. Mixtures containing organic chlorine compounds have also proved efficient. In any case, when a double treatment is necessary for de-oxidation and degasification, it is essential to carry out the degasification last. Alloys containing magnesium in particular exhibit a tendency to renewed gas absorption when they are stirred again.

Generally speaking, it is preferable (and cheaper) to avoid anything which promotes the absorption of gas and the oxidation of the molten metal rather than later to have to go to the trouble of eliminating these quality-impairing inclusions. When it is necessary to melt down fine turnings or scrap and so forth, they will be introduced into the bath through a salt covering of sufficient thickness. The composition of such salt baths will also be selected so that their melting point is low and so that their oxide dissolving power is as great as possible.

As well as by the presence of oxides and gases, the quality of remelted aluminium is frequently impaired by a high content of unwanted metallic impurities. A high iron content—and here much may be gained by prophylactic means—renders the alloys brittle and also reduces the efficiency of heat-treatment by causing the formation of ternary insoluble Al-Cu-Fe compounds. If the unwanted alloy constituents are present in an excessive amount, there is no other means than that of diluting them by adding pure aluminium. Here, again, virgin aluminium is always more efficient than remelted pure aluminium, especially if good elongation figures are to be rehabilitated in the new alloy.

Raw materials are not inexhaustible, and this undoubtedly also applies to the raw materials necessary for the production of aluminium, despite their being so widely disseminated. To economise in aluminium is expedient, because, apart from a number of raw materials, considerable quantities of energy have to be consumed in its production. Losses in quantity and quality can only be avoided by careful operation guided by experience.

DISCUSSION

Herr Rohrig, when referring to the section of his Paper dealing with the degasifying of molten baths, added that chloride treatment had been introduced successfully in England.

Mr. A. Logan pointed to statements made in the Paper touching upon the "quality" of aluminium alloys from the foundryman's point of view. One such statement was that "The extent to which the casting properties of a melt which is 'dry,' in consequence of its content of oxide films, may be improved by the addition of 10 to 20 per cent. of electrolytic aluminium is often surprising." In other words, he said, by adding from 10 to 20 per cent. of electrolytic aluminium the "quality" of the material was improved.

With regard to the statement in the Paper that the oxide content of remelted metal should be kept as low as possible, particularly from the point of view of the ability of the surface to take a polish, he asked what was a low and a high oxide content; in other words, what were the limits of aluminium oxide content?

Mr. A. Dunlop, discussing the equation referred to by Herr Rohrig, in which copper sulphide was reduced, asked whether a similar reaction occurred with nickel sulphide and magnesium. He also asked whether the magnesium sulphide was easily disposed of.

"Dry" Alloys

Herr Röhrig replied that the magnesium sulphide was not easily disposed of. Dealing with Mr. Logan's reference to the statement concerning the improvement of the casting properties of a melt which was "dry" by the addition of from 10 to 20 per cent. of electrolytic aluminium, he said that the expression "dry" meant a metal in which the flow was short; the flow could be improved or lengthened by the use of a flux containing cryolite. He recalled an experience at a factory which was melting sheet scrap and where they used virgin aluminium from the electrolyte. On one occasion, instead of having the virgin aluminium from the electrolyte, they had re-melted pure aluminium, and in consequence had experienced great difficulties. Blisters had occurred on the sheet. He had suggested the addition to the metal of a flux containing cryolite. When that was added, the metal flowed better in the mould; the metal-cast was "longer," it had better fluidity and the blisters had disappeared in consequence of the removal of the oxide content. Subsequently the factory had reverted to the use of the virgin aluminium from the electrolyte.

It was difficult to say what should be the oxide content of the remelted metal, 0.05 per cent. being an amount that should not be surpassed.

NOTES ON THE STRUCTURE AND CHARACTERISTICS OF ALUMINIUM ALLOYS

Paper No. 612

By **H. C. Hall, M.Met., F.I.C.**

There is a considerable volume of published research dealing with the properties of cast alloys of aluminium. Much of it is, however, very specialised and theoretical, and its application to normal foundry practice is not very obvious. In this Paper it is proposed to discuss some of the properties of aluminium alloys, making a survey of present knowledge, with particular reference to structure, life and physical strength.

Although the ultimate nature of molecular structure of metals is of fundamental importance, governing as it does the specific gravity, modulus of elasticity and general characteristics, no attempt will be made to penetrate into this still controversial subject. Initially, it is proposed to consider what happens when a pure metal solidifies in a mould. As is well known, the metal starts crystallising from various centres or surfaces when it has cooled (about 660 deg. C. in the case of pure aluminium).

The grain size of metals and alloys of a particular composition and cast under particular conditions is extraordinarily constant, as is indicated by fracture and micro examination. This may be partly due to characteristic grouping just prior to, and during solidification. Also, it appears that when there is a considerable solid solution of one metal in another the greater affinity between them results in either a greater number of crystals in a given volume, or marked dendritic tendency due to more gradual solidification. The latter is also observed when a pure metal solidifies in the presence of a considerable proportion of a constituent of much lower melting point.

In the case of aluminium the macro structure is not much affected by eutectics or compounds which largely make up the cell walls of the micro structure. If an alloy of aluminium containing only a small amount of metal capable of being retained in solid solution is rapidly cooled from a temperature considerably above its melting point,

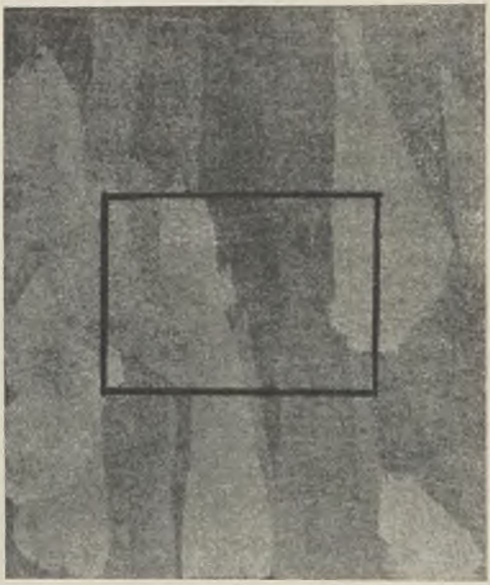

FIG. 1.—RAPIDLY-COOLED ALUMINIUM CONTAINING 1.4 PER CENT. FE AND 0.3 PER CENT. SI. × 5.

very large macro crystals are generally observed. In the case of aluminium containing 1.4 per cent. iron, 0.3 per cent. silicon, the large crystalline structure as shown by macro etching in Fig. 1, is found on micro examination to have a detail form, such as is indicated by Fig. 2. Slower cooling as the result of casting in a sand mould generally promotes crystallisation from numerous centres without the development of sufficient energy in a given time to permit an extended orderly arrangement, *i.e.*, large macro crystals made up of units with predominant axial tendencies (Fig. 3).

Fig. 4 shows the usual so-called idiomorphic crystals of irregular external, but with definite

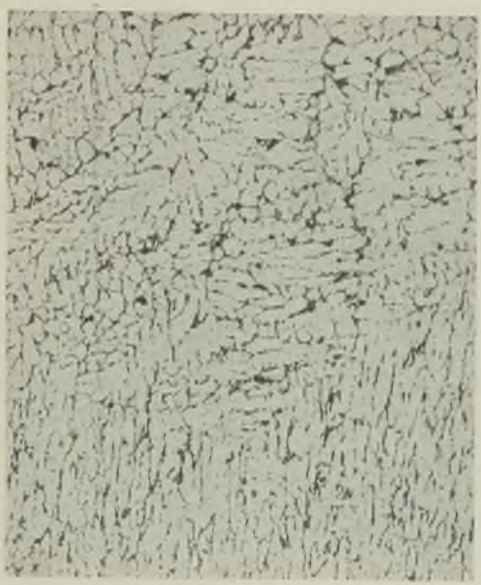

FIG. 2.—MACROSTRUCTURE OF AREA MARKED IN FIG. 1. × 100

internal symmetry or packing as indicated. The dark line across the illustration is where the section shown in the upper half meets with the lower half section at right angles. A suggests the possible production of a cube by "splitting off" parts of an idiomorphic crystal along cleavage planes. B shows a crystal with subsidiary crystals, these having slight variation in crystal orientation relative to each other, owing to impurity or internal stress, after solidification has taken place. E shows the impurity ejected to the cell walls.

The crystalline axes or cleavage planes of adjacent crystals may be different, as shown in the case of D and C. The etching is generally greater if a plane happens to be at a certain inclination to the surface—as indicated on the lower part of the illustration, or the amount of attack may depend on electrolytic effect; neighbouring crystals having a potential difference due to variation in individual orientation. The resulting steps at crystal junctions show up as a line on microscopic examination.

Fig. 3.—Crystal Structure Resulting from Slow Cooling in a Sand Mould. × 10.

One may conclude that molecular packing is closest inside the cells. This is generally confirmed by controlled density estimations—eliminating other variables as far as possible—and the more cell walls there are in a unit volume the lower is the density. In aluminium, crystal-growth may take place easily, two or more cells becoming one by simple annealing; this confirms the theory that the boundaries are not in the nature of ultra-microscopic oxide films since in the case of aluminium such would resist solid diffusion owing to its impermeable nature.

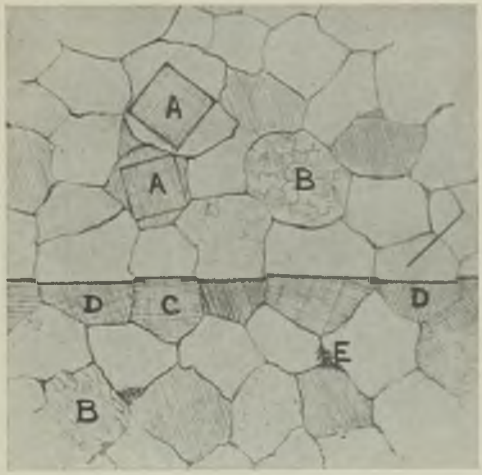

Fig. 4.—Idiomorphic Crystals of Irregular External, but Regular Internal Symmetry. × 300.

The strength of the structure depends both on cohesion between the constituent crystals at the cell walls and also on the cohesion at crystal cleavage planes, etc., inside. On deforming a ductile metal, slip takes place along these planes, but cell-wall accommodation is also necessary for change of shape without fracture. Thus, brittle cell walls due to the ejection of impurities or metallic compounds during solidification and cooling in the mould may even in very small quantity have a great effect on ductility.

Resistance to fatigue is different since breakdown may occur without any measurable plastic deformation. It has been proved, however, that at the region of stress concentration, the material should, for reliable service under most conditions, be capable of accommodation, accompanied by an increase in hardness without crack development. This tends to shift the locality of stress concentration to adjacent parts. At the same time its magnitude is automatically reduced owing to its distribution over a larger volume of material.

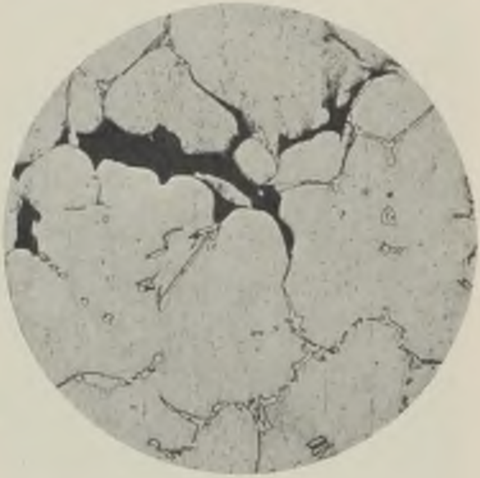

FIG. 5.—PORES IN A 6 PER CENT. COPPER ALLOY. × 150.

In the case of magnesium—a metal which crystallises according to the hexagonal system—very minute intercellular pores are much more common, owing apparently to the greater difficulty in packing or dovetailing hexagons at the boundaries of crystals. Such pores are particularly important when considering fatigue resistance. Aluminium alloy sand castings will contain cavities or pinholes if they are contaminated when in the liquid condition by the disengagement of hydrogen, carbides of hydrogen, and carbon monoxide, etc., during solidification. The development of these defects is facilitated by the considerable contraction that takes place simultaneously, *i.e.*, when the metal is changing from the liquid to the solid state. In chill castings the gases are generally trapped in solution owing to rapid cooling. There is no separation of slag as in steel, however, but there may be local intercrystalline weakness, due for instance to the separation of a copper-aluminium compound from its aluminium-rich matrix owing to the difference in coefficient of contraction. This may be one reason for the low strength of alloys compared with their calculated values from physical data.

Pinholes are often found, on microscopic examination, to be associated with copper segregation in spite of the solid separation of the latter taking place at a much lower temperature than that at which the pinholes form. Fig. 5 shows the pores in a 6 per cent. copper alloy, which suggest that some kind of association has existed even in the liquid state. Similarly an oil-water emulsion often has air bubbles trapped in it.

It should be observed that the mechanism of solidification has been considered by Desch, who investigated the supposition that the initial structure produced in an alloy was comparable with foam cells which appeared prior to normal crystallisation. The membranes, according to this theory, are similar to the "amorphous cement" of Rosenhain, both consisting of less pure metal than that inside the cells; this will be referred to again when considering "fluidity."

Modified Alloys

Common unavoidable impurities in aluminium are silicon and iron. The former if below 0.3 per cent. may be in a so-called solid solution in the aluminium, and is then invisible under the microscope. About 20 per cent. silicon can be dissolved in molten aluminium at about 800 deg. C. in spite of its own high melting point of 1,600 deg. C. On cooling to room temperature it is largely thrown out again. Fig. 6 shows the silicon-aluminium equilibrium diagram, wherein it is seen that the eutectic composition is 12 per cent. silicon, solidifying at 576 deg. C. The dotted lines show the undercooling effect of modification by traces of sodium. Rapid cooling produces a similar effect to a sodium addition, as it increases both tensile strength and the ductility. The curves on the lower part give an approximate idea of the change in ultimate strength and ductility with increase in silicon. This is a modified alloy cast in sand.

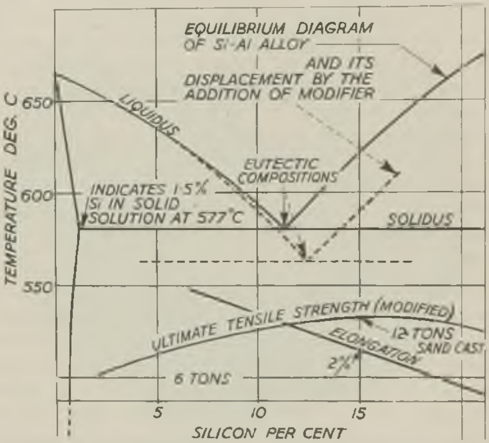

Fig. 6.—Si-Al Equilibrium Diagram, and the Effect of Si on the Physical Properties of a Sand-Cast Modified Alloy.

Fig. 7 shows the structure of an unmodified alloy containing 12.7 per cent. silicon, in which the silicon in excess of that necessary for forming the eutectic is in massive particles. Fig. 8 shows the same alloy modified by 0.6 per cent. cobalt; an amount of 0.1 per cent. lithium and strontium would have a similar effect.

Aluminium Copper Alloys

Modification appears to alter the solubility of silicon in aluminium, tending to retard their separation on cooling. The fact that casting from a very high temperature, say 950 deg. C., into a chill mould produces a finer grain structure than casting from about 700 deg. C. in the same mould, suggests that separation or grouping of the silicon and aluminium takes place above the apparent solidifying temperature. This is confirmed by soaking a molten eutectic alloy at about 600 deg. C. in the crucible with-

Fig. 7.—Unmodified Aluminium-Silicon Alloy containing Massive Particles of Silicon. × 100.

out stirring, when it is found that the lighter constituent, silicon, tends to rise. For similar reasons a copper-aluminium alloy with about 12 per cent. copper, treated in the same way, may have twice as much copper at the bottom of the pot after standing. Zinc behaves in a similar manner in spite of its greater solubility in aluminium. This is one reason for preferring alloys with relatively small percentages of heavy constituents, particularly for large melts or if the alloy be required to remain molten in the furnace for a considerable period.

Fig. 8.—Aluminium-Silicon Alloy, containing 12.7 per cent. Silicon, Modified by 0.6 per cent. Cobalt. × 100.

It may be noted in this connection that induction-electric melting tends to maintain uniformity of composition by the stirring effect which tends to set up eddy currents. This may, however, increase oxidation if the alloy is inadequately protected by surface flux.

Copper was probably the most important constituent of aluminium alloys used in the past, and with more than 3 per cent. of copper, whether chill or sand cast, there is a cellular structure such as shown in Fig. 9, which is a 6 per cent. sand-cast aluminium alloy. The network is the copper-aluminium compound $CuAl_2$—a very brittle constituent—and it is understandable that ductility is much decreased by its presence in the form shown. With the common 8 per cent. copper alloy, sand-cast, there is about 12 per cent. of compound by volume, and this reduces the ductility on the tensile test from about 25 per cent. elongation in the case of commercial aluminium to 2 per cent. This is further reduced by low temperature heat-treatment at, say, 150 deg.

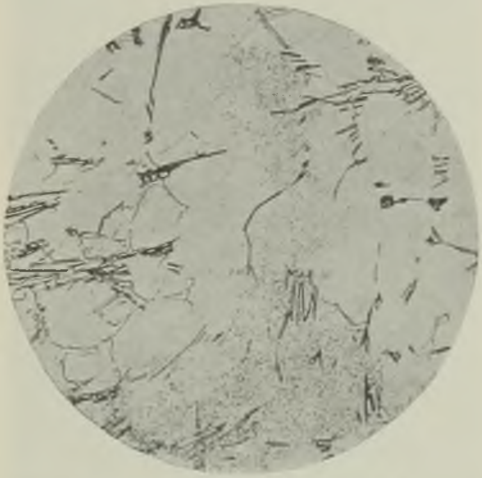

FIG. 9.—CELLULAR STRUCTURE OF 6 PER CENT. SAND-CAST COPPER ALUMINIUM ALLOY. × 150.

Efforts to eliminate the cellular formation of copper-aluminium eutectic, particularly in sand castings with about 8 per cent. copper, and thus to increase the ductility, have not been very successful, though 1.0 per cent. iron and about 0.25 per cent. titanium are beneficial. Beryllium and lithium also have a similar influence.

Another very important constituent of aluminium alloys is the compound magnesium silicide, Mg_2Si. Since silicon is always present in commercial aluminium and has a strong affinity for magnesium, it follows that Mg_2Si is always present when magnesium is added to aluminium. In this case (Fig. 10) distinct cellular formation is not produced. Nevertheless Mg_2Si has a great effect on the physical properties. Copper aluminide and magnesium silicide are the two most important constituents of aluminium alloys from the heat-treatment

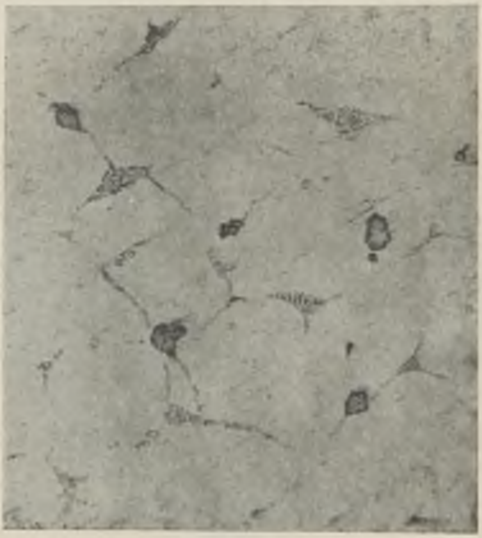

Fig. 10.—Aluminium containing Magnesium Silicide. × 300.

point of view, and both go into solid solution in aluminium containing them, if heated at about 500 deg. C. for a suitable period, *i.e.*, about half an hour for chill-cast alloy and at least three hours for a sand-cast alloy. Fig. 5 shows the 6 per cent. copper alloy treated in this way. Silicon also has a similar, though less marked, hardening effect, even without magnesium.

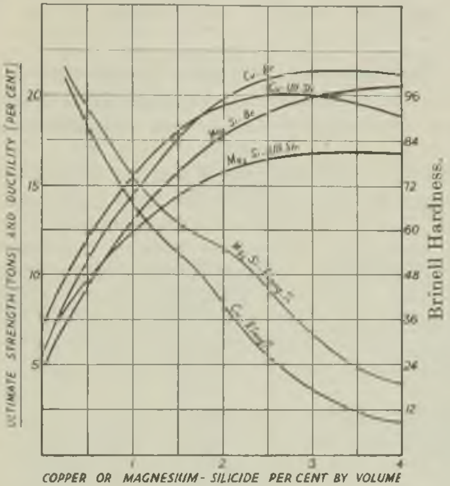

Fig. 11.—Variations of Ultimate Tensile Strength, Ductility and Brinell Hardness, with an Increase in Copper and Magnesium Silicide (Chill Cast and Heat-Treated).

Table I shows the relative solubility of various constituents of aluminium alloys at ordinary temperature and at about 500 deg. C. The considerable difference in solubility at the two temperatures when alloys are capable of considerable response to heat-treatment is noteworthy.

Quenching from the solution temperature traps a large proportion of the $CuAl_2$ and Mg_2Si or Si in the solid-solution state. If more than one is present mutual effect on individual solubility in the aluminium is observed, as would be expected. Other constituents also complicate the behaviour of aluminium alloys, so that phase and equilibrium investigation may be very difficult when, for instance, iron about 1.0 per cent. is present. The compound $MgZn_2$ behaves similarly to Mg_2Si, although its solution temperature is lower, *i.e.*, about 450 deg. C., and its optimum ageing temperature about 100 deg. C.

Hardness and Strength Developments

Solution treatment is, of course, carried out in order to develop maximum hardness and strength, but, as is well known, this result is not fully achieved without subsequent ageing or precipitation treatment. This latter may be practically complete by storage at normal air temperature for a week or so. Cast alloys, however, as a rule, require artificial heat, *i.e.*, heating to about 150 deg. C. for 12 hrs., the hardness thereby increasing from about 75 in the solution-treated condition to as much as 150 Brinell. The changes in mechanical properties may be considered to be largely due to the intimate association of one volume unit of the constituent Cu or Mg_2Si (by atomic dispersion

TABLE I.—*Solid-solubility of Various Elements in Aluminium.*

Constituent.	Temperatures.	
	10 to 30 deg. C. Per cent. by weight.	490 to 510 deg. C. Per cent. by weight.
Copper	0.25	4.1
Magnesium	1.30	12.0
Silicon	0.20	1.1
Magnesium silicide ..	0.45	1.4
Manganese	0.20	1.0
Lithium	2.40	2.8
Silver	1.5	40.0
Cadmium	0.05	0.8
Zinc	3.2	42.0

in the aluminium space lattice during solution treatment) with about 50 units of aluminium. The resultant group, *i.e.*, 51 in volume plus a slight increase due to the new arrangement or packing, has special properties. For instance, on precipitation treatment the Cu or Mg_2Si, which is present as a distorting factor in each group, tends to cause internal stress by diffusion and segregation, which upsets the normal easy slip along crystal planes, acting apparently as if to increase the internal friction. Thus, under externally loading plastic, deformation is less, *i.e.*, the material is harder.

From tests it can be shown that with about 2.0 per cent. Cu or Mg_2Si by volume there is, as previously suggested, a maximum effect due to heat-treatment when about 50 volumes of aluminium are associated with one unit of these compounds. If more compound than this proportion is present, hardness is not increased in proportion, but ductility decreases markedly owing to the excess $CuAl_2$ or Mg_2Si being deposited at cell walls, these taking little part in the changes during solution and ageing treatments.

Fig. 41 shows at volume percentages the hardness and ductility variation and maxima obtained by complete heat-treatment with an increase in copper and magnesium silicide.

Heat-Treatment

Heat-treatment does not result in serious volume dimensional change so long as precaution is taken to avoid distortion at the moment of actual quenching from the " solution " temperature. On the other hand, heat conductivity is considerably reduced by it as compared with the alloy in the " as cast " or " annealed " condition. This may be important when considering piston and cylinder-head castings for high power internal combustion engines.

Quenching a large casting which has considerable local variation in section results in local internal stress. Subsequent normal ageing treatment does not tend to reduce this, and may

TABLE II.—*Compositions and Mechanical Strength (Tensile and Hardness).*

	Cu.	Ni.	Mg	Fe	Si.	Ti.
R.R.50	1.3	1.1	0.12	1.1	2.30	0.18
R.R.53C	1.2	1.3	0.50		2.50	0.16
R.R.53	2.1	1.3	1.50		1.0	0.07

	Low temperature heat treatment (160 deg. C. for 8 hrs.)				High temperature duplex treatment (520 deg. solution treatment then 160 deg. C. for 8 hrs.).			
	Proof stress	M.S.	E. per cent.	Br. H.	Proof stress	M.S	E. per cent.	Br. H.
R.R.53O sand cast	9.0	12	3.0	70	13	17	2.5	90
R.R.50 sand cast	9.5	14	2.0	77	19	21	2.0	103
R.R.53 chill cast	12.5	17	1.0	96	21	25	1.0	140

even aggravate it, owing to the simultaneous increase in hardness which occurs. Such stress may approach the elastic limit of the material and cause the casting to fail under relatively light loading in service. A semi-anneal treatment with some consequent sacrifice in Brinell hardness and elastic limit, may be beneficial in such a case.

Fig. 12.—Structure of R.R.50 Alloy, Sand Cast from 710 deg. C. × 100.

Castings are often given an ageing or precipitating treatment only at about 150 deg. C., primarily to prevent future distortion. Some increase in hardness and reduction in ductility is noted as a rule. This is more marked with chill-cast alloys in which more $CuAl_2$ and Mg_2Si, etc., are retained in solid solution owing to relatively rapid cooling in the mould; this is equivalent to a mild solution treatment. After about 6 hrs. at 150 to 170 deg. C. internal stresses due to casting contraction are generally eliminated completely if the material is not solution treated. The alloy RR50 is treated in this way since the gain in strength, obtained by the duplex treatment, is not sufficient to warrant the added cost. With higher Mg_2Si, however, as present in RR.53C, or extra copper, a considerable increase in ultimate stress results. Both treatments improve machinability.

FIG. 13.—STRUCTURE OF R.R.53 ALLOY, SAND CAST FROM 710 DEG. C. × 100.

Table II shows a comparison between RR50, RR.53C and RR53 fully heat-treated and also precipitation treated.

These alloys, like those of the rest of the series, are characterised by fineness of grain, partly owing to carefully-balanced composition and partly due to the presence of titanium, which is now generally acknowledged to have a great refining effect. The structure of RR50 and RR53 alloys is given in Figs. 12 and 13 respectively. Their utility is particularly in the field of heavily-stressed engine parts. Both were sand-cast from 710 deg. C. and given low temperature heat-treatment only.

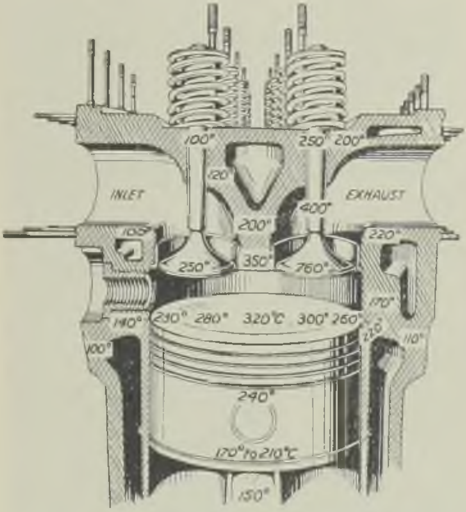

Fig. 14.—Section through a Water-Cooled Aero-Engine Cylinder showing the Working Temperature at Various Points.

Fig. 14 shows the section of a water-cooled aero-engine cylinder, the temperature obtained during actual service being indicated. The piston may be made of RR.53 or RR.53C alloy, which are somewhat more resistant to heat than RR.50, but more difficult to cast. Y alloy is even more difficult to handle, particularly for the production of sand castings. Fig. 15 shows the tensile strength curves for RR.50, RR.53 and Y alloy compared with several other alloys up to 350 deg. C. The Y-alloy test is made on forged heat-treated alloy RR53 chill cast and heat-treated.

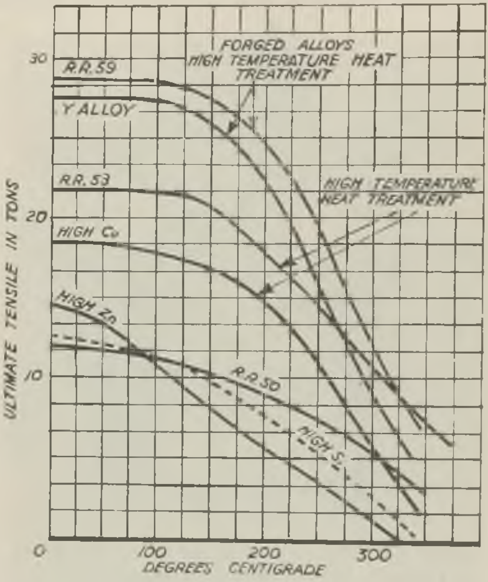

Fig. 15.—Tensile Strength Curves for R.R.50, R.R.53 and Y Alloy and other Alloys compared.

If the hot tensile test result and the limiting creep strength of a casting alloy be both relatively good at the temperatures prevalent in more highly stressed regions in the engine, it may be concluded that service will be satisfactory if other conditions are normal.

Aluminium containing 8 to 12 per cent. copper is liable to be too ductile at about 300 deg. C.

If other constituents such as manganese, magnesium or silicon are added, particularly when used for sand castings, in an attempt to correct this fault, the characteristic brittleness of these alloys in the cold is further increased, or heat conductivity may be seriously reduced, as is the case with manganese addition. For instance, a 10 per cent. copper and 90 per cent. aluminium alloy has a value of 43 per cent. that of copper, and if 1 per cent. manganese be added, it is then only about 30 per cent. (in the range 0 to 300 deg. C.).

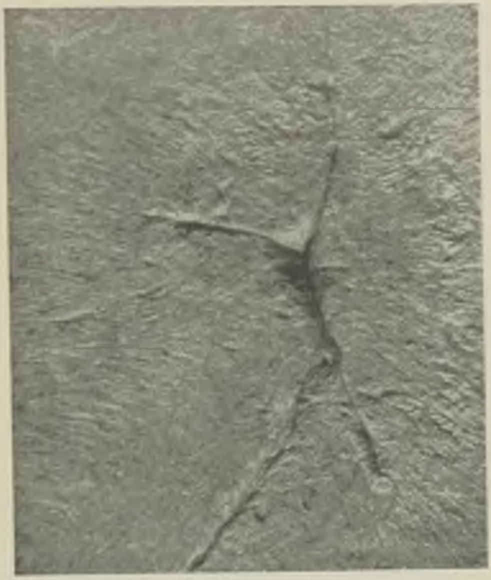

FIG. 16.—SURFACE FOLD IN A HIGH MAGNESIUM ALLOY. × 10.

High-Magnesium Alloys

High-magnesium alloys are also very sensitive to other additions, and are not sufficiently resistant to heat for most engine parts. This may be partly due to their liability to oxide flaws and skin blemishes, owing to their reactive tendency either with the oxygen in the air or during casting, particularly in the mould. Even the sand of a dry mould may contain combined moisture, which causes skin oxidation if the alloy contains over 0.2 per cent. magnesium with consequent liability to folds and leaky castings.

Fig. 17.—A Crack Associated with a Surface Fold Passing through Eutectic Particles. × 500.

Fig. 16 shows a surface fold, whilst Fig. 17 shows an associated crack passing through the eutectic particles. Surface treatment of the sand mould to reduce reactivity of the internal face, as employed in the production of magnesium base castings, should be further investigated.

Cast alloys containing about 4 per cent. magnesium, together with relatively small additions of other metals for refining or hardening purposes, though much superior in the forged condition to other forging alloys, are not so in the sand-cast condition, when considering original and final physical properties after exposure to air, water, or saline spray. For instance, under boiling-water conditions as a water-cooled cylinder casting, RR50 shows better to advantage than a 4 per cent. magnesium alloy. High-zinc alloys such as 2L5 are liable to surface disintegration, even in the air, due to electrolytic action; similarly, the copper eutectic in high-copper alloys results in rapid surface corrosion, particularly in the presence of moisture.

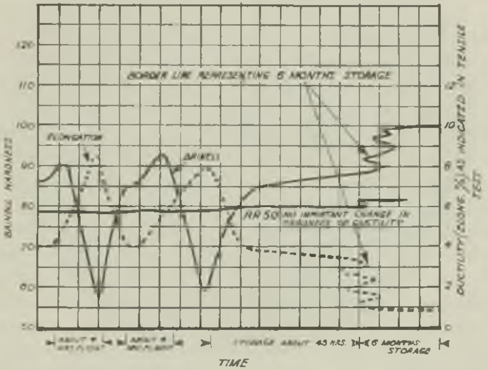

Fig. 18.—Physical Properties of High-Zinc Alloys.

High-Zinc Alloys

High-zinc alloys are too susceptible to heat for use if the temperature in service exceeds about 90 deg. C. owing to their tendency to soften with moderate heat. This softening persists on cooling, but after a time a type of ageing at ordinary atmospheric temperature results in the Brinell hardness rising from about 57 to as much as 100 (Fig. 18). It appears that this cycle of change which takes place each time the engine is run and cooled again often results in local cracking after comparatively short service.

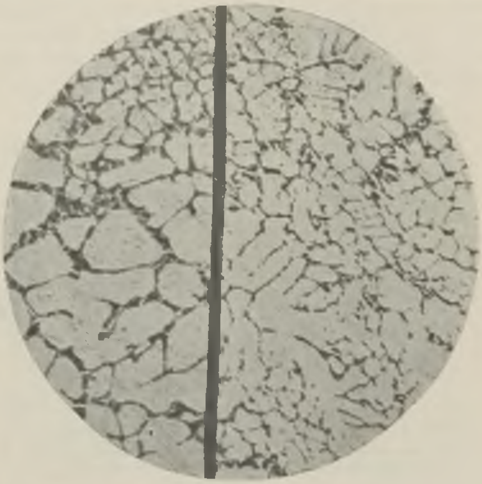

Fig. 19.—Right-hand side: 1.5 per cent. Nickel Aluminium Alloy. Left-hand side: Aluminium Alloy containing 1.4 per cent. Nickel, 2.4 per cent. Copper. × 150.

With time, the ductility is almost completely lost, even if the part is in store.

Nickel, when alloyed with aluminium, is more finely dispersed than other metals of high melting point. Iron comes next in order, and these two metals form with silicon and aluminium complex eutectics which are not liable to coarse segregation if not more than about 1.5 per cent. of either is present; the same holds good if their total does not exceed about 2.5 per cent. Fig. 19 shows, on the right hand side, a chill cast alloy containing 1.5 per cent. nickel (with iron about 0.3 per cent.). Nickel also associates well with copper in aluminium alloys, a triple eutectic being produced. The nature of this alloy, containing 1.4 per cent. nickel, 2.4 per cent. copper and 0.3 per cent. iron, is shown on the left hand side of Fig. 19.

Other heavy metals of high melting temperature should only be present to a small extent since they tend to result in segregation. Consequently uniformity of melt composition is difficult with more than about 0.3 per cent. total of chromium, vanadium, molybdenum and tungsten, etc. Manganese, owing to its greater solubility, may be used in quantity, but it is liable to result in brittleness. In casting alloys castability and fluidity are of vital importance. For this purpose the three testing outfits shown in Fig. 20 are useful.

The castability test is made up of two rigid steel bars, between and also around the ends of which a particular alloy is cast under standard conditions. The longer the bar can be cast without cracking the less liable is that alloy to give trouble in the foundry. With 4 per cent. copper alloy 6 in. can be cast, with 12 per cent. copper, 10 in., with 12 per cent. zinc, 11 in., with 12 per cent. silicon, 16 in. and with RR50 14 in. Casting is generally carried out at about 680 deg. C. This temperature is also used when testing for fluidity. Table III gives the length or volume obtainable with various alloys. The volume method is more easily carried out. The reason that various alloys give such different results in tests is not fully understood. To obtain a good result with the castability test, the alloy generally requires to have a low contraction during solidification. Other factors which affect the result are its strength and ductility just after solidification, and the relative solidification range. Table IV gives the solidification ranges

Table III.—*Fluidity Test (Chill Mould).*

Volume of metal collected is taken as proportional to the fluidity.
Alloys not fluxed, cast from 690 deg. C. in mould at 180 deg. C.

	Alloy.	Volume.		Alloy.	Volume.
1.	Commercial aluminium (containing iron 0.30 per cent., silicon 0.22)	11.5 c.cs.	7.	2 per cent. manganese to No. 1	11.8 c.cs.
2.	Aluminium (iron 1.4 per cent., silicon 0.32)	12.8 c.cs.	8.	3 per cent. nickel to No. 1	15.0 c.cs.
3.	2.5 per cent. copper to No. 1	12.6 c.cs.	9.	12 per cent. silicon to No. 1	25.6 c.cs.
4.	6.0 per cent. copper to No. 1	17.7 c.cs.	10.	24 per cent. silicon to No. 1	10.7 c.cs.
5.	12.0 per cent. copper to No. 1	22.0 c.cs.	11.	12 per cent. zinc to No. 1	17.3 c.cs.
6.	6.0 per cent. magnesium to No. 1	18.6 c.cs.	12.	R.R 50	22.5 c.cs.

of various alloys and the volume contraction at the moment of solidification from the completely liquid to the completely solid state.

The separation of compounds or eutectics just after solidification by rapid diffusion is often associated with temporary "hot shortness" and this may cause cracks if the core stresses in the mould are considerable.

High Silicon Alloys

In high-silicon alloys, approximating to the eutectic composition, cavities are often found at large changes of section, due in part to their very small solidification range. It also appears that there is a critical percentage of silicon between 0.5 and 1.8 per cent., which tends to result in cracked castings, owing to the existence of sufficient eutectic (melting point 570 deg. C.) to cause intercellular weakness just after solidification, but insufficient to result in liquid communication with runners or risers. Feeding is thus inadequate. The addition of nickel, however, and small amounts of other metals have a corrective effect even in the range indicated.

A small reduction in coefficient of expansion is realised by raising the silicon content from 2 to 12 per cent., *i.e.*, from about 0.000023 to 0.000021 (range 0 to 200 deg. C.). Much has been made of this; it must be borne in mind, however, that a 12 per cent. silicon alloy is too soft for even moderately stressed parts even under relatively cold service conditions. If it be stiffened up by small amounts of copper, magnesium, manganese, etc., it is liable to be deficient in ductility, particularly if given a high temperature heat-treatment. As heat-resisting alloys these compositions are restricted in their application, owing to their relative weakness above 250 deg. C.; further, their heat conductivity is much lower than more heat-resisting alloys containing 1 to 2 per cent. silicon. These conclusions have been confirmed by performance when used for pistons, etc.

Flowability is not quite the same as "viscosity," since surface tension and the relative tendency to form oxide skin are both particularly important when casting into a sand mould.

Elements producing stable solid solutions tend to decrease fluidity. If present beyond the limit of true solubility, they then appear to produce a kind of emulsion which may or may not increase fluidity. Substances that produce precipitated compounds disseminated in the liquid generally increase fluidity; if present in considerable quantity they tend to make the alloy noticeably sluggish. This may be corrected in some cases, however, by increasing the temperature, when floating crystallites may be converted into more rounded forms or be partly dissolved; or, again, they may become completely liquid and have no important frictional influence. This subject is, however, very complex and controversial.

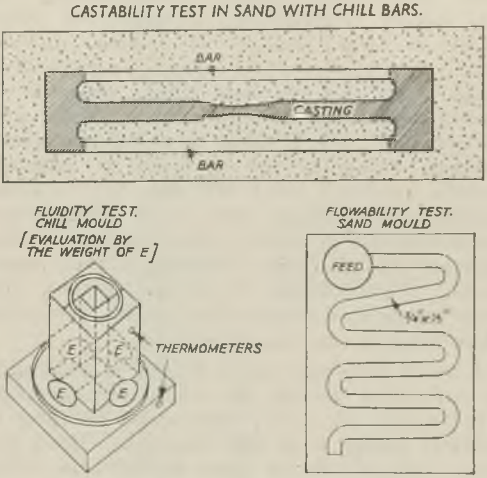

FIG. 20.—APPARATUS FOR TESTING LIFE AND FLUIDITY OF ALUMINIUM ALLOYS.

Fig. 21 shows aluminium containing a manganese aluminium compound in rounded form produced by rapid cooling from a relatively high temperature, and Fig. 22 shows the crystalline form as the result of slow cooling. Two per cent. manganese and traces of copper and titanium, etc., are present in each case. A similar difference is observed if the liquid alloy is agitated before casting instead of being heated to a high temperature.

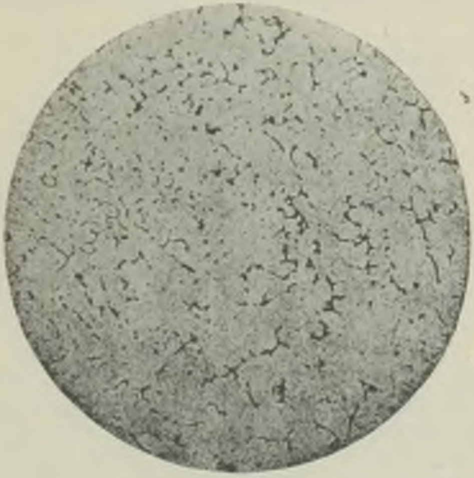

Fig. 21.—Aluminium Alloy containing Aluminium-Manganese Compound. The Rounded Form is Produced by Rapid Cooling. × 150.

Fluidity is much influenced by the presence of suspended oxide. Pure aluminium is not liable to contain it. In alloys, such oxide is often associated with the occluded gas bubbles in regions high in dissolved hydrogen, carbides of hydrogen, and carbon monoxide, owing to contamination by furnace gases or moisture. The efficiency of flux depends mainly on its liability to coagulate such dispersed oxide. The action is generally stimulated by the production of chloride from chlorides in the flux which produce hydrochloric acid gas with the hydrogen in the metal. This gas, being insoluble, rises with the oxide to the surface. The evolution of nitrogen or fluorine from a flux may also be beneficial, and the gas itself in the former case may be bubbled through the alloy for stirring purposes, either in the furnace or ladle.

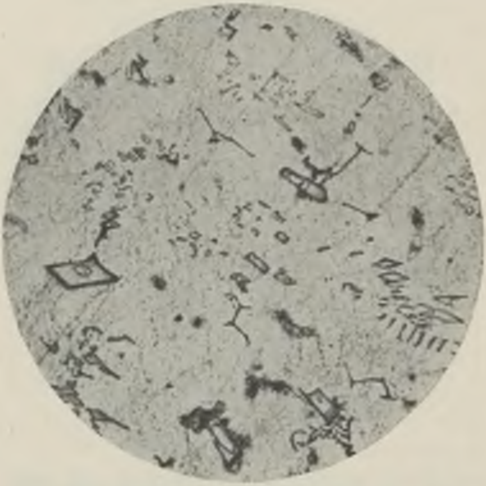

Fig. 22.—Same Alloy as in Fig. 21, but Crystalline Structure, produced by Slow Cooling. × 150.

The addition of traces of alkali metal may modify surface tension, and such additions as chlorides or florides may be added shortly before casting, to increase the fluidity. Opalescent tints on the exposed surfaces of runners and risers indicate the presence of dissolved alkali metal, and, when these are noted, pinholing is very unlikely to be observed in the casting concerned.

Being in the nature of a survey, this Paper has touched on a wide range of subjects; consequently acknowledgment is due to many workers and authors; time and space make individual recognition impossible. The author would like, however, to record his indebtedness to Mr. E. J. Whitehead for photomicrographical work and Rolls Royce, Limited, for permission to publish this Paper.

Table IV.—*Solidification Range and Liquid Contraction for Various Alloys.*

Alloy.	Solidification Range. Deg. C.	Liquid Contraction. Per cent.
Aluminium (commercl.)	657 — 655 (2)	8·4
8 per cent. copper ..	620 — 550 (70)	6·2
12 per cent. zinc ..	620 — 590 (30)	5·8
12 per cent. silicon ..	570 — 567 (3)	3·4
4 per cent. magnesium	647 — 595 (52)	5·8
3 per cent. nickel ..	642 — 635 (7)	5·7
R.R. 50	630 — about 600*	—

* Less distinct owing to complexity of composition.

DISCUSSION

Mr. Arthur Logan congratulated the organisers of the Derby conference, and the Literary Committee, on having arranged so interesting a symposium on non-ferrous foundry subjects and on having recognised at last that cast iron was not the only metal which was made into castings or which foundrymen had to handle. It was high time the Institute recognised the value and importance of non-ferrous alloys and non-ferrous founding. Aluminium and aluminium alloys were rapidly coming into their own, and were achieving the prominence and importance which their remarkable properties warranted. Civilisation was now entering upon the Aluminium Age. One of the most outstanding features of modern social conditions was mobility; cheap and rapid transport had done more to revolutionise our manner of living since the war than had almost any other single feature. The efficiency of the modern internal combustion engine was definitely dependent upon aluminium alloys; even the railways were beginning to wake up and to use aluminium alloys to promote the design of locomotives of greater speed and efficiency. He was, however, interested in the Papers particularly as a manufacturer of aluminium pistons for internal combustion engines.

The Paper by Mr. Hall provided much useful, interesting and original information, and raised many points which would provide fruitful ground for discussion. Commenting upon a statement in that Paper that crystal growth might take place easily in aluminium, two or more cells becoming one by simple annealing, Mr. Logan asked what were the minimum temperatures at which that occurred, and whether the statement referred to pure aluminium only or to alloys of aluminium.

Another statement to which the author drew attention was to the effect that "pinholes were often found, on microscopic examination, to be associated with copper segregation." It was also an unfortunate fact, he said, that pinholes and porosity were often associated with oxide inclusions.

Flowing Power

It was very interesting to note that the author had studied the castability and fluidity of various aluminium alloys, for those properties were of paramount importance from the foundry point of view. He asked for some further details of the castability and fluidity tests, and of the practical manipulation—details of the apparatus used, etc. In experimental work he had found it extraordinarily difficult to secure consistent results, and to fix conditions as to temperature, etc., to be exactly the same in each test.

The reference in the Paper to the fact that fluidity was much influenced by the presence of suspended oxides led Mr. Logan to a consideration of the general problems which beset the aluminium founder. One of the vital factors in aluminium founding was the "quality" of the material. That was a very nebulous and indefinite property, but every foundryman who had to deal with aluminium would appreciate what was meant by that term. There was no doubt, for instance, about the difference between an ingot of correct and newly-made alloy from virgin metal and the same material after repeated meltings. The difference was a difference of "quality." Although the general chemical composition of the alloy remained the same, there would be still a big difference between a casting made from a new ingot and one made after, say, ten meltings. The causes of that difference were difficult to define; yet the lack of "quality" was a vital factor, and could be shown to be a direct cause of high proportions

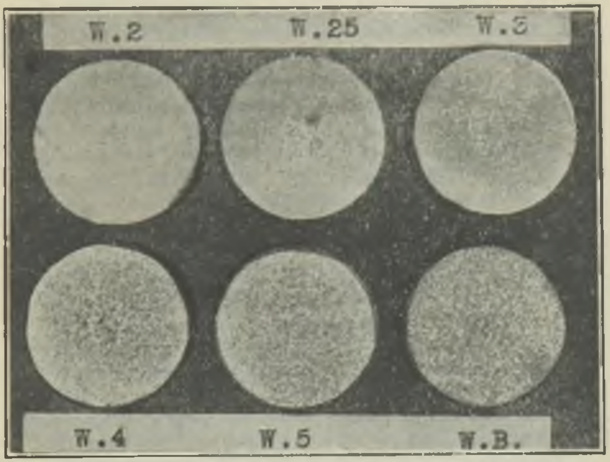

Fig. 23.—Aluminium Alloy with 7 per cent. Copper (Actual Size).

of scrap in production. Repeated melting was accompanied by gas absorption, oxidation and oxide film entanglement, resulting in poorer casting properties, lack of fluidity, greater porosity and very frequently large grain size. He asked what was the connection and relation between "quality," gas content and grain size. It seemed apparent that in certain alloys there was some definite and complicated inter-connection. How, then, was the foundryman to determine the all-important but elusive factor of "quality?" What was the criterion? Could the aluminium oxide content of the material alone, or the nitrogen content and/or the measured gases be used as a criterion, as hinted in M. Chaudron's French exchange Paper? Or must those factors be combined with castability and fluidity tests? Or would castability and fluidity tests alone serve as criteria?

Nomenclature

MR. V. C. FAULKNER (Past-President), discussing the problem of nomenclature, said that in the translation of M. Chaudron's French exchange Paper the word "Rochage" was used, and he had discovered by reference to other Papers that that was definitely to be associated with the problem of gas evolution during freezing. Apparently there was no omnibus word in the English language which would cover that particular phenomenon, and he asked whether members of the Institute could suggest a word giving a close translation to the word "Rochage," thus eliminating the necessity for the use of an expression each time.

Again, Professor Desch had made a very nice compromise with regard to nomenclature in the course of the "Edward Williams" lecture which he had delivered on the previous day. For generations at least the steel and iron foundrymen had used the word "life" in expressing the ability of the metal to fill the mould. Then the metallurgists, in the course of their researches, had noted the same phenomenon and, approaching the subject from various angles, had hit upon the horrible word "castability." It was pleasing to note that Professor Desch had used the expression "flowing power," and Mr. Faulkner suggested that the expression "flowing power" might be standardised.

Mr. E. Noble, referring to the use of chills and the benefits of rapid chilling, asked if Mr. Hall had had experience of ultra rapid cooling by means of water-cooled moulds.

Mr. A. Dunlop asked if Mr. Hall had had experience of the use of mould materials of high thermal conductivity, such as carborundum and carborundum mixtures.

Mr. Jones, pointing to the reference, in Mr. Hall's Paper, to opalescent tints on the exposed surfaces of runners and risers, indicating the presence of dissolved alkali metal, and the statement that when those tints were noted, pinholing was very unlikely in the casting, asked in what particular alloys Mr. Hall had noted those tints.

AUTHOR'S REPLY

Mr. Hall, replying to the discussion on his Paper, said that various mould materials had been used with a view to increasing the heat conductivity. Carborundum and metallic powders had been used, chrome iron ore had been used, as well as certain qualities of sand. There were advantages in their use, particularly in regions where extra strength was specially important.

He had done some work on ultra-rapid chilling with nickel and chromium. The chilling or cooling from the liquid state of an alloy containing 1 per cent. chromium and the balance aluminium resulted in a considerable proportion of the chromium being trapped in solid solution, if the alloy were cast at a temperature considerably above its melting point (say 100 deg. C. above) in a mould which was relatively cold. In that case, the hardening after ageing, which suggested there was some solid solution, might be about 43, whereas it was only about 16 in the case of a specially pure aluminium casting, treated under the same conditions. In the case of nickel it was more difficult to achieve the solid-solution state. There seemed to be a sort of breakdown rather similar to that of martensite from austenite, but the fine dispersion that could be obtained seemed to produce the hardening and refining phase of that metal, and particularly in alloys which had a tendency to under-cooling. It appeared, however, that neither of those metals under so-called equilibrium conditions were soluble in aluminium up to a temperature of about 600 deg. C. Chill quenching method might produce more stable solid solution, when subjected to heat, than that produced by the normal solution and ageing treatment.

Oxide Films

With regard to the problem of oxide films, he had found a great advantage in using certain fluxes, and the cryolite originally present in the aluminium seemed to increase fluidity. That explained the advantage, referred to by Herr Röhrig, of adding new aluminium which also contained traces of cryolite from the electrolytic fluxing process. The bubbling of nitrogen through the metal had been proved to reduce the amount of oxide owing to the elimination of other gases, and nitrogen itself, not being very soluble, was easily brought to the surface. Another method which had been found useful in the case of certain alloys was to heat the oxidised metal to a rather high temperature and then to treat it with a special flux. Some people had suggested that that treatment, in an ordinary gas- or oil-fired furnace, would increase the carbon percentage, which was detrimental; but if certain fluxes were used subsequently, at about 720 deg. C., a much more fluid metal was obtained than by just heating to a temperature sufficiently high to cast.

He agreed fully with Mr. Faulkner that "flowing power" would be a very much better term than "castability," even though it might not express quite the same quality.

Influence of Carbon

Carbon was rather an interesting impurity in aluminium, and it seemed not to have been investigated very much. In some chromium alloys there seemed to be carbides of a different nature from those in steel; they were perhaps triple eutectics or even quadruple eutectics, which were rather persistent, and he felt that some of the best heat-resisting alloys were interfered with by the presence of the carbon. So far he had not been able to find very good methods of eliminating it. In chromium and molybdenum and tungsten aluminium alloys it might reach about 0.1 per cent. He did not know whether anyone had confirmed those results. The combustion of aluminium alloys for carbon estimation was very exciting sometimes, due to the violence of the reaction; in order to secure concordant results, it was generally necessary to mix the aluminium with a large proportion of mild steel of known carbon content, and then, by subtracting from the total the amount of carbon in the iron, to arrive at the amount in the aluminium.

Of course, some alloys were much more easy than others to refine and clean. The problem of fluxes had been considered fairly thoroughly, but not very systematically, and if anyone could undertake a serious research on fluxes, the results would represent a very valuable addition to the material which was accumulated by the Institute. The work might be applied to pure aluminium and also to some of the common alloys in use.

Replying to Mr. Jones, Mr. Hall said that the opalescent tint had been observed on high-silicon alloys, on moderately high-copper alloys with aluminium, and on alloys containing small quantities of copper, nickel, silicon, iron and titanium. When the tint was noted one did not usually find the small pinhole roughnesses at the tops of the runners or risers which were generally associated with pores in the bigger sections of the castings.

Mr. Hall intimated that he would extend his reply, if necessary, by means of a written communication.

AUTHOR'S WRITTEN REPLY

With respect to Mr. Logan's query as to crystal growth, these photographs (Fig. 23) may be of some interest. They are of a chill cast alloy containing 7 per cent. copper balance commercial aluminium. The metal was at 710 deg. C. and the mould at 350 deg. C. The sections ($\frac{7}{8}$ in. diameter bar) were polished and etched.

W.B. shows the grain size as cast.

W.2 ditto plus 24 hrs. heating at 200 deg. C.
W.25 ditto plus 8 hrs. heating at 250 deg. C.
W.3 ditto plus 4 hrs. heating at 300 deg. C.
W.4 ditto plus 2 hrs. heating at 400 deg. C.
W.5 ditto plus 1 hr. heating at 480 deg. C.

All slowly cooled after treatment.

The masked refining effect due to heating (precipitation) at 200 deg. C. is to be noted. Crystal growth due to annealing is not marked until 300 deg. C. is reached. Alloys high in zinc also show this, those relatively low in copper and zinc are less liable to change in grain size. Diffusion at annealing temperature is also marked in alloys containing considerable silicon and magnesium. Change in micro-structure, due to heat-treatment, is less liable to occur in alloys that have been very slowly cooled from the liquid state.

Queries were also made in connection with the 'castability' test and the other apparatus shown in Fig. 20. The former is drawn about $\frac{1}{16}$ natural size. It is an open mould $1\frac{1}{2}$ in. deep. The 'waist' central portion is parallel for $1\frac{5}{16}$ in. wide (not quite as shown in Fig.). The two rings shown on the fluidity tester, are to prevent overflow, they can be made of sheet iron and are about $\frac{5}{8}$ in. in width. The chill and bottom plate are kept free from scaling or rusting black lead—finishing with a brush and rag to wipe off excess. The former is 10 in. long, $2\frac{3}{4}$ in. square, with a 0.8 in. square hole in it, the slots at the bottom 0.040 in. These being four in number (and 0.8 in. wide) as indicated in the sketch.

The flowability outfit is a closed sand mould, the feed being $2\frac{1}{8}$ in. dia. and 4 in. high. The amount of metal used in these last two tests is controlled sufficient to completely fill each as used.

Paper No. 613

TRENDS IN THE NON-FERROUS FOUNDRY

By L. B. Hunt, M.Sc., Ph.D. (Member)

To attempt to outline the current trends of development in the non-ferrous foundry is an unenviable task, if only for the reason that it is almost impossible to arrive at a satisfactory definition of the non-ferrous foundry. The activities and outlook of the small brass foundry, for example, are obviously very different from those of the firm producing large quantities of aluminium or magnesium alloy castings for the special requirements of the motor vehicle and aircraft industries, while the production of zinc-base pressure die-castings involves a further set of factors but must necessarily be included as an important section of the industry. Each branch has its own problems and each is making its own developments; these are well known to those engaged in the individual sections of the industry, but it will be readily admitted that many of the principles underlying foundry technique and progress in these more or less water-tight compartments are essentially the same. For this reason the author will attempt to meet the request for a Paper dealing in a broad way with present trends and probable future developments by describing what appears to him as the most important factors bearing upon the manufacture of cast non-ferrous metal products in general, but with particular reference to those developments which, now fully apparent in one branch of the industry, show promise of more widespread influence in others, and also to certain developments in competitive materials and fabricating methods as they affect the non-ferrous foundry.

It will be convenient to group these factors under three headings, covering (1) materials, (2) methods, and (3) products. A certain amount of overlapping is unavoidable, but this appears to be the most logical system upon which to base such a discussion.

I. MATERIALS

The objectives in all foundry work may be taken as improvements in soundness, strength and economy. In what ways are the metallurgical materials available to the non-ferrous foundry to-day contributing towards the attainment of these objectives? Among the most important factors are the remarkable improvements in the purity of the primary metals during the past few years, and the development of new and improved alloys of high strength properties. The great strides that have been made in the production of high-purity metals have not all been of immediate practical value to the foundry, however; oxygen-free high-conductivity copper, for example, containing less than 0.004 per cent. of impurities, and melted and cast in an inert atmosphere, obviously cannot be re-melted for foundry use and still remain the same product, while the high-purity aluminium produced by the Gadeau process, and averaging over 99.99 per cent. purity has not yet found any foundry applications, although it will quite probably find employment in the production of special alloys before long. However, aluminium of over 99.8 per cent. purity has been made available by the exercise of careful control in the production of alumina from bauxite, in the production of carbon electrodes, and in the reduction of the metal.

The outstanding achievement that concerns foundrymen is the production of 99.99 per cent. zinc by the process of fractional distillation. It has been established that the production of successful zinc-base die-casting alloys demands a very high-purity basis metal, and for this reason a plant was laid down in this country in 1934 by the Imperial Smelting Corporation, Limited, for the further refining of the zinc produced by the vertical-retort process. By the fractional distillation process a zinc is produced with a purity well above 99.99 per cent., lead having been reduced to well below 0.001 per cent. while cadmium and iron remain to the extent of about 0.001 per cent. Great care is, of course, taken in the subsequent production of the die-casting alloys that no contamination takes place, and similar care is necessary in the use of these alloys in the die-casting shop. The result of this development has been a marked improvement in the physical properties of the alloys, freedom from intercrystalline corrosion, and dimensional stability under adverse atmospheric conditions.

Internal Competition

Internal competition among the primary metals is a factor worthy of some consideration. This is affected not only by technical advantages and limitations but also by questions of availability and price. Aluminium casting alloys have, of course, eaten somewhat into the field of the brass and bronze foundry, as into that of the iron foundry, and have recently been assisted in this by the high price of copper. Although no statistics are available, it is known that the consumption of aluminium alloy sand- and die-castings has increased very markedly during the past few years. The use of aluminium-alloy cylinder-heads is increasing, but an interesting movement in the opposite direction is the tendency—chiefly in the United States—to turn to copper as a basis for motor vehicle cylinder heads. High-conductivity copper alloys, containing a small percentage of chromium, have been employed for this purpose.

The increasing consumption of magnesium alloy castings is reflected in the steps which have been and are being taken to produce magnesium in this country on a large scale. It is likely that a reduction in the price of this metal will eventually result from these activities, and will be followed by a further increase in consumption.

The rapid growth in the consumption of zinc-base die-casting alloys over the past few years has not been at the expense of other non-ferrous metal products to any appreciable extent, but rather at the expense of cast iron, malleable iron and, more recently, of sheet steel pressings.

Consumption of these alloys has increased from about 6,000 tons five years ago to 13,000 or 14,000 tons per annum at the present time, the major part of this increase having taken place over the past two years, or since high-purity zinc has been available.

Secondary Metal

Many of the requirements of the non-ferrous foundry are met by secondary metal of one kind or another, and here a noticeable and desirable tendency is towards the production of secondary ingots by refiners specialising in this business. With increasing control of the virgin metals available, the varied nature of the scrap entering the foundry becomes increasingly dangerous, and must obviously be avoided as far as possible. The obvious solution to the difficulties presented by this problem and by the increasing quantities of re-worked metal in circulation is to turn the whole problem over to the specialist, who will in any case have many subsidiary problems to tackle in connection with the control of his furnace atmospheres and the action of his fluxes. If these be handled thoroughly, there is no reason why secondary alloys having excellent and consistent physical properties should not be produced.

New and Improved Alloys

The non-ferrous foundry is constantly being provided with improved materials as the result of continuous research on the constitution and properties of the alloys of the principal basis metals. The range of high strength non-ferrous casting alloys was well described by Murphy[1] in 1935, and need not be reiterated here. In the case of aluminium alloys in the past year or two the major tendencies have been the increasing use of heat-treated alloys, improvements in the heat-treatable aluminium-silicon alloys containing from 6 to 10 per cent. of silicon, and the use of grain-refining additions such as titanium and cerium. Gwyer and Dyson[2] report that the heat-treated silicon alloys show definite advantages over some of the other heat-treated alloys, are easier to cast, give less trouble in the foundry, and seem less liable to develop internal cracks and strains on quenching from high temperatures.

Several new magnesium alloys are in course of development, including a cerium-cobalt-manganese alloy which retains an appreciable proportion of its strength at temperatures up to 300 deg. C., and is stated to be suitable for pistons. Improvements are needed and may be expected in magnesium alloys particularly suitable for pressure die-casting.

Mould Materials

The increasing attention which is being given to the treatment and control of moulding sands is too well known to foundrymen to require emphasis. This is only one example, in fact, of the major tendency towards greatly increased precision and control which characterises all the activities of the non-ferrous foundry.

In addition, there is evidence of a slow but valuable increase in the knowledge of the properties of sand, particularly at those temperatures at which it is really important to know something more about them—the temperatures at which castings are poured. Hudson[3] has published the results of his investigations on this subject, and has indicated possible methods for controlling the properties of mould and core materials at elevated temperatures with the object of eliminating or minimising scabs, hot tears, dimensional inaccuracies and other defects.

Considerable interest is being taken in the possibilities of using materials other than sand for moulds. The Randupson process, employing a weak type of concrete, gives a more rapid rate of solidification than sand, and a greater permeability. Quite recently Hudson[4] has described an investigation of several plastic moulding compositions in respect of their thermal conductivities. From this work it is established that the commonly-used moulding sands have a low and fairly constant thermal conductivity, and that it is a practical proposition to produce plastic moulding compositions having a conductivity superior to that of steel and almost equal to that of copper. Such mixtures, based upon graphite or carborundum with additions of bentonite and a liquid binder, can be used repeatedly, and will undoubtedly warrant further investigation and trial.

In the die-casting branch of the industry the mould material problem is more or less acute, and improved die steels are constantly in demand. Steels are required which will withstand rapid heating and cooling, have a high thermal conductivity, and be machinable in the soft state. The difficulties encountered naturally vary with the casting temperatures employed, and become apparent with the aluminium alloys. With the copper alloys, however, the die steel problem is actually the limiting factor, and any further developments in brass pressure die-casting will be entirely dependent upon the provision of improved mould materials.

II. METHODS

When considering the methods employed in the non-ferrous foundry, the factor previously apparent—increasing precision and control—is again in evidence, but is accompanied by another major factor, the tendency towards the planning of operations in advance by foundry engineers and the consequent smaller part played by the skilled operative. It is not proposed to enter into a discussion of the relative merits of the various types of melting equipment now available, but it can be said that in choosing such equipment, the tendency is to give greater consideration to the possibilities of rigid control of the furnace atmosphere, pouring temperature and composition of the charge rather than to the question of first cost. The ideal melting conditions are obviously those in which contamination of the melt is impossible, and electric arc resistance and induction furnaces offer considerable advantages in this direction. At the same time, by reason of marked improvements in the manufacture of crucibles and in the design and construction of furnaces, the possibilities of contamination by gaseous or non-metallic impurities have been considerably reduced with other types of melting equipment.

Cleansing Methods

It is well known that considerable research has been carried out on the contamination of melts, particularly of aluminium alloys, by gases, and a number of methods have been devised and operated with more or less success for the removal of these gases. This is really only one aspect of the whole problem of the "cleansing" of melts, or of what has been described by Prof. Hutton as "sanitary metallurgy," and one of the most important factors in the near future is certain to be that of the application of more fundamental knowledge of gas-metal equilibria to non-ferrous foundry practice. Part of this tendency may already be observed in the attention given to contamination by gases during melting, but it is most likely that improved and probably simpler methods of removing gases will be developed, while at the same time greater control of shrinkage and the position of shrinkage cavities is likely to be obtained.

The precise action of deoxidisers and fluxes in the removal of impurities also requires much further study and elucidation, and when more is known of the mechanism of these reactions an appreciable improvement in the soundness, consistency and physical properties of castings may be expected. The remarkable results obtained by Lepp[6] give some idea of the possibilities. The suggestion has been made more than once that molten metal should be actually shaken up with solvent fluxes, much as the chemist uses his separating funnel, and as it is apparent that the efficiency of fluxes depends largely upon the intimate mixing of flux and metal, this idea may quite possibly find application in certain branches of the non-ferrous foundry. Whether or not such shaking is resorted to, however, it is substantially certain that more efficient mixing must be achieved before the full benefits of deoxidisers and fluxes are realised. Looking rather a long way ahead, it is possible that advantage may be taken of the properties of supersonic waves—sound waves of such high frequency that they are well beyond the limit of audibility—in bringing about the required degree of agitation of metal and flux.

An extensive amount of literature exists on non-metallic inclusions in steel, but metallurgical authors generally maintain a discreet silence on the subject of oxide, sulphide and similar inclusions in non-ferrous metals and their effects on structure and properties. An important field for investigation exists here, and should one day yield results of value to foundry metallurgists.

Professor Hutton[6] has suggested the actual filtration of molten metals, and while this may be more suited to the production of billets for rolling, etc., it is a possibility to be borne in mind in the foundry. In fact a desirable tendency would be to regard molten metals in much the same light as the chemical engineer regards his solutions. Chemical engineering technique has been successfully adapted to the purification of molten zinc by fractional distillation, and there appears to be further scope for the application of such technique to the purification of metals for foundry use.

Moulding and Pouring

The tendency towards the employment of the unskilled or semi-skilled machine moulder and the ordered planning of moulding and running methods by the technical staff of the foundry shows, of course, every sign of continuing to its logical conclusion in all but the smallest of jobbing foundries or in those foundries where conditions are obviously unsuited to such methods by reason of the unusual size or nature of the castings produced. In this, the foundry is but following the machine shop, in which every operation is foreseen and provided for. Foundry planning may not be by any means so simple a matter as this, but its advantages cannot be denied, and it is certainly coming to stay. Probably the greatest difficulty is in finding the right type of man for such work, as he must be something of the engineer, the foundryman and the metallurgist; he must stipulate in advance the precise method of moulding to be employed, the type of pattern equipment required, the disposition of gates and risers, the pressure of ramming and the nature of the sand to be used. It is quite probable that, partly as a result of the educational facilities now available in foundry practice, a new type of foundry engineer will slowly develop to fill this kind of post. His most important requirement will, in the author's opinion, be the ability to visualise the flow of molten metal in a mould, and thus the optimum conditions for pouring and running any particular casting, so as to obtain progressive solidification and a sound casting with the absolute minimum of preliminary experiment or adjustment.

At the present time it has been found necessary to devise special running methods for particular groups of aluminium alloys, and this tendency towards more or less standardised practice for special materials will undoubtedly continue.

Casting methods for ingots and billets of aluminium and copper have received considerable attention in the last few years, and a number of improved methods have been evolved to ensure the slow and steady flow of metal into the mould. In the foundry, however, very little attention has been paid to improving the methods of pouring that have been in use for generations, although it appears to be a reasonable assumption that similar methods of mechanised pouring, suitably modified from those employed for billets, should find application in the progressive foundry.

One very marked trend in the production of cast non-ferrous products is, of course, the application of pressure to both pouring and solidification, and the consequent transfer of certain types of products from the sand foundry to the pressure die-casting shop, and the capture of several markets from the iron foundry and the press shop. The technique of pressure die-casting does not require description here, but its advantages—high-speed production, dimensional accuracy, good surface finish, economy and elimination or reduction of machining operations—have rapidly made it a most important branch of the non-ferrous foundry. The main tendencies of recent years have been towards higher pressures and thus greater freedom from unsoundness, and the use of hydraulically-operated machines. With modern machines die-castings of virtually perfect soundness can be produced, while the production of brass pressure die-castings has been made practicable.

III. PRODUCTS

To enlarge upon the improvements in the mechanical properties of non-ferrous castings during the last few years would be merely to stress the obvious. As with cast iron and other materials, cast non-ferrous products are providing engineers and other users with materials of marked superiority to those of several years ago, largely, of course, owing to the developments and improvements which have been referred to earlier in this Paper, but particularly on account of the attention given to soundness, grain refinement and heat-treatment. In the recent discussion on light alloys at the London Congress of the International Association for Testing Materials, for example, Murphy emphasised the very great advance that had taken place in the heat-treatment of magnesium alloy castings on a large scale, and the consequent improvement in proof stress obtained, while Sutton drew attention to the remarkable improvement in the fatigue resistance of both the aluminium and the magnesium alloys. There is a conspicuous gap in the available knowledge of one property of these materials, however—their sensitiveness to stress concentration effects due to notches and rapid changes of section. It is realised that aluminium alloys are generally more susceptible in this respect than copper alloys, while magnesium alloys are still more sensitive, but little or no real data exist on the matter. The related property of damping, in which cast iron shows up so well, also requires further investigation as regards the non-ferrous casting alloys.

The grain refining influence of such additions as titanium and cerium on aluminium alloys and the modification of the aluminium-silicon alloys have led to some speculation on the possible application of the same idea to the copper alloys. Lorig and Dayton,[7] for example, have reviewed the possibilities of modifying brasses and bronzes with small additions of iron, manganese, molybdenum, tungsten and other sparingly soluble metals to bring about grain refinement, greater uniformity in structure and freedom from segregation. To some extent, of course, the manganese brasses (improperly called manganese bronzes) represent a step in this direction.

Basic Properties

Much further knowledge is required of the properties which can reasonably be expected from perfectly sound and pure cast alloys, *i.e.*, of the ideals towards which developments can be directed. A good beginning has been made in this work by the British Non-Ferrous Metals Research Association,[8] who have carried out preliminary work to ascertain the properties of pure and gas-free bronzes and have obtained some very high strength and density figures. Starting from this datum line it is proposed to ascertain accurately the influence of external factors, particularly gas atmospheres, on the physical and mechanical properties of foundry bronzes.

Competitive Methods and Materials

One of the most interesting studies connected with the non-ferrous foundry lies in attempting to follow the ebb and flow of competition from alternative methods of production. Whatever progress has been made in the foundry in recent years, it must be conceded that still greater progress has been made in the various plastic working methods taken collectively, and in methods of joining—soldering and welding. The most outstanding feature is the increasing use of the power press in one form or another, and the non-ferrous foundry industry has undoubtedly lost some of its territory to the producers of hot brass stampings, aluminium and magnesium alloy forgings and other wrought materials. To a certain extent this is inevitable with the advancing technique of plastic working, but at the same time the foundry itself must be held responsible for the loss of certain markets.

Not many years ago engineering design was very largely a question of choosing a casting or a riveted structure; any not-too-recent text book on machine drawing and design will clearly demonstrate this. With the rise of the production engineer and the development of a much wider range of fabricating methods, however, designers have been given very much more scope, and a new concept of the utilisation of methods and materials has grown up. In addition to those mentioned above, therefore, the foundry has to meet the onslaught of sheet metal working methods, extrusion—which is producing more complicated sections almost daily, and can now provide closed sections in aluminium alloys —cold upsetting, and welded or soldered assemblies. It is not merely a question of one or other of these methods capturing certain types of engineering components from the foundry, but of ingenious combinations of two or more methods being devised by the production engineer to increase output and reduce costs. For example, many small parts once made in the foundry are now being fabricated by the projection-welding of two or more sheet steel pressings, while combinations of extrusion and cold upsetting or press forging are becoming more prevalent.

One very important factor in this drift is the untrammelled outlook of those responsible for the newer metal working methods. There is no tradition which says that this or that cannot be done, and it is partly for this reason that on many occasions orders are lost to the foundry—particularly the brass or bronze foundry—which might have been secured by a greater exercise of initiative from within. Designers may employ a different method of fabrication in re-designing a particular part to reduce weight or cost, when actually a re-designed or improved casting would meet their case as well or better. Rowe[9] quotes an interesting example of this kind of thing:—

> " A certain engineering part had been made in bronze for over 30 years. The use of bronze for this part was universal in the trade and its indispensability for the duty regarded as axiomatic. But a bold spirit in the engineering world, defying tradition, decided that a heat-treated light alloy stamping should be used for this part and his early trials clearly indicated that this was, as compared with the bronze casting, superior. It was only when the bronze founder spent a considerable amount of money in research and discovered that the bronze castings could be made at least 40 per cent. better that the situation was saved for the industry."

Mr. Rowe adds, and the author fully endorses the remark: " Not all such examples end or will end so satisfactorily for the bronze founding industry." The need here is obviously for progress coupled with propaganda to keep engineers and designers fully alive to the advantages that foundrymen can offer in competition with wrought products. It is here that the metallurgist or metallurgical engineer associated with an engineering concern can be most helpful in linking the foundryman and the designer. This point has previously been emphasised by the present author[10] in the following words:—

> "There has been considerable talk of co-operation between the designer and the foundry—of fillets and recesses, cored lugs and changes of section—and although such points as these certainly require full mutual discussion, there is actually a far wider field for co-operation between manufacturer and user than is indicated by these details of casting design. The available methods of production are becoming at the same time so diverse in nature and so complicated in their gradation from one to the other, that it is fast becoming impossible for designers and buyers to keep pace with developments and to make the best possible use of the available production methods. It was once suggested that the right and proper person to provide the necessary link between drawing office and foundry was the metallurgist; this suggestion certainly contains the germ of the truth, but in the view of the present writer much more of the services of the metallurgist or metallurgical engineer of the future will be required in helping to sort out the most appropriate and economical production methods for the components required by the designer, but imperfectly visualised by him in terms of casting or forging, pressing or die-casting, machined stock or extruded or cold-drawn section."

Among all this welter of competitive methods there is one shining example of the foundry industry re-capturing business formerly lost. Pressure die-castings, particularly in the zinc alloys with which considerable intricacy of detail and minimum wall thickness may be obtained, are being employed to an increasing extent in place of sheet metal assemblies, with a reduction in cost, and generally an improvement in finish and appearance. One such die-casting may thus replace two, three or four small pressings and eliminate welding or other joining operations. Motor vehicle radiator grilles, for example, are being die-cast in zinc-base alloys in America by a number of firms, and developments in this line, and probably even more surprising cases of the replacement of sheet metal assemblies, may also be expected very shortly in this country. A further case of carrying the war into the enemy's country is the die-casting of mouldings—such as are now produced by extrusion—in either straight or curved lengths up to 50 in. These may be obtained in the United States in a variety of sections, and are surprisingly thin.

Casting Tubes and Rods

Finally, although it is not perhaps foundry work in the strict sense of the term, one further development which must be referred to as an indication of the trend of events is the production of copper and brass wire rods, tubes and other sections by a continuous casting process. This method,[11] associated with the name of Eldred, is based upon the very careful control of cooling conditions, so that freezing progresses continuously in one direction, the major portion of the heat being removed through the preceding solid metal. By casting these semi-manufactured products, the preliminary hot-working stage, where most difficulty and wastage usually occur, is reduced or eliminated, and the cast shapes have superior properties to those produced by the usual methods. The direct casting of sheet metal is also, of course, being developed in the United States.

Outlook for the Future

Before concluding this survey of the non-ferrous foundry industry, it seems desirable to consider what lies ahead, and what is needed to help in attaining the objectives sought.

It has been shown that increasing precision and control of metal, sand and temperatures are well in evidence, with careful planning taking the place of empirical and individualistic methods. To produce still sounder, stronger and more uniform castings it appears that foundrymen will require a considerable amount of new information on melting practice and on the properties of alloys prepared under ideal conditions, and a fresh outlook on quite a few points, particularly on pouring methods and on the purification of melts by fluxes and other methods. They will need to pay greater attention to casting under pressure, both for low- and high-melting point alloys, and to the advantages obtained with this process, and they can apparently look forward to the development of two new or improved types of technologists--the foundry engineer-cum-metallurgist on one side, and the metallurgical or materials engineer on the other. The future lies to a great extent in the hands of these two, working closely together.

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Paper No. 614

THE USE OF NICKEL IN NON-FERROUS ALLOY CASTINGS

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Nickel is to-day being used in many different types of non-ferrous castings, and for the present symposium it was thought that it would be of interest to review its position in this field. This Paper, therefore, does not touch original ground, nor is it intended to be highly technical, or even inclusive, but its purpose is to show the scope of the application of nickel in relation to all the common non-ferrous casting alloys. The field is so wide that much detail has of necessity been omitted and attention has been directed primarily to those alloys considered to be of special interest from the foundry point of view at the present time, *viz.*, the bronzes and nickel-silvers.

Whilst the Paper is confined in most cases to describing the beneficial effects of nickel additions, it must not be concluded that all the foundryman has to do is to add some nickel to his casting, whatever the alloy, to improve it. There are cases where nickel or excess nickel can be deleterious, and, when nickel is used, extra foundry precautions may sometimes be necessary. Nickel additions, like those of other alloying elements, may well be wasted if not scientifically used.

Although the melting point of nickel is higher than the other common non-ferrous metals used in the foundry, it dissolves without undue difficulty in the majority of them, though pre-alloys or alloyed ingots are desirable for certain compositions. The facility with which nickel alloys with other elements has been one of the reasons why it has received so much attention in the past.

With few exceptions, the general influence of nickel is similar, whatever the base to which it be added, and it can be broadly stated that it has the following effects:—(1) Raises the melting point; (2) increases the strength and hardness; (3) assists in the retention of these properties at elevated temperatures; (4) decreases the grain size; and (5) improves the corrosion resistance. Apart from the consideration of the intentional addition of nickel to castings, the fact that appreciable percentages of nickel are frequently present in available scrap renders it doubly important to understand its influence.

Bronze

The use of nickel in bronze dates back many years, and there have been many references to the matter in technical literature, but apart from broad statements of its beneficial effects, there has not, until comparatively recent years, been any fundamental study of the subject. Now, however, as the result of researches carried out, particularly in America,* the position is rather more clear. Special attention has recently been focussed on this subject, because of the present wide price difference between tin and nickel and the possibilities that exist for effecting substantial economies in metal cost by the replacement of a portion of the tin by nickel.

The α-phase area of tin bronzes is considerably narrowed by the addition of nickel, and consequently the hard constituent separates out at progressively lower tin contents as the nickel content is raised, thus enabling a minimum tin content to be used to give a desired hardness. There is, in addition, evidence of some not yet fully understood constituents present in nickel-containing bronzes. High nickel contents give rise to precipitation-hardenable alloys, since the solubility of the constituent that separates out falls with temperature. It has been stated that very roughly equivalence in gross structure follows the substitution of nickel for a like amount of tin and the desirable tin contents in bronzes

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* See Bibliography; page 368.

containing nickel are less than in the nickel-free bronzes.

A further structural effect resulting from the presence of nickel relates to the distribution of lead in lead-containing bronzes. The fact that the addition of a small percentage of nickel promotes even and fine distribution of lead in bronzes of both low and high lead content has been recognised for many years, and this has been attributed to the fact that it increases the solubility of lead in molten copper. In addition, the solidification point is raised and the lead has less chance to segregate and is mechanically trapped. Zinc appears to counteract this effect of nickel, and nickel is not so effective in low tin content alloys. It has been suggested, therefore, that as lead appears to be carried with the hard tin constituent, the effect of nickel is through its influence on the distribution and the proportion of this constituent. In the presence of phosphorus, nickel, like copper, forms a phosphide compound.

The effect of nickel on the physical properties of bronzes is marked. It is generally accepted that nickel densens bronzes, although exactly what is meant by this is not always clearly defined. It has been demonstrated, however, that whilst the true freezing-shinkage is not modified to any important extent by the addition of nickel, this element does enable sounder castings to be produced, particularly when the pouring temperature is high. Associated with this effect is the question of grain refinement. This again is a definition requiring further explanation, since, as Pilling and Kihlgren[1] [3] have pointed out, true grain size is probably only one of the several factors affecting the texture of a fracture as seen by the naked eye. The elimination of internal oxidation, the dispersal of incipient shrinkage cavities, the method of fracture, as well as changes in size or shape of the grain itself, all alter the nature of this appearance. Apart from its influence on density, however, nickel did appear (from Pilling and Kihlgren's experiments) to have an actual effect in reducing the true grain size. In the usual range of pouring temperatures, the refinement averaged about 50 per cent. reduction in mean grain size (diameter) for the addition of 1.5 per cent. of nickel or less. It has also been reported that the coarse dendritic grain growth caused by the presence of small quantities of aluminium or silicon in low-tin leaded-bronzes is counteracted by nickel, although 2 to 3 per cent. is necessary to offset the effect of 0.05 per cent. silicon.

Considerable investigation has been made of the way in which the mechanical properties of bronze are influenced by the presence of nickel. The magnitude of the effect depends on the nature of the base metal, and foundry practice, and differs also according to whether nickel is being used to replace copper or tin. Most of the data available relates to additions to a standard base-alloy but, as mentioned above, the present tendency is to consider the matter from the tin-replacement point of view. In general, it may be said that nickel improves the tensile and compressive strengths and hardness of bronzes, without detriment to, and frequently with improvement in, toughness and ductility. Increases in proportional limit and yield point relatively greater than the increase in maximum strength are achieved. The optimum nickel content varies with the base mixture, and is, in general, lower with higher tin and/or lead content. Increasing the nickel beyond this optimum content may result in a decrease in the elongation value and necessitate special foundry treatment. The most useful nickel range is usually between 1 and 2 per cent., but in certain instances as little as ½ to ¾ per cent. is distinctly beneficial. (Table I.)

Improvement by Heat-Treatment

Interesting results have been obtained on the improvement by heat-treatment of the mechanical properties of nickel-tin bronzes of rather higher nickel content than dealt with above. A prolonged soaking at a high temperature (in the region of 760 deg. C.), followed by a softening quench and subsequent low-temperature tempering treatment at approximately 260 to 300 deg. C., markedly increases the mechanical properties of certain compositions. As an alternative to this heat-treatment, the cooling of a sand casting can be so controlled as to develop the precipitation-hardening effect in the as-cast condition. Special care is necessary in melting these heat-treatable alloys, and impurities need to be carefully controlled to give optimum results. Typical compositions which show promise of considerable development falling in this group are the 88:5:5:2 copper-tin-nickel-zinc alloy, and the alloy containing 7.5 per cent. nickel and 8 per cent. tin. The latter, in the form of heat-treated test-bars, has given a tensile strength in excess of 40 tons per sq. in., associated with an elongation of 15 per cent.

Nickel, either in the form of pellets or as 50:50 cupro-nickel alloy-shot, dissolves quite readily in molten copper at a temperature well below its own melting point. It may either be added with the charge or to the copper when molten. No loss is normally experienced in remelting. Nickel raises the melting point of bronzes without appreciably affecting the freezing range. This fact does not, however, introduce difficulties, since nickel appears to have a fluidising action on bronze, and although the value of this is difficult to assess quantitatively in the foundry, laboratory spiral fluidity tests have shown increased lengths of run up to 40 per cent., resulting from an addition of 0.5 per cent. of nickel. The magnitude of this effect increases with the nickel content up to a certain moderate percentage of nickel and varies considerably with the basis mixture.

The number of different compositions used at present is too large to give in great detail here, but some representative compositions will be taken and the type of purpose for which they are suitable will be indicated.

Gunmetal Types

For general purposes, modifications of the 88:10:2 and 88:8:4 types of alloys are widely used. Up to 5 per cent. nickel may be substituted for tin or added direct, giving an im-

TABLE I.—*Properties of Some Typical Nickel-Bronzes.*

Composition.					Y.P. Tons per sq. in.	M.S. Tons per sq. in.	E. Per cent.	B.H.N.	Remarks.
Ni.	Cu.	Sn.	Pb.	Zn.					
5	88	5	—	2	9	21	34	86	
5	88	5	—	2	29	38	38	136–171	By heat-treatment.
4	88	4	—	4	—	21	30	—	
3	87.75	8	1.25	—	—	15	12	90	
*1	88.25	10.5	—	—	8–14	14–22	8–30	70–85	Phosphorus 0.25 per cent.
*0.5	88	11.2	—	—	12–16	18–22	5–15	90–105	,, 0.3 per cent.
									Centrifugal castings
*1	81.7	12	5	—	10–14	13–18	4–10	70–80	Phosphorus 0.3 per cent.
*1	80.7	10	8	—	10–12	14–17	6–12	65–75	,, ,, ,,
*1	76.7	10	12	—	6–7	13–18	20–30	45–55	,, ,, ,,
1	84	6	3	6	—	16	27	65	
2.5	85	2.5	9	1	—	12	12	—	
1	69	5	25	—	—	10	17	47	Chill Cast.
7	77	5	3–6	8	—	9 min.	9 min.	—	
14	74	4	—	8	12 min.	22 min.	11 min.	—	

* By courtesy—David Brown & Sons (Hudd.), Limited.

provement in strength properties and ductility. An interesting point established in America is the fact that for castings which require to be subsequently nickel and chromium plated, the finer grain of the nickel-bronze casting enables a better adhesion of the deposit to be secured. No systematic determination of the corrosion-resistance or erosion-resistance of nickel-containing bronzes has been made, but it has been frequently reported that improvements over a straight bronze have been obtained, and this has been attributed in part, not to any change in what might be called inherent resistance, but to the denseness and fine grain of the casting itself. Where the bearing property of a bronze is of prime importance, care must be exercised in the use of nickel percentages in excess of one or two per cent., since, in some circumstances, the addition of higher percentages of nickel than this adversely affects the bearing property. In addition, more adequate feeding may be necessary; it is generally recommended that 0.04 per cent. of phosphorus be added to deoxidise these higher nickel alloys.

The 88:5:5:2 copper-tin-nickel-zinc alloy has been extensively used for catenary clamps and trolley-wire hinges in railway electrification schemes abroad and, after a heat-treatment such as described above, the alloy is used for heavy-duty electric circuit breakers. The 88:4:4:4 copper-nickel-tin-zinc alloy is a general all-purpose alloy, conveniently handled in the foundry and largely used for fittings in the marine field. In lead-containing alloys for anti-frictional bearing purposes, nickel is included in the whole range of compositions. Typical alloys for medium and heavy loads are 80:11:1:1, 80:8:10:2, 70:6:15:1 copper-tin-lead-nickel. The last also contains ½ per cent. of zinc, and is used for railway carriage bearings. In pressure castings of the red-brass type, 1 per cent. nickel is used in such articles as plumbing fittings, valves, etc., to increase pressure tightness.

High-duty worm-wheel phosphor-bronzes, containing in general 10 to 11 per cent. tin, 0.2 to 0.5 per cent. phosphorus, usually contain 0.5 to 1 per cent. of nickel; the nickel addition has been found useful in centrifugal castings to give shock resistance in thin sections, whilst it also prevents excessive grain growth in heavy sand-cast sections. Wear resistance is a further property which benefits from nickel additions to this type of material.

Aluminium-Bronze

The difficulties associated with the production of good sand castings in aluminium-bronzes have seriously limited their application and the valuable strength and corrosion-resisting properties of this series of alloys have consequently not been fully utilised. Whilst the systematic attention given to the effect of nickel in tin-bronzes has not been paid to its effect in the corresponding aluminium-containing alloys, nickel is known to exert an interesting influence on the physical and mechanical properties of the alloys, and in some cases with high nickel contents completely to change the nature of the heat-treatment required to produce maximum strength and hardness. Quenching softens such alloys and re-heating hardens them, the reverse procedure of normal aluminium-bronze castings.

The "self-annealing" or embrittlement occurring during the comparatively slow cooling of some aluminium-bronze sand castings can, as is well known, be overcome by the addition of 3 to 4 per cent. of iron, nickel or combined nickel and iron additions, and this constitutes one of the reasons for the presence of nickel. In chill or die castings, where cooling is too rapid to enable the embrittling $\beta \rightarrow \alpha + \delta$ change to occur, nickel is added, in conjunction with iron, to give maximum mechanical and elastic properties.

Smaller percentages of nickel, *e.g.*, 1 to 3, are used in the general run of aluminium-bronze compositions, and it has been stated that in addition to the strengthening effect, nickel helps to ensure a close, dense, fine-grained alloy, suitable for hydraulic castings.

In castings, 7 per cent. of nickel is generally considered to be the upper limit, beyond which, although the tensile strength may further increase, a sharp decline in ductility occurs. The alloy containing 10 per cent. aluminium and 5 per cent. nickel has been found to have excellent all-round properties, particularly from the point of view of resisting sea water corrosion, in which direction the presence of nickel is specially helpful. A similar alloy with 5 per cent. iron and nickel developed under the name of Superston L189 has the following properties as sand-cast:—

Maximum stress ..	42 to 45 tons per sq. in.
Yield point	22 tons per sq. in.
Elongation on 2 in. ..	15 per cent.
B.H.N.	160 to 190.
Fatigue strength ..	15 tons per sq. in.

Die-castings of nickel-aluminium bronzes are widely used for automobile parts, motor boat fittings, etc. Alloys such as Superston L189 mentioned above, due to their resistance to chemical reagents, find use in the chemical industry for valves, in the paper industry and for many acid-resisting purposes.

Nickel-Brass and the Nickel-Silvers

The high-tensile brasses or manganese-bronzes owe their excellent mechanical properties to a large extent to small percentages of added elements, of which nickel is, in certain instances, one. On the basis of Guillet's well-known and widely used " coefficients of equivalence," 1 per cent. of nickel is equivalent to − 1.3 per cent. of zinc, *i.e.*, it acts as copper and tends to increase the α content of the alloy, differing in this respect from elements such as aluminium, tin and iron, which have the opposite effect. The data available on the effect of nickel and, in fact, of other elements on the cast high-tensile brasses are not altogether conclusive, due in part to the fact that the direct effect of the added element may have been masked by the change in the relative amounts of α and β present.

Guillet, Smalley and Sturney have all studied the effect of nickel and have established that a useful range of alloys can be obtained by adding this element, which, as would be expected from a negative coefficient of equivalence, has, unlike aluminium, no outstanding effect on the mechanical properties, but results in improvements in other directions.

In quaternary and the more complex high tensile brasses, nickel improves ductility, and an alloy of this nature, known as " Turbadium " bronze (containing 45 per cent. of zinc, 2 per cent. of nickel with smaller percentages of iron, tin and manganese), has in the sand-cast condition a tensile strength of over 40 tons per sq. in. combined with good ductility. This bronze has been used particularly for marine propellers, as it withstands well the erosive action of sea water.

With a four to one nickel-aluminium ratio, castings are being made which are susceptible to heat-treatment of the age-hardening type. After heat-treatment such castings have sufficient hardness to make them valuable as non-sparking tools, *e.g.*, hammers.

Pilling and Kihlgren[1] have studied the effect of nickel on a yellow brass containing 70 per cent. copper, 1 per cent. tin and 2 per cent. lead, and conclude that this mixture is distinctly improved by nickel additions, with no indication that the useful effect of nickel terminates at any low percentage. Three per cent. of nickel increased the tensile strength, under standard conditions of experiment, by as much as 28 per cent., maintained good elongation and substantially improved compressive properties.

It is of interest to mention here a special brass developed under the name of " Tungum," which contains over 80 per cent. of copper, with small amounts of silicon and aluminium and approximately 1 per cent. of nickel. In the as-cast condition, this alloy has a tensile strength of 24 tons per sq. in., with an elongation of 37 per cent., and is particularly noteworthy for its resistance to corrosion.

The nickel-silvers have been grouped with the brasses, because they can conveniently be considered as brasses to which substantial percentages of nickel have been added. The popularity of the nickel-copper-zinc group of alloys lies in the fact that they represent the most economical casting alloys available possessing a white colour, good hardness and mechanical properties and corrosion resistance, and do not give rise to much difficulty in the foundry. In certain cases trouble may have been experienced in obtaining sound castings in nickel-silver, but this can largely be attributed to the fact that straightforward brass-foundry practice has been applied, whereas, by a few simple modifications of this practice, very little difficulty need be encountered.

Until the last few years the so-called white-metal castings used for plumbing fittings contained perhaps a maximum of 12 per cent. nickel; such castings, although appreciably whiter than brass, could not truly be called "white." A move was therefore made towards increasing the nickel content to give a whiter alloy, until the present day practice of using a minimum of 20 per cent. nickel has become standardised for general casting work. By modifying the nickel content, however, colour matches may be made with the more yellow extruded nickel-silver sections used for architectural purposes and with the bluer tinge associated with the stainless steels.

A typical modern nickel-silver alloy for making castings has a composition as follows:—

Nickel ..	..	18 to 22 per cent.
Copper ..	..	50 to 55 ,,
Zinc ..	..	20 to 25 ,,
Lead ..	..	0 to 5 ,,
Tin ..	..	0 to 2 ,,

In America the practice is to use a lower zinc alloy and the standard U.S. Government specification No. W.W.P.· 541 calls for the following:—

Nickel	20 per cent.
Copper	65 ,,
Zinc	6 ,,
Lead	5 ,,
Tin	4 ,,

Lead is frequently intentionally present in cast nickel-silvers where ease of machining rather than tensile strength is of primary importance. It is often more economical, for instance, to cast a leaded rod required for screwed tap-spindles than to use a drawn or rolled leaded rod the production of which entails some difficulty. Whether or not lead helps in the production of sound castings is still a debatable point, but since it stays out of solution it helps to break up the structure, thus aiding machining. Tin is said to increase the fluidity of nickel-silvers and to assist in the production of sound castings. It has a slight hardening effect on the alloys.

Iron is an element to which some attention has recently been given in connection with nickel-silvers, and it is in fact sometimes used up to about 5 per cent. Apart from increasing the tensile strength, it has recently been shown that iron brings out certain characteristics useful in the food handling industry; for instance, it prevents the accumulation of scum or fog on the surface, although having a general tendency to decrease the tarnish resistance. Clean tin cans or Armco iron sheet are used for making the iron addition. For normal purposes, iron is regarded as an impurity to be kept as low as possible.

With regard to the remaining impurities, oxygen is definitely harmful, and steps for deoxidising nickel-silver melts are necessary if sound castings are to be obtained. Sulphur, as in other nickel alloys, should be kept at a minimum, that is not more than 0.035 per cent Silicon and aluminium, which are occasionally used as deoxidants, have a hardening effect if present in excess, and silicon is said to be detrimental to the pressure-tightness of the alloy. Incidentally, the presence of substantial quantities of aluminium, *e.g.*, over 1 per cent., may render the alloy susceptible to heat-treatment. Excess phosphorus, another deoxidant, results in a hardening and embrittlement of the alloy. Carbon is also undesirable, although more so in worked alloys than in cast alloys. The two elements the influence of which is beneficial are manganese and magnesium. The former is usually intentionally added up to a quarter per cent. for deoxidation purposes, and a final small addition of the latter helps to finish the deoxidation process and to supplement the effect of manganese, by combining with and rendering inocuous any sulphur that might be present. Excess magnesium leads, however, to "dirty" metal. Manganese appears to have no obvious effect on the physical properties of the alloys, other than that brought about by the elimination of unsoundness, etc.

Little attention has so far been given to the mechanical properties of the nickel-silvers in the cast condition, no doubt because the principal applications of nickel-silver castings have been decorative and the alloys are not so widely used for engineering purposes. Depending on pouring temperature and the lead and other alloy contents, quite useful strengths in the region of 20 tons per sq. in. are possessed by these alloys, the elongation averaging 10 to 25 per cent. for lead-containing alloys and up to 40 per cent. for lead-free alloys. The Brinell hardness number of the 20 per cent. alloy is usually of the order of 75, but by adjusting the composition higher hardnesses are obtainable.

It is now generally recognised that whatever degree of stainlessness and tarnish-resistance a metal possesses, it is necessary to clean it occasionally, if only to remove the dirt accumulated on the surface. This being the case, it is often preferred nowadays to use a soft, coloured metal, such as one of the nickel-silvers, which, although not having the degree of corrosion-resistance of the more truly corrosion-resistant and harder-toned alloys, can be maintained in good condition with very little attention. The tarnish-resistance of the nickel-silvers increases with the nickel content and to a lesser extent with the zinc content. The effect of lead on this property has been found, under laboratory conditions of test, to be slight, but small additions of tin appear to have some benefit. As compared with brass, the nickel-silvers may be regarded as corrosion-resistant materials, and they do in fact give good service under marine and other atmospheric conditions.

Production of Sound Nickel-Silver Castings

In this connection it is important to remember that nickel-containing alloys are particularly susceptible to the absorption of harmful impurities and gases from the furnace, and it is therefore advisable to keep the melting time to a minimum, and everything possible should be done to this end. In addition, steps should be taken to protect the metal from atmosphere during melting.

Natural or forced-draft crucible furnaces are generally used for melting nickel-silver for sand castings, and provided a strong draft is available and coke is used that does not burn away too quickly, these furnaces are satisfactory. Oil and gas furnaces can be used with advantage, but electric melting methods, either of the resistance, induction or arc type, have not so far been used to any extent in the nickel-silver foundry, although some success has been achieved with the rocking-arc furnace. The high-frequency induction furnace has, also, recently been employed with excellent results for making nickel-silver ingots for rolling.

The charge may be composed of ingot metal, virgin metal or a combination of either of these with scrap, but the latter should not exceed 50 per cent. of the charge and should be carefully selected. No excessive zinc loss is experienced when this is put in with the original charge, but lead should not be added until just before pouring. It is advisable to use a cover, and for this purpose an 80:20 mixture of borax and boracic acid is suitable or a proprietary flux known as "Borocalcite." Glass may also be used, and although not such a good flux, is less severe on crucibles. In the choice of the latter the smallest size which will take the charge should be used in order to prevent undue variation in pouring temperature. Either carborundum or graphite crucibles give good results, but it is important that these should not be continued to be used after, say, 20 heats; after this stage poor castings may result, due to the fact that the pots get thin and transmit more furnace gases into the melt, also the pots do not hold their temperature so well during pouring. When molten an addition of 2 ozs. of manganese per 100 lbs. of metal should be made for the purpose of deoxidation. This can be added as metallic manganese or as cupro-manganese. A few minutes should be allowed to lapse between the addition of the manganese and pouring, and it may be advisable just before pouring to make a small addition of metallic magnesium, say $\frac{1}{4}$ oz. per 100 lbs. of metal. So that the magnesium does not burn away on the surface, it should be attached to an iron rod and plunged rapidly into the melt. The recommended deoxidation technique for the American-type alloy referred to above, is the successive addition of 0.10 per cent. manganese, 0.05 per cent. magnesium and finally 0.02 per cent. phosphorus.

Many of the faults found in nickel-silver castings are associated with the moulding technique rather than with the preparation of the molten metal. The use of unsuitable sands for moulds and cores, insufficient feeding, sudden changes of section, wrong pouring temperature and lack of adequate venting are common causes of faulty nickel-silver castings that are not difficult to remedy.

Highly-refractory open sands are necessary and moulds should be generously vented. For light castings, well-ventilated fine sands are used. For cores, bronze-founding practice can be successfully followed, and generally cores used should be collapsible. Plumbago mould facings containing loam, china clay or molasses are applicable to this type of work.

The nickel-silvers have a high shrinkage, and it is important to make adequate provision for feeding castings, heads considerably larger than those required for other copper-base alloys being required. It has been found advisable to lay out nickel-silver castings with a smaller number of pieces per gate than would be considered good practice on ordinary brass work. Whilst it is not easy, due to pyrometer difficulties, to keep a constant check on the pouring temperature, it is desirable not to vary appreciably from 1,250 deg. C. for the 20 per cent. nickel alloy and to pour fairly rapidly.

Progress in the pressure die-casting of nickel-silvers is being made, and for this purpose the zinc content is increased to give an alloy of maximum whiteness with minimum melting point.

A typical composition is as follows:—

Nickel	16 per cent.
Copper	42 ,,
Zinc	41 ,,
Lead	1 ,,

This is an alloy of $\alpha + \beta$ structure and melts at a temperature below 1,000 deg. C. A high-tungsten steel is used for the dies. Developments might be expected in the application of die-castings in this type of material.

Nickel-silver castings, in general, are used for all kinds of plumbing fittings, taps, brackets, etc., valves and cocks for food-handling plant and for general architectural metal work. In the latter connection, if it is desired to weld the casting to a wrought product, lead should be omitted from the composition, since this element promotes cracking during the welding operation.

Zinc-Base Alloys

The effect of nickel in zinc-base die-castings is of particular interest because of the likelihood of nickel or nickel-plus-chromium plated scrap being occasionally present in the charge. From this point of view nickel, if it goes into solution at all, is not regarded as deleterious, and it is not essential, as is the case with lead, tin and cadmium, to place strict limits on its presence. Nickel acts like copper and magnesium in retarding the decomposition of the unstable β constituent into α and γ. As is well known, this decomposition is accompanied by a volume change and results in microscopic cracks and a strong liability of the castings to intercrystalline corrosion.

Up to 0.3 per cent. of nickel is being used to a limited extent in zinc-base die-castings of the usual aluminium and copper and magnesium contents, but the effect of nickel in preventing intercrystalline oxidation is not as great as that of magnesium alone. . Although comparative figures on the effect of nickel on the mechanical properties of zinc-base die-castings are lacking, it is said to give a mild improvement in the tensile strength and impact values without loss in elongation. Since the melting point of nickel is so much higher than that of zinc, difficulty might be expected in getting the nickel into the alloy. Actually by using an intermediate alloy, *e.g.*, of nickel and aluminium, no trouble is normally experienced.

Tin-Base Alloys

The *rôle* of nickel in tin-base bearing metals is still a matter of some controversy. Its presence is not considered harmful, and it is, indeed, actually the practice in some instances to incorporate a small percentage of it in tin-base alloys.

It has been stated that nickel increases the ductility and eliminates the tendency to cracking without impairing the wearing qualities, but evidence in support of this statement is somewhat contradictory. Increase in the copper content appears to be necessary to counteract the effect of nickel in combining with the copper and consequently suppressing the formation of the strength-giving copper-tin needles. High percentages of nickel, *e.g.*, 5 per cent., give an appreciable increase in hardness but, owing to the formation of the compound Ni_3Sn_2, such additions lead to unfavourable impact properties.

In some standard specifications,[4] nickel is specified and indeed is often present up to 0.6 per cent., although 0.25 per cent. nickel is a more usual percentage. An alloy containing 0.25 per cent. of nickel, 7.5 per cent. antimony and 2.25 per cent. copper is in use in America for motor vehicle bearings subjected to heavy loadings and high speeds. It has a Brinell hardness number of 26.

Lead-Base Alloys

The position of nickel in relation to lead-base bearing alloys is rather more definite than in the case of the tin-base alloys in that it has an established function. Widespread efforts have been made to devise a lead-base bearing metal which would have properties comparable with those of the tin-base alloys, and experiments have taken the direction of the improvement of ternary lead-antimony-tin alloys by the addition of further elements. As a result the well-known "Thermit" alloy has been developed. Thermit (or Eel Brand) has the following approximate composition:—

Antimony ..	14 to 16	per cent.
Tin ..	5 to 7	,,
Copper ..	0.8 to 1.2	,,
Nickel ..	0.7 to 1.5	,,
Arsenic ..	0.3 to 0.8	,,
Cadmium ..	0.7 to 1.5	,,
Lead ..	72 to 78.5	,,

The nickel combines with antimony and the compound so formed acts as a hardening agent. Best results are obtained if the nickel content does not exceed 10 per cent. of the antimony content. Nickel also raises the softening temperature of the alloy to approximately 230 deg. C. Certain precautions in tinning and casting must be taken but it is a useful alloy for general purposes, and has been particularly successful for cold-rolling mill bearings and turbo-generator journal bearings. It has a comparatively high compressive-strength and a Brinell hardness of 29, from which it can be seen that from a hardness point of view it compares favourably with the tin-base alloys.

Cadmium-Base Alloys

A further group of bearing alloys which has been studied and developed in recent years is that having cadmium as a base. Silver and copper have both been used as hardeners in cadmium, but most commercial development has taken place with an alloy containing nickel as the essential hardening element called "Asarcoloy" in America and cadmium-nickel N.S.5 bearing metal in this country. This alloy contains 1.3 per cent of nickel. Nickel combines with cadmium (to a formula approximating to $NiCd_7$) to give a hard metallic compound which itself is embedded in a eutectic of this compound and cadmium, resulting in a typical so-called bearing structure. The requirements in a bearing metal for high-duty service are well satisfied by an alloy of this nature, especially from the point of view of retention of hardness and strength at elevated temperatures, a matter of growing importance in modern internal combustion engines. The following figures illustrate this point:—

Temperature. Deg. C.	Tensile strength. Tons per sq. in.	Brinell hardness number.
28	7.2	32.5
100	6.8	17.5
150	—	12.0
200	1.47	7.5

As in the case of the nickel-containing lead-base alloys, care is necessary in the metalling operations. Melting points and pouring temperatures are, of course, higher than the tin-base alloys, and slow cooling is essential to prevent cracking. High bond-strengths are, however, readily obtainable. Cadmium-nickel bearing alloys have been adopted as standard for big-end motor-vehicle engine bearings, etc., and probably they would have become further established were it not for the uncertainty which has existed concerning world cadmium supplies and prices.

Aluminium Alloys

A further group of alloys to be considered in connection with small nickel additions is the important field of light aluminium alloy castings. The general effects of nickel, when correctly applied, are, both before and after the usual type of age-hardening treatment, an all round improvement in physical and mechanical properties, particularly from the point of view of strength at elevated temperatures. It would not be possible in the space available to deal with each nickel-containing aluminium casting alloy individually, but Tables II and III set forth the composition and properties of those commonly employed in this country. Table IV gives the heat-treatments required to develop the maximum mechanical properties and Table V shows the physical properties of the same alloys, some of which are covered by patents

The heat-treatment of the nickel-containing alloys is of the same nature as that for Duralumin, namely, a softening quench followed by a hardening (precipitation-hardening) ageing treatment at room or slightly elevated temperatures. The constituents causing hardness are not, however, identical with those in Duralumin. Nickel modifies the normal $CuAl_2$ compound and also combines with aluminium as $NiAl_3$.

" Y " alloy, the best-known alloy in this group, was first developed during the war to meet the need for a strong light alloy suitable for aero-engine pistons. Its properties at high temperatures are particularly good, and it is free from hot-shortness. Gravity die-cast " Y " alloy pistons are extensively used in the motor industry, but to some extent castings are being replaced by forgings in aero engines. Light marine diesel-engine pistons are cast in " Y " alloy and improved results, from the point of view of overcoming distortion troubles in these castings have been obtained by increasing the ageing temperature over that shown in Table IV.

The "R.R." group of alloys are a further development in the field of high-strength aluminium casting alloys. R.R.53C combines the excellent casting properties which R.R.50 possesses with the high tensile strength of R.R.53, in such a way as to permit intricate parts to be cast and heat-treated without fear of excessive casting and heat-treatment stresses. At temperatures above 200 deg. C., however, it is inferior to R.R..53 The applications of the R.R. casting alloys are similar to those of "Y" alloy and include such parts as crankcases, cylinder heads, etc.

In the "Ceralumin" alloys use is made of cerium to improve the running property of the alloys and generally to refine the macrostructure. The properties and applications of these alloys are not substantially different from those previously mentioned. "Lo-Ex" is interesting in that, whilst its mechanical properties are slightly lower than the other high-strength aluminium casting alloys, the high silicon lowers the coefficient of expansion to an extent sufficient to reduce considerably the design troubles associated with the high expansion of the ordinary aluminium alloys. The nickel gives increased hardness and improved properties at elevated temperatures. The presence of 3½ per cent. nickel in the "Birmasil Special" alloy enables an alloy to be produced possessing the good founding properties and resistance to corrosion of the high silicon alloys without the disadvantage of the low yield point normally associated with this type of alloy. "P.2" has been specially developed for small pressure die-castings required with close tolerances.

The foregoing remarks by no means include all the various alloys of aluminium containing nickel used in other parts of the world, nor do they more than suggest the applications of this type of alloy.

In preparing nickel-aluminium alloys, the

TABLE II.—*Chemical Compositions of Nickelcontaining Aluminium Casting Alloys.*

Alloy.	Cu.	Ni.	Mg.	Fe.	Si.	Mn.	Ti.
"Y"	4.0	2.0	1.5	0.6*	0.6*	—	—
R.R.50	1.3	0.9	0.1	1.2	2.25	—	0.18
R.R.53	2.2	1.3	1.5	1.2	1.25	—	0.07
R.R.53C	1.15	0.8	0.5	1.1	2.5	—	0.16
Ceralumin "C" ..	2.5	1.5	0.8	1.2	1.2	—	Ce 0.15
"Lo-Ex"	0.9	2.0	1.0	—	14.0	—	—
"Birmasil Special" ..	0.1*	2.5–3.5	—	0.6*	10.0–13.0	0.5*	—
"P.2"	3.0–4.5	1.75–2.5	0.5*	2.0–4.0	4.0–5.0	0.5*	—

* Maximum.

TABLE III.—*Mechanical Properties of Nickel-Containing Cast Aluminium Alloys.*

Alloy.		Tensile.					B.H.N.	Fatigue limit. Tons per sq. in.
		Heat-treatment.	Proof stress 0.1 per cent. Tons per sq. in.	Y.P. Tons per sq. in.	M.S. Tons per sq. in.	E. Per cent.		
"Y"	Sand cast	Quenched and aged	—	—	14–16	1–3	95–105	—
,, ...	Chill cast	Quenched and aged	—	—	18–20	3–5	100–110	± 7·1*
R.R.50 ..	Sand cast	Precipitation only	9–11	—	11–13	2–4	65–75	± 4.5†
,, ...	Die cast	Precipitation only	11–13	—	13–16	4–6	70–80	± 5.8†
R.R.53 ..	Sand cast	Complete	—	—	18–20	0.5–1.0	124–148	± 5.5†

,,	Die cast	,,	19–22	—	21–23	0.5–1.5	124–148	± 6.9†
R.R.53C ..	Sand cast	" Solution " only	9–10	—	14–15	2.5–3.0	70–75	—
,, ..	,,	Complete	18–20	—	19–22	1–2	100–115	—
,, ..	Die cast	" Solution " only	10–12	—	18–20	6–8	75–85	—
,, ..	,,	Complete	19–21	—	22–24	3–6	110–120	—
Ceralumin " C "	Sand cast	" Solution "	11–13	—	14–16	1–3	98–104	—
,, ,,	,,	Complete	18–20	—	19–20	0–1	130–140	—
,, ,,	Chill cast	" Solution "	13–14	—	19–21	4–6	98 104	—
,, ,,	,,	Complete	21–24	—	23–27	0–1	130–140	± 8.25*
" Birmasil Special "	Sand cast	—	—	7–9	12–14	2–4	50–70	± 3.5*
,,	Chill cast	—	—	8.5–10.5	16–18	3–6	70–39	± 5.3*
" Lo-Ex " ..	,,	—	—	9.5–11.5	10–13	0–0.5	65–75	—
,, ..	,,	Complete	—	15.2–16.4	16–19	0–0.5	125–140	—
" P.2 "	Pressure die cast	—	—	7.0–11.5	9.5–12.25	0.5–2.0	65–101	± 4.25*

* 20,000,000 reversals. † 40,000,000 reversals.

nickel is most frequently added to the molten aluminium in the form of a nickel-aluminium or nickel-aluminium-copper " hardener " containing 20 per cent. nickel, but the presence of nickel entails no special treatment in the production of castings.

Copper

Little attention has been given in the past to castings in copper containing a relatively small percentage of nickel, *e.g.*, below 10 per cent. For one application, however, castings in such alloys are of considerable industrial importance. These are the slip-rings used in various electrical machines. Slip-rings collect and deliver current to rotating members and have constantly been a source of trouble, due to the occurrence of uneven wear. Cast cupro-nickel rings containing 4 to 6 per cent. of nickel have been found to overcome this trouble and are in wide use. The nickel hardens the copper, increases its corrosion resistance and enables it to be more easily cast. Sand castings are rather more easily produced than chill castings; oxidising conditions in the furnace followed by a manganese deoxidation treatment are desirable. Higher nickel/nickel-copper alloys are, of course, in extensive use, but it is not proposed to deal with these in any detail here.

Nickel-Base Alloys

The foregoing sections have dealt with the question of the effect of nickel additions on commonly used non-ferrous casting alloys—the main purpose of the Paper, but in addition to the materials falling into these classes there are, of course, numerous casting alloys which have nickel as their base and which should be briefly mentioned. For reference purposes a summary of the various types is given in the following pages.

Nickel.—Pure nickel itself is used in the form of castings required for chemical plant. It has a melting point of approximately 1,450 deg. C., and therefore requires efficient melting equipment. Special attention must be paid to the presence of impurities and to moulding. The

TABLE IV.—*Heat-Treatment of Cast Aluminium Alloys.*

Alloy.	Solution treatment.			Ageing treatment.		
	Heat at deg. C.	Hrs.	Quench in.	Heat at deg. C.	Hrs.	Quench in.
" Y "	510–520	2	Boiling water	100	2–3	Water or air
" Y "	510–520	2	,, ,,	Room temperature	120	
R.R.50	—	—	—	170	10–20	,, ,,
R.R.53	525–535	2–4	Boiling water	170	15–20	,, ,,
R.R.53C	525–535	2–6	,, ,,	165	15–20	,, ,,
Ceralumin " C " ..	515–535	4–6	Water	175	16	Water
" Lo-Ex " ..	515	2–3	,,	180	2	—

following are the approximate mechanical properties of nickel castings:—

Yield point. Tons per sq. in.	Maximum stress. Tons per sq. in.	Elongation. Per cent. on 2 in.
9 to 13	27 to 31	15 to 35

Monel.—The nickel-copper alloy "Monel" (nickel 67, copper 28 per cent., iron, silicon, manganese balance) is widely used in the cast form for valve parts, chemical castings, etc. As in the case of nickel, close attention to foundry details is essential. As-cast Monel has the following typical properties:—

Yield point. Tons per sq. in.	Maximum stress. Tons per sq. in.	Elongation. Per cent. on $4\sqrt{\text{area}}$.	B.H.N.
14	24	18	120

By increasing the silicon content of Monel castings, the hardness is greatly increased and silicon Monels are specially useful for steam valve parts. They are susceptible to further hardening by a heat-treatment of the precipitation-hardening type.

	Yield point. Tons per sq. in.	Maximum stress. Tons per sq. in.	Elongation. Per cent. on 2 in.	B.H.N.
Monel with 2.75 per cent. silicon	23	38	16	210
Monel with 3.75 per cent. silicon	40	45	5	270

Cupro-Nickels.—Cupro-nickels containing 20, 30 and 45 per cent. of nickel are sometimes used for decorative castings, chemical castings and castings to resist sea-water. Their strengths are not as high as Monel, and in cases where a cast

TABLE V.—*Physical Properties.*

Alloy.	Sp.Gr.	Thermal conductivity, c.g.s. units.	Coefficient of linear expansion per deg. C. from 20 to 100 deg. C.	Patternmaker's shrinkage, in. per ft.
"Y"	2.80 (max.)	0.42	0.000022	0.155
R.R.50	2.73	0.415	0.000022	0.125
R.R.53	2.73	0.43	0.0000224	0.140
R.R.53C	2.73	0.415	0.000022	—
"Lo-Ex"	2.65–2.75	0.28–0.4	0.000019	0.048–0.084
"Birmasil Special"	2.65–2.75	—	0.000019	0.156
"P.2"	2.7–2.9	—	—	—

cupro-nickel is required, it is often preferred to use the more easily cast and cheaper nickel-silvers.

Nickel-Copper-Tin Alloys.—The nickel-copper-tin group of alloys, containing usually between 20 and 60 per cent. nickel and 5 and 15 per cent. tin, with and without appreciable quantities of zinc, iron and sometimes lead, aluminium, chromium and silicon, is practically standard for steam-valve parts, and is also used for bearings under corrosive and bad-lubrication conditions. These alloys show a high hardness, which is largely retained at steam temperatures, and good resistance to steam erosion and corrosion. They are somewhat brittle but, like silicon-containing Monel, resist metallic abrasion or galling. Silicon has a powerful hardening effect in the alloys, and in fact with silicon present lower tin contents can be used to give comparable hardnesses. The presence of 5 per cent. of lead gives a useful bearing alloy. The compositions used are numerous, and hardness ranges from 200 to 450 are obtainable by correct adjustment of the alloying constituents.

TABLE VI.—*Physical Properties of Copper Nickel Alloys.*

Alloy.	M.S. Tons sq. in.	E. per cent. on 2 in.	B.H.N. 2-mm. ball. 40 kg. 30 secs.	Spec. resistance. Microhms per cm.
90 : 10 Copper-nickel chill cast	16.1	52	75	14.8
90 : 10 Copper-nickel sand cast	12.8	17	62	15.0
96 : 4 Copper-nickel chill cast	14.2	50	64	7.4
96 : 4 Copper-nickel sand cast	11.6	22	61	8.3

Nickel-Chromium and Nickel-Chromium-Iron Alloys.—There are two standard types of high nickel alloys in this category, *viz.*, the 80 : 20 nickel-chromium alloy and the alloy having as a base 60 to 70 per cent. nickel and 10 to 15 per cent. chromium, the balance being iron. Their outstanding characteristics are oxidation-resistance and strength at high temperatures. Without electric-melting equipment they are not easy to handle in the foundry, although small quantities can be made in good coke-fired pit furnaces. A tensile strength of 32 tons per sq. in. is obtained in a nickel-chromium-iron alloy falling in the range given above. Their principal applications are for furnace parts, and under correct conditions they can be used at temperatures up to 1,150 deg. C.

Nickel-Molybdenum-Iron Alloys.—For resisting hydrochloric acid a group of alloys has been developed with a nickel-molybdenum-iron base, under the name of " Hastelloy." The following are the compositions and hardnesses of various grades of Hastelloy " as sand cast."

Hastelloy " A "	Nickel	60 per cent.
	Molybdenum	20 ,,
	Iron	20 ,,
	Brinell hardness	262.
Hastelloy " C "	Nickel	58 per cent.
	Molybdenum	17 ,,
	Iron	6 ,,
	Chromium	14 ,,
	Tungsten	5 ,,
	Brinell hardness	217.

A further alloy for the same purpose but not containing molybdenum is Hastelloy " D."

Nickel	85 per cent.
Silicon	10 ,,
Copper	3 ,,
Aluminium	2 ,,
Brinell hardness	364.

These alloys are likely to find an extending use, particularly for pump parts.

Miscellaneous Nickel Base Alloys.—Whilst there are innumerable casting alloys with a nickel base, there is only one further type to be mentioned here, the very hard facing alloy produced in America as "Colmonoy" No. 6. This alloy is being used for a type of construction which is being rapidly developed, namely, the building up of metals by depositing an alloy from a welding rod, essentially a casting process. Colmonoy No. 6 contains 75 per cent. nickel, chromium and boron. As deposited or cast it has a Brinell hardness number of 534 to 587, and is useful for producing hard facings on certain valve parts, etc., the hardness obtained being due to the presence of boride crystals.

The information contained in this Paper has been derived from a wide range of sources, and whilst it has not been possible to refer individually to these a general acknowledgment is made of the help received in its compilation.

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[4] (DTD 214 Antimony 6.5 to 7.5 per cent., copper 3.0 to 4.25 per cent., nickel up to 0.6 per cent., tin balance.)

(DTD 244 Antimony 6.0 to 7.0 per cent., copper 5.5 to 7.5 per cent., nickel up to 0.6 per cent., tin balance.)

(2B22 Antimony 3.5 to 4.0 per cent., copper 3.75 to 4.25 per cent., nickel up to 0.6 per cent., tin balance.)

JOINT DISCUSSION ON NICKEL IN ALUMINIUM BRONZE AND TRENDS IN THE NON-FERROUS FOUNDRY

Mr. J. A. Reynolds asked if Mr. Hitchcock had had any experience of the effect of nickel in aluminium bronze cast in green sand or dry sand. Emphasising that all his remarks were directed to sand castings and not to chill castings, he said that for six months he had been experimenting with a view to finding a high-tensile bronze or brass which must have a certain degree of electrical conductivity; the material was required for overhead trolley bus and electric railway fittings and also for fittings for electric resistance welding. In most alloys nickel would obviously reduce the electrical conductivity to a very low figure, so that great care must be exercised in the addition of it. When making small sand castings of section averaging not more than 1 in. square, with a straight aluminium bronze of the ternary type, *i.e.*, with 10 per cent. aluminium and 3 per cent. iron, with manganese-copper as a deoxidiser, he had found a species of porosity in those castings which was very like that caused by self-annealing. Since self-annealing could not possibly occur in a section of 1 in. square or less, he was forced to the conclusion that there must be some interaction between the steam or air of the green sand mould and the aluminium bronze. When the castings were made in dry sand, of course, the defects seemed to be minimised; but dry sand moulding was a much more expensive and a slower method of producing small fittings than was green sand moulding.

New Alloys Suggested

He was also experimenting with an alloy containing 9 per cent. aluminium, 1½ per cent. iron, and 3 per cent. nickel, which seemed to be quite a good and close-grained metal; but he was up against the electrical conductivity problem. Also, he wondered whether an increase of head pressure would eliminate porosity.

Another alloy mentioned by Mr. Reynolds was a silicon-aluminium bronze, which apparently had been used to a fair extent in America, but not much in this country, as far as he could ascertain. It contained about 7 per cent. aluminium and, say, 3 per cent. silicon; it had a high yield point and a high ultimate tensile strength, but the elongation was very small, being very rarely more than about 2 per cent. He asked for the experiences of other workers in respect of that alloy, and particularly whether quenching would have the effect, as it had in *some* non-ferrous alloys, of softening the alloy and increasing the elongation.

Use of Fluxes

Mr. F. Hudson, having complimented the authors upon their able summaries of present-day knowledge of non-ferrous founding, expressed particular interest in Dr. Hunt's reference to the uses of fluxes. Many of the most practical workers in the non-ferrous field, he said, were rather apt to regard fluxes as being quite unnecessary; but he considered that conception as being altogether wrong, because, to look at the matter logically, molten metal was essentially a liquid, and just as in the laboratory certain reagents were used for that liquid to form definite reactions, so in a scientifically conducted melting shop, by the use of properly balanced fluxes, one brought about very definite metal reactions leading to improved results.

He would have liked to have heard Dr. Hunt refer to the possible need for actually pouring the castings in a non-oxidising atmosphere; and he recalled a Paper presented in 1936, he believed by an American colleague,* in which reference was made to the casting of aluminium bronzes in an inert atmosphere. Some workers in this country, he added, were extending that policy because, in addition to filling the mould with an inert gas, they were trying to rig up some means of actually pouring the metal through a column of that same gas from a bottom pouring ladle, so that the metal did not come into contact with air at all. He believed that the solution of the production problem in the case of aluminium bronze castings lay in that direction; and he coupled his remarks on the matter with the reference made by Dr. Hunt to the effect of gas upon the physical properties.

Use of Inert Gases

Discussing Mr. Hitchcock's Paper, Mr. Hudson was particularly interested to note the analyses

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* M. T. Ganzange, "Production of Aluminium Bronze Castings to withstand High Pressure." Trans. A.F.A., 1936, Vol. 44, p. 482.

given therein for nickel-silver casting alloys. British practice, he said, entailed the use of an alloy containing from 20 to 25 per cent. of zinc, whereas American practice used only 6 per cent. of zinc, and it seemed to him that the latter alloy was very much easier to handle than the former. With ordinary brass castings having a zinc content of more than 20 per cent., troubles were experienced in pressure work, but when the zinc content was below 20 per cent., very little trouble indeed seemed to be experienced in the foundry. This might have some bearing upon limiting the zinc content certainly to below 20 per cent. in the casting of nickel-silvers.

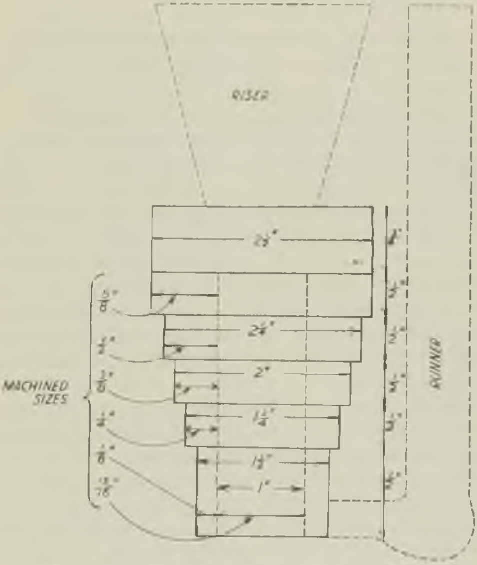

Fig. A.—Form of Test Block Used.

There were many interesting experiences in conducting work on the uses of inert gases or relatively inert gases in the production of castings, and he warned others not to make the mistake that he had made when he first filled the moulds with carbon dioxide. One poor fellow in the foundry was holding a copper tube connected to a cylinder of this gas, in order to fill the mould during the pouring of the casting; although he was very hot in some parts, he was extremely cold in other parts, due to there being icicles hanging from the carbon dioxide tube, and altogether uncomfortable.

Alloys for Use with Superheated Steam

Mr. A. Dunlop referred to the use of nickel in non-ferrous alloys that were required to withstand superheated steam—as, for example, in the seats and lids of steam valves—which alloys often failed on hydraulic test, due to porosity; and he gave some results of a series of tests conducted with a view to ascertaining the best conditions for the melting and casting of such alloys, having regard to the many variables associated therewith. He did not claim that the tests covered all the variables completely, but he put forward the results in the hope that they would help those engaged in the manufacture of nickel bronze castings.

There appeared to be no doubt, he said, that the primary cause of porosity in nickel bronze was gas absorption during melting.

Test-pieces were used each consisting of a series of cylindrical sections of varying depth and of diameters increasing from the bottom to the top. As cast, the bottom section was of 1½ in. dia. and 1 in. depth, the next was 1¾ in. by ½ in., the next 2 in. by ½ in., the next 2¼ in. by ½ in., the next 2½ in. by ½ in., and the top section 2½ in. by ¾ in. The runner entered at the bottom and there was a large riser at the top. The test-pieces were produced under carefully controlled conditions, and after machining were subjected to hydraulic test. That type of test-piece, shown in Fig. A, was chosen because it was simple to mould, easy to machine, easy to test hydraulically, and it illustrated the effect of section.

The results obtained were as shown in Table A.

The conclusions to be drawn from the results, said Mr. Dunlop, were that:—

(1) Casting temperature for the alloy should be at least 1,400 deg. C.

(2) Thin sections were more easily obtained tight than thicker ones, due probably to more rapid cooling retaining the gas in solid solution. That seemed to indicate that the higher the thermal conductivity of the mould, the better.

(3) Specific gravity provided a good and quick test of porosity. Very few nickel bronze castings leaked under pressure before the cast skin was broken. By finding the specific gravity of unmachined castings, machining time on many of the subsequent defective castings would be saved.

(4) The condition of the top of the riser indicated the soundness of the casting. A well shrunk riser indicated a sound casting, while the swelling of the riser was a sure sign that porosity would be found.

(5) The degassing treatment, allowing the superheated metal to solidify slowly and then to remelt rapidly, did not give better pressure tightness than casting at a high temperature; however, a better cast skin was obtained due to the lower casting temperature. When casting at temperatures over 1,400 deg. C., the metal was likely to eat into the ordinary brass-foundry sand. The result obtained by rapidly remelting the hot solid alloy indicated the advantage of rapid melting.

There was doubtless a shortage of published information, he said, in foundry practice of the non-ferrous alloys containing nickel, and many would welcome the section in Mr. Hitchcock's Paper devoted to the production of sound nickel-silver castings. Mr. Dunlop agreed with many of the statements made therein. He believed

TABLE A.—*Experimental Results on Nickel Bronze for use with Superheated Steam.*

Composition. Per cent.	Test No.	Casting temp. Deg. C.	Hydraulic test, lbs. per sq. in.					Specific gravity.	Condition of top of riser.	Remarks.
			Thickness of section							
			$\frac{1}{8}$ in.	$\frac{1}{4}$ in.	$\frac{3}{8}$ in.	$\frac{1}{2}$ in.	$\frac{5}{8}$ in.			
Ni, 33 ; Cu, 57 ; Sn, 10.	1	1,250	—	—	—	—	—	—	—	Metal too cold ; would not run casting.
	2	1,280	Tight 1,000	Tight 1,000	Tight 1,000	Porous 50	Porous 50	7.7	Badly swollen	On machining large number of gas holes exposed in all sections.
	3	*About 1,400	Tight 1,000	Tight 1,000	Tight 1,000	Tight 1,000	Tight 1,000	8.9	Deep shrink	On machining surface of all sections perfect.
	4	1,280	Tight 1,000	Tight 1,000	Tight 1,000	Porous 50	Porous 250	8.6	Slight shrink	Metal heated to above 1,400 deg. C. allowed to solidify in crucible, then quickly remelted and cast at 1,280 deg. C.

* Pyrometer only registers up to 1,300 deg. C.

the most prevalent cause of trouble was gas absorption from the furnace. A flux was essential, and he recommended one of ground glass. Thorough deoxidising was also to be commended; but under certain conditions it was often very helpful to treat the molten metal with an oxidising agent, such as manganese dioxide, 10 minutes before pouring. Such treatment thoroughly cleansed the metal of reducing gases, which were the main source of porosity. The oxidising treatment, however, must be followed by complete de-oxidation with magnesium immediately before pouring.

Having noted Mr. Hitchcock's statement that one of the advantages of adding nickel to tin-bronze was a decrease of grain size, Mr. Dunlop asked for his views on the effect of nickel on the grain size of high-tensile brass. His own firm made castings up to 15 to 20 tons weight in high-tensile brass, and had found that the tensile strength of pieces taken from thick sections was, on the average, from 2 to 3 tons less than the tensile strength of pieces from thin sections. That reduction of strength appeared to be due to grain growth, particularly in the alpha-phase. A programme of research had been drawn up for investigating the influence of various elements on grain growth and, naturally, nickel was included. He asked if Mr. Hitchcock could suggest the best amount of nickel to use in high-tensile brass.

Mr. HITCHCOCK'S REPLY

Mr. Hitchcock, commenting upon the experiments described by Mr. Dunlop, referred to the beneficial effect of large feeding heads on alloys of the nickel-copper-tin type and noted in this connection the greater soundness of the thinner sections at the bottom of the test casting described. He wondered whether deoxidation treatment was applied to the metal, because often it was found desirable to use a percentage of magnesium, which not only helped to deoxidise the metal but seemed to have a tendency to degasify it as well.

The oxidation treatment mentioned by Mr. Dunlop had been used for some years; where one used a lot of Monel scrap, which might have a high carbon content, it was customary to charge a certain amount of manganese ore and to deoxidise subsequently. In a recent Paper by Mr. Kihlgren to the American Foundrymen's Association, dealing with the casting of 70 : 30 cupro-nickel, oxidation treatment was recommended, a few ounces of nickel oxide or copper oxide being added to the molten metal, followed by a manganese-silicon deoxidation treatment about 3 to 5 minutes before casting.

There was very little information available concerning the effect of nickel on the grain size of high-tensile brass castings, and Mr. Hitchcock suggested that Mr. Dunlop might carry out some tests on that matter, using nickel additions of the order of ½, 1, 1½ and 2 per cent.

Nickel Silvers

Commenting on Mr. Hudson's references to the zinc contents of nickel-silvers, he said that the higher zinc-content alloy was the cheaper, of course, and he believed that was one of the prime reasons why zinc content had been standardised at approximately the 20 per cent. level in this country. There were indications that the lower zinc content alloys can be cast more easily, but the presence of 4 per cent. of tin also had an effect on the castability; the flowing power of the metal, but, of course, adding to the cost. Atmospheric corrosion tests on nickel-silvers of different zinc contents had indicated that zinc had a beneficial effect in that respect; the high zinc-alloys were also somewhat whiter than the lower zinc alloys, though the difference was small.

Trolley-Wire Fittings

Recalling the remarks of Mr. Reynolds concerning experiments with aluminium-bronze for trolley-wire fittings, Mr. Hitchcock drew attention to his reference in the Paper to an 88 : 5 : 5 : 2 copper-tin-nickel-zinc alloy, which was used extensively on the Pennsylvanian Railway for catenary clamps for overhead trolley wires. He believed there were two main reasons for standardising that alloy—one being that a saving was effected in metal costs, and the other that an alloy of high nickel content improved resistance to atmospheric corrosion. He did not think the conductivity question had been considered, because he believed the fittings were made quite massive. Aluminium-bronze was notoriously difficult to handle in the foundry, of course, and was prone to porosity troubles. Whether or not increased feeding would improve the soundness of the 1½ per cent. iron, 3 per cent. nickel and 9 per cent. aluminium alloy was an open question; so many other factors were liable to enter into the problem that, without considering all these factors, it was difficult to say definitely that advantage would be derived from modifying one only.

Electrical resistance welding electrodes were engaging attention at the moment, but he did not think that any of the experiments on nickel alloys were sufficiently far advanced to enable him to make any statement about them yet. However, he would be pleased to pass on such information as became available when the tests had been in progress a little longer.

Finally, he said, he hoped to comment in further detail on the tests described by Mr. Dunlop on the 33 per cent. nickel alloy when he had studied them further and to communicate to Mr. Reynolds such information as is available concerning the silicon-aluminium-bronzes.

Dr. HUNT'S REPLY

Dr. Hunt, commenting on Mr. Hudson's reference to the use of fluxes, emphasised that molten metal was a liquid and should be treated as such, in much the same way as the chemical engineer treated his liquids. Further study of the reactions that occurred and the application of the knowledge thereby obtained to purification by fluxes was probably the most important factor in the non-ferrous foundry at the present time. He emphasised again that the work of Lepp, in France, was well worthy of careful study. The production by him of high-tensile gunmetals, bronzes and aluminium alloys had resulted virtually from the study of the liquid reactions.

Finally, Dr. Hunt said he still felt that two of the most important needs of the non-ferrous foundry were increasing precision of control and the development of new ideas—even if those new ideas were taken as a leaf from the other fellow's book—from such operations as the production of copper cakes and similar products for subsequent plastic working.

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THE APPLICATION OF SCIENCE TO THE CONTROL OF FOUNDRY SANDS*

By H. H. SHEPHERD (Member)

Introduction

During the past ten or fifteen years the British foundryman has been able to increase very considerably his knowledge of the subject " Foundry sands and their control "—especially if he be a member of this Institute and a reader of " The Foundry Trade Journal "—since a large number of excellent Papers have been given before the Institute by British authorities on this important subject during this time. One need only refer to a few very well known investigators: W. Y. Buchanan, F. Hudson, W. J. Rees, Dr. J. G. A. Skerl, J. J. Sheehan, and W. West, the B.C.I.R.A. and the Sands Sub-Committee of the Technical Committee of the Institute of British Foundrymen, to recall immediately at least some of the valuable information which these gentlemen and organisations have given from time to time, ranging from what may be termed pure research to control of sand properties, new methods of control, and the relation of castings defects with sand conditions, and/or factors which effect foundry technique.

The foregoing is mentioned for two reasons, one is to indicate that however much this country lagged behind in scientific foundry technique up to ten or twelve years ago, it is now catching up with the most progressive countries, in fact in some instances we are probably leading. If lagging behind America be considered, one can

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* The Author was awarded a Diploma for this Paper.

† Joint Meeting.

modify the self criticism to some extent when it is realised that organised sand control in the United States had been given little thought prior to 1922, the year in which the Moulding Sand Research Committee of the American Foundrymen's Association was formed. In view of this intensive sand research it becomes increasingly difficult to present a Paper on the subject and include anything which is really new, unless one is able to spend a large amount of time in investigation or research work. The author has therefore very little which is new to offer, and proposes to review the inception of, and some of the benefits and knowledge gleaned from, the application of scientific control.

It is an interesting fact that if one studies this subject in its progressive sequence, it soon becomes apparent that the progress of sand technique follows that of foundry technique; in other words, the rapid advent of the mechanised foundry has compelled attention to proper sand control methods—whether the foundry be on mass or continuous production, or a jobbing or general engineering foundry. The far reaching importance of sand control has been stressed many times by progressive foundrymen and metallurgists, and it is rapidly becoming recognised that it should be regarded as important as control of metal if the production of good castings is to be assured.

There is another factor which renders sand control a vital point of any foundry organisation, especially in these days of keen competition and repetition production; it is that of costing. Perhaps one is apt to forget that more labour hours are spent in sand handling and working than in any other material or process in the foundry. H. Dietert[1] recorded that for a particular foundry producing 100 tons of castings per day, the labour cost of sand handling and working was 22 times that of the metal preparation and handling.

The author's first contact with what may be termed pure scientific control of sands was similar to that of all chemists and metallurgists who were engaged in the industry twenty years ago. Reference is made to the procedure of carefully analysing a sand, and writing a report to the effect that it was found that a particular sand was really not suitable because its lime or alkaline contents were too high; only to be told by the " gentleman in the bowler hat " that he had used "that sand years afore you were born."

Nowadays one rarely makes a chemical analysis—except under special circumstances, such as when determining the refractoriness from the silica content, and even in this case the physical refractory test is the only satisfactory way of determining this property, because it is realised that chemical analysis is no criterion of the suitability of a sand, and that most of the recognised control tests in use to-day are related to the actual properties required in the foundry. The trouble which arose from the rule-of-thumb method of the foundryman was that one man's " good sand " was another man's scrap .

Again with regard to chemical composition, Skerl[2] has pointed out that whereas at one time it was assumed that the bonding power of a sand could be judged from its alumina content, it is now appreciated that other minerals in sand, besides the bonding material, contain alumina. and that high alumina content does not necessarily indicate good bonding properties. It is possible for a sand to contain a considerable amount of this compound and yet possess little or no bonding properties.

The introduction of modern methods for the control of sands did more in the direction of forcing closer *liaison* between the foundry manager or foreman and the metallurgist than any other progressive movement in the industry. Possibly the reason for this lies in the fact that the first men to attempt to introduce control methods were more intimately associated with foundry practice than with the truly scientific aspect. The author has in mind Mr. John Shaw and others, such as the late Mr. Eugene Smith, who was general foundry superintendent of the Crane Company of Chicago for many years, and a very prominent American foundryman who devised methods of control which were very successful under certain conditions.

Whereas Shaw[3] in 1913 gave a Paper describing tests for the determination of strength, permeability, refractoriness, and also a method of mechanical analysis (sieving) which were made in line with present day methods, Smith's scheme involved a single method known as the vibratory test, which if used with discretion and experienced judgment was certainly valuable, but it could not be termed scientific. In 1923 J. E. Fletcher described his subsidence method, somewhat similar in principle to the vibratory test but more scientific.

The author of this Paper employed Smith's method during the early days of his association with Crane, Limited, whilst waiting the arrival of sand testing equipment. He still uses this test as a rapid and approximate check on moulding and core sands as received, for clay content, the results are, of course, only comparative, but by this means it has been possible to avoid trouble from core sands which may from time to time carry higher clay contents than normally; this is likely to occur with some silica sands after heavy rain falls when clay-containing stratas may be washed down. The value of this quick test in respect of core sand will be readily understood, for, as is well known, clay absorbs considerable quantities of oil and if the oil-sand core practice has been standardised for a given clay content or no clay, the sudden appearance in the mixture of excessive amounts of this material means trouble in the core room, apart from the extra cost involved by the additional oil required.

Vibratory Test

Briefly, the author's modification of Smith's vibratory or bottle test consists of placing in an 8-oz. tall-form oil-sampling bottle enough of the sand to fill about a quarter of the bottle. If the sand be an all-silica type such as used for core making, it can be inserted as received, but if moulding sand it is best roughly to dry a sample and rub it down. The bottle is then filled with water, preferably containing 5 per cent. of a 1 per cent. solution of caustic soda to help in separating the clay from the quartz grains, it is then thoroughly shaken for three to four minutes, placed on a moulding machine carrying a vibrator, and vibrating for the same period of time. The sample is then allowed to stand for a short time, after which one is easily able to observe if the clay content is greater or less than required, and silt can be seen as a ring between the bottom layer of silica and the top layer of clay if present in unusual amounts. Figs. 1 and 2 illustrate the method and the reading of the various constituents. The application of the test just outlined marks the commencement of the application

FIG. 1. FIG. 2.

FIG. 1.—THREE GRADES OF SAND FROM THE SAME DEPOSIT.

FIG. 2.—THIS SPECIMEN SHOWS AN EXCESS OF SILT OR FINES.

of sand control for the malleable, grey iron, and gunmetal foundries of Crane, Limited.

Moisture Determination

Another test which is applied to the sands as received, especially core sands, is that of moisture determination. At one time it was the practice to dry all the core sands and then add a definite amount of water. Fine sand, however, very easily floats about in the air even when handled carefully, and in view of the health hazard it was decided to eliminate drying of sand as much as possible—not a very simple matter in a repetition foundry where thousands of cores are made in a day and very careful control of mixtures is essential to maintain the required output of good cores.

First, complete elimination of drying was tried, but unsuccessfully, as the sand stuck to the iron shells in which the cores were made. It soon became apparent that if the laboratory could rapidly determine the amount of water in the sand the men could add sufficient dry sand to counteract any excess moisture. The use of the Speedy moisture tester enabled this to be done, and by adopting the method outlined the management were able to cut down the drying of sand by more than 60 per cent., resulting in considerable economy and a distinct aid to healthier conditions.

The value and importance of a rapid test for the water content of new sands or sand mixtures will be appreciated if it be realised that the moisture content is the most important of all the physical properties of sand mixtures.

It is not proposed to describe the many standard methods employed for determining and controlling the various properties of sands as in view of the publicity which the recommended methods of the B.C.I.R.A. and the A.F.A. have received during the past few years it is assumed that foundrymen are conversant with them. The author uses almost entirely the A.F.A. methods, this is not because there is any serious disagreement with the methods of the B.C.I.R.A., the reason being that his firm have foundries in Chicago, Bridgeport, Tonawanda, Montreal, and Paris, and if the methods employed are common to all, these branches may communicate with each other on this subject in the same terms.

The malleable and grey iron foundries of the Ipswich factory are mechanised plants operating on a continuous moulding and pouring basis and it may be of interest to mention how the management came to standardise on the particular type of moulding sand used. By far the greater proportion of the production consists of small castings in general dimensions and/or actual thickness, and necessitating good finish. With this in mind and not being very conversant with the particular properties required of a sand for a continuous production foundry, the author started the malleable plant with the Erith loam type of sand. Its use soon had to be abandoned for considerable trouble arose in the form of blowholes and unsoundness (all the castings have to be pressure tested) which was found to be due to the very low permeability (A.F.A. permeability 17) of the sand caused by excessive fines and silt.

The surface of the castings was excellent but to obtain sound, pressure-tight castings with this type of sand generous use of the vent wire was necessary, it will be recognised at once that such a procedure would not be possible in foundries of the type described.

Another important factor arose; with a mechanical sand handling system the sand passes round the system many times during the day and so gets very warm and " steamy," and again it was experienced that certain sands would not function satisfactorily under such conditions. The author stresses the importance of giving very careful thought in choosing sand if one is changing a foundry over to mass production methods including mechanised sand plants, for it does not follow that a sand used successfully before such a change-over will be suitable under the altered conditions. Resort was made to

Worcester red, and later satisfactory results were obtained from the use of Worksop sand mixed with small quantities of strong sand of the Pickering type.

A few years later large deposits of a dark yellow or orange coloured sand having considerable clay contents were discovered in Suffolk, and this was found to possess very similar characteristics to Belgian and French deposits. This sand proved eminently suitable for the grey and malleable foundries, and it has now been used continuously for the past five to six years.

As the result of the experiences related above the author concluded that the red sands were more suitable for continuous casting plants, being of the opinion that the bonding material of these sands has a greater "life" than that of the buff or light yellow types. It is appreciated that the colour of a sand bears no relation to the iron oxide content, but it is also a fact that in red sands a good proportion of the bond is due to iron oxide of a particular form, believed by Prof. Boswell to be a form of hematite, possibly of a colloidal nature, and referred to by C. W. H. Holmes[4] as "static" bond. It is this bond which the author believes possesses a more durable life than ordinary clay or "mobile" bond.

De Witt and Brown[5] in a Paper presented to the American Foundrymen's Association some years ago gave data which tended to support the view expressed above. They summarised their work as follows:—"The tests reported in this Paper certainly support the claim that sands bonded by a ferruginous bond (ferric hydrogen) are less affected by heating than those not so bonded, as the bonding strength of clay bond is rapidly destroyed at 315 deg. C., while ferric hydrogel bond is practically unaffected at this temperature."

Mechanical Analysis

Tables I and II show the fineness test results, indicating approximate grain size of some of the many sands personally investigated by the

TABLE I.—*Sieve Analyses (Grain Size or Fineness) according to Standard A.F.A. Method.*

	Moulding Sands.					
	(1)	(2)	(3)	(4)	(5)	(6)
Per cent. on						
6 ..	—	—	—	—	—	—
12 ..	—	—	—	—	—	—
20 ..	0.06	0.29	0.05	0.06	0.04	—
30 ..	0.96	0.28	0.08	0.06	0.14	—
40 ..	12.72	0.36	0.23	0.14	1.14	0.68
50 ..	28.32	0.48	6.23	0.58	11.00	10.08
70 ..	25.84	0.73	27.05	2.20	18.18	20.60
100 ..	22.68	0.85	25.84	18.58	24.70	31.30
140 ..	4.60	9.25	16.92	36.84	19.80	15.60
200 ..	1.02	35.73	8.19	27.28	10.68	8.50
270 ..	0.48	29.30	4.19	5.50	4.80	2.24
Pan (through 270) ..	0.86	10.81	4.18	1.34	1.80	4.00
Clay substance ..	3.56	12.88	6.44	7.36	7.62	7.26

Remarks.—(1) Not very uniform—low in clay and silt. (2) This consists almost entirely of fines or silt and clay; would give very low permeability. (3) Fairly fine—fines and silt moderate. (4) A better sand than No. 3; finer and more uniform; less silt. (5) Note similarity in clay content with No. 4—not very uniform. (6) Similar to No. 5.

author as to their suitability for the purpose of his firm. In submitting these results of mechanical analysis by sieving it is realised that the method is open to criticism since it is known that it does not enable very accurate determinations to be made of the mechanical constitutents of a sand, because the bonding material and silt, which have such an important bearing on the strength and permeability, are too fine to be separated accurately by sieving. The most accurate procedure is known as the elutriation method, which involves the use of sieves only to determine the grains above 0.25 mm. diameter (approx.), special apparatus known as elutriators being used to separate the other constituents into fine sand, coarse silt, fine silt, and clay grade, the last being material of less than 0.01 mm. in size. Elutriation has been clearly defined by Dr. Skerl as " The classification of particles according to their size by the pressure exerted by upward currents of water." As the merits of this method of mechanical analysis of sands and descriptions of the method have been given in several Papers, it is not proposed to consider it in detail. Whilst one can obtain the accuracy desired by using the elutriation method, it can only be carried out accurately by a fairly experienced laboratory man; further, it involves a considerable amount of time before complete results are obtained. The author makes these statements only in the interests of making scientific control in the foundry really useful, and in these days rapidity in obtaining results is perhaps of more importance than obtaining very accurate results, especially when dealing with material like sand.

Mechanical analysis by sieving should—in the author's opinion—be included in the routine of all foundries who practice, or intend to practice, sand control. The method is very simple and rapid, and no delicate apparatus is required, while the results obtained, if considered judiciously, do yield a large amount of valuable information which is of considerable help to the

TABLE II.—*Sieve Analyses (Grain Size or Fineness) according to Standard A.F.A. Method.*

	Moulding sands.					
	(1)	(2)	(3)	(4)	(5)	(6)
Per cent. on				June 16, 1933.	June 27, 1936.	
6 ..	—	—	—	—	—	—
12 ..	—	0.05	—	—	—	—
20 ..	0.01	0.35	0.08	0.06	0.42	—
30 ..	0.05	0.25	0.32	0.14	0.70	0.0
40 ..	0.11	0.24	5.75	0.28	1.44	0.6
50 ..	6.60	0.39	20.70	1.20	14.88	4.31
70 ..	24.92	0.62	21.72	6.36	33.04	9.55
100 ..	31.48	25.16	21.72	46.84	25.48	29.15
140 ..	16.88	37.18	3.75	27.78	8.30	19.14
200 ..	6.93	10.40	1.12	5.38	1.44	3.89
270 ..	2.91	2.58	1.42	0.84	1.24	7.18
Pan (through 270) ..	2.81	0.99	3.37	0.84	0.34	8.98
Clay substance ..	7.23	22.20	20.16	10.00	12.58	17.18

Remarks.—(1) Similar to No. 3, Table I. (2) An excellent, strong, fine sand, with low silt content ; good uniformity. Compare with No. 2, Table I. (3) A strong bonded, low silt sand, similar to No. 2, but coarser and not so uniform. (4) A good bonded sand of excellent uniformity (N.B.—Sieves 100, 140), and is low in silt. (5) Compare with No. 4. Sand is coarser and not so uniform. (6) Strong bonded sand—lacking in permeability because of excessive fines (N.B.—270 sieve and pan).

foundryman. Briefly, sieve analysis, according to the A.F.A. standard method, consists of weighing off a definite amount of the dried sand (usually 50 grammes) and transferring to a suitable vessel for separation of the clay material. A milk or drink shaker of the electric type serves this purpose very well. To the sand 475 ml. of water and 25 ml. of a 1 per cent. solution of caustic soda is added, the stirrer is switched on and agitation allowed to proceed for a timed period of five minutes, after which the liquid and sand are carefully transferred to a quart-size milk bottle, more water is added, and then, after 10 minutes' standing, the solution is syphoned off to a level of 1 in. of the liquid above the sand.

The bottle is again filled with water to the same height as originally, taking care that the sand particles are thoroughly beaten up, syphoning is carried out again after a further 10 minutes' standing, the addition of water is repeated as before, but now only five minutes' settling time is allowed, before each syphoning which is continued until further addition of water remains clear. By this method material which fails to settle at the rate of 1 in. per min., *i.e.*, particles of less than 0.02 mm. dia. (20 microns), is removed and classified as "clay substance"—not "clay," as the material contains some of the fine silt.

The grains left are washed, dried and weighed, and the difference in weight from the original sample weight represents the clay substance; the grains are then transferred to the uppermost position of a standard series, *i.e.*, shaking is carried out mechanically by using a Rotap or Coombs gyratory machine; the time of shaking is standardised at 15 min., after which the amount of grain left on each sieve is weighed and expressed as percentage of the sample weight.

The above description is only an outline of the process, and there are a number of essential, but quite simple, details to be adhered to if accurate results are to be obtained, but space does not permit consideration of these. The author will, however, be pleased to give full particulars of the method to anyone interested. He would point out that all the equipment necessary for this and other sand testing methods are available from a British supplier.

Fig. 3 illustrates a portion of the author's company's sand testing laboratory, and the apparatus for sieve testing can be seen. The sand retained on the 200 sieve may be classified as fine sand and coarse silt, that on the 270 as coarse silt and that passing into the pan as fine silt. In this scheme of sand control is included sieve analysis of any samples of core or moulding sand offered, in addition to testing of consignments and all the mixtures in use, the latter being tested at least once a fortnight. By this means the laboratory can tell at a glance whether the clay is sufficient or too much, also if the amount of silt is too great and the constancy or variation of grain size and uniformity.

FIG. 3.—THE SAND TESTING LABORATORY OF MESSRS. CRANE, LIMITED.

Sand giving more than 5 per cent. on each of the 270 sieve and pan is regarded as too silty, and not favoured for use, as it would tend to give a fairly low permeability. The consideration of silt in sand and the question of sand silting up has given rise to many divergent views. Personally, the author believes that the red sands do not "silt up," unless the silt is put into them by the addition of other materials. For example, certain types of rebonding materials give rise to increased silt contents in a sand mixture. The view expressed is very largely supported by Hudson.[6] The author's plant has used the same sand—plus, of course, new sand additions—for more than six years, and the silt content has shown no appreciable increase. The moulding sand, No. 4 of Table II, shows that the amounts on the 200, 270 and through the 270 sieves are:—5.38 and 1.44 per cent., 0.84 and 1.24 per cent., and 0.84 and 0.34 per cent., while for the malleable facing and system sands the amounts are:—6.04 per cent., 1.4 per cent. and 2.76 per cent., and 6.12 per cent., 1.30 per cent. and 2.24 per cent. respectively. The increase on the 200 sieve over the figure given for the new sand is due to variation in the latter sand and also to a proportion of core sand which finds its way into the mixtures. The increase in the 270 sieve is small enough to be ignored. Considering the increases in pan material, it is believed that this is due to the ash of the coal dust in the sand rather than to dehydration of the clay, this tends to be supported by the fact that the "grey" iron sand—which has added to it almost twice the amount of coal dust added to the malleable sands—contains considerably more pan material or silt, yet the original sand and the new sand added were both Stowmarket.

Table III shows the physical properties and mechanical analyses results of the various sand mixtures used. It should be noted that none of the first three sands shown possesses uniformity of grain size to the extent preferred, this is due to the fact that over the past 9 to 12 months the new sand deposits have become considerably coarser, which will be seen by comparing the two sieve analyses of the No. 4 sand (Table II). Another point of interest is that this variation in grain size has been accompanied by a variation in clay content from 7.5 per cent. to nearly 13 per cent. These factors all indicate the necessity for close scientific control at all stages in the foundry.

Core Sands

Another problem likely to confront foundry executives is " contamination " of the moulding sands by core sand. It is a matter of considerable importance to mechanised plants handling each day maybe thousands of cored castings such as pipe fittings, since core sand contamination in such cases is bound to be considerable. The best solution of this problem is to endeavour to find and use core sands as near as possible similar in grain size to that of the moulding sands, here again the sieve test is of undeniable value.

The major portion of cores in the author's foundry are made from a very uniform silica sand found in Suffolk, and the sieve analysis shown in Table IV compares very favourably with that of the moulding sand (see Table II). The sand (1 to 4) Table IV is used for very small cores, but its use is limited as much as possible in order to minimise its effect on the grain size of the moulding sand.

Although this sand is very fine its permeability value is good, this is accounted for by the fact that the sand is normally low in silt. Of the silica sands referred to in Table V, some of these are used mainly for medium and large grey castings; it will be noted that these are of much coarser grain size than those previously mentioned, and that they contain practically no silt or clay, also that several of them are very uniform. Comparative uniformity of grain size and freedom from silt are regarded as being two of the most important factors to be borne in

TABLE III.—*Details of Test Results on Foundry Sands.*

	Malleable facing.	Malleable system.	Grey iron system.	Gunmetal facing.	Gunmetal system.
Ramming density = $\frac{\text{weight of sand}}{\text{volume of sand}}$					
1 Ram =	1.46	1.45	1.44	1.48	1.43
2 Rams =	1.53	1.52	1.53	1.53	1.52
3 Rams =	1.57	1.56	1.68	1.59	1.56
Green compression strength—Adams A.F.A. method. Lbs. per sq. in.—					
1 Ram =	4.50	3.50	3.75	5.50	4.50
2 Rams =	7.00	5.50	6.00	8.50	7.50
3 Rams =	9.50	7.50	8.25	10.75	10.00
Permeability (A.F.A.)—					
1 Ram =	142	104	104	63	80
2 Rams =	91	80	64	47	56
3 Rams =	77	70	45	39	46

Moisture (Speedy)	4.00	3.40	—	3.90	3.20
,, (laboratory)	4.20	3.60	7.40	3.80	3.40
Loss on ignition	4.30	—	7.20	3.80	—
Fineness A.F.A. sieve analyses—					
6	—	—	0.18	—	1.02
12	0.28	0.54	0.10	0.78	2.60
20	0.22	0.26	0.20	0.28	0.30
30	0.34	0.34	0.46	0.10	0.14
40	1.22	1.30	1.50	0.30	0.34
50	12.40	12.56	11.94	1.44	1.54
70	24.38	24.64	21.88	3.80	4.42
100	26.48	26.20	22.42	8.40	10.24
140	15.18	16.54	14.10	42.14	41.12
200	6.04	6.12	6.44	24.64	22.40
270	1.40	1.30	1.64	2.54	2.36
Through 270 on pan	2.76	2.24	4.02	3.58	2.96
	90.70	92.04	84.88	88.00	89.14
Clay substance	9.14	8.00	15.00	11.96	10.56
	99.84	100.04	99.88	99.96	99.70

TABLE IV.—*Sieve Analyses (Grain Size or Fineness) according to Standard A.F.A. Method.*

	Core sands.					
	(1)	(2)	(3)	(4)	(5)	(6)
Per cent. on					Aug. 30, 1933.	Jan. 1, 1936.
6 ..	—	—	—	—	—	—
12 ..	—	—	—	—	—	—
20 ..	—	—	0.01	0.04	0.04	0.14
30 ..	—	0.02	0.02	0.04	0.04	0.52
40 ..	0.02	0.06	0.20	0.30	0.18	1.38
50 ..	0.08	0.14	0.39	1.16	1.54	3.08
70 ..	0.14	0.30	1.14	2.08	12.54	14.56
100 ..	0.45	1.16	5.01	10.38	70.04	63.62
140 ..	54.86	64.55	69.17	47.00	12.04	12.66
200 ..	38.54	28.31	18.66	25.68	1.10	1.86
270 ..	4.11	3.40	2.87	4.44	0.34	0.14
Pan (through 270) ..	1.15	1.14	1.09	4.02	0.64	0.80
Clay substance ..	0.80	1.01	1.22	4.92	1.46	1.00

Remarks.—(1), (2) and (3) are very suitable for small cores. Note low silt and fines, although the sands are a very fine variety. (4) Compare with Nos. (1), (2) and (3). Note high clay, also increase in fines and silt. This consignment was received after heavy rainfalls. (5) Another good sand for small cores; excellent uniformity (N.B.—Sieve 100). (6) Compare with sand No. (5). Note the sand is getting coarser, but still possesses comparatively uniform grain size.

mind when judging core sands, as the degree of permeability so much depends on these. Owing to the size and weight of castings made in the grey iron foundry, there is little or no core contamination by these coarse sands; again sieve analysis is of use in revealing this (Table III).

Coal Dust

During the past few years there has been a fair amount of controversy in respect of the advantages and disadvantages arising from the coal dust additions to moulding sand mixtures. The main purpose of these additions is to prevent the sand fritting to the castings and to aid in producing a good surface finish; beyond these two factors there appears to be little justification for its use, since it weakens the sand, and the ash left after combustion reduces permeability. It requires to be kept within close limits if the advantages to be obtained are not outweighed by the disadvantages, the latter of which are, of course, increased if the amount used is too great, giving rise to the defects of short runs, cold shuts, blowholes, shrinks, mapping, etc.

To add excessive coal dust because the finish is not satisfactory is wrong; when the amount required is above normal, the properties of the new and used sand should be checked, particularly for grain size and uniformity.

The effect of coal dust on the permeability is clearly indicated if reference is made to Table III. The malleable facing sand system and the grey iron system sand mixtures are all made from the same grade of moulding sand, and it will be seen that the sieve analyses are almost the same until one arrives at the " pan " material and clay substance. The amount of coal dust added to the grey iron sand mixtures is much greater than that for the malleable sands, and its effect is reflected very strikingly by the much lower permeability. It should be pointed out that the " clay substance " of mixed foundry sands also includes any coal-dust ash;

TABLE V.—*Sieve Analyses (Grain Size or Fineness) according to Standard A.F.A. Method.*

	Core Sands.					
	(1)	(2)	(3)	(4)	(5)	(6)
Per cent. on						
6 ..	—	—	—	—	—	—
12 ..	—	—	—	—	—	—
20 ..	0.30	0.20	0.10	—	0.50	0.02
30 ..	3.14	1.80	1.60	0.80	1.94	0.02
40 ..	16.00	4.28	7.94	1.54	14.24	0.32
50 ..	43.14	18.64	37.74	18.00	68.94	24.18
70 ..	28.24	41.64	41.14	48.00	12.98	38.62
100 ..	7.34	25.80	9.28	28.54	0.98	29.72
140 ..	0.34	4.10	1.08	2.40	0.14	4.72
200 ..	0.14	1.50	0.32	0.68	—	1.14
270 ..	—	0.88	0.08	0.18	—	0.24
Pan (through 270) ..	—	0.52	0.04	0.10	—	0.20
Clay substance ..	1.22	0.56	0.66	0.22	0.20	0.50

Remarks.—(1) Uniformity is good for a coarse sand. Note absence of fines and silt. High in shell matter, which usually gives rough core finish. (2) Grain size fairly uniform. A good medium core sand. Low in fines and clay. (3) An excellent medium core sand, it is low in silt and clay, and is uniform in grain size. (4) Another sand very suitable for cores, possessing comparatively uniform grain size, and with little clay and silt. (5) Compared with No. (1), this sand is coarser. It is excellent as regards grain size, uniformity and is low in clay and silt is absent. (6) A local sand very suitable for small cores.

in the cases quoted the actual clay content is the same for all the foundry mixtures.

Other points which perhaps are often neglected are that the size of the coal dust particles should be reasonably uniform; badly ground material which contains coarse and fine particles will cause uneven casting surface finish. Scientific control of coal dust and its additions should start with selection of suitable grades as regards quality of composition and grain size, and follow on checks on consignments from time to time to ascertain if the standard set is being maintained.

To answer the question, "what is the most suitable size of coal dust particles," is not easy, since it depends so much on the size and type of castings; some text books state that the size should be closely related to the average grain size of the sand, but it can be taken that such recommendation can only apply with success when making large castings where a very smooth surface finish is not essential. In general, the use of coal dust of particle size approximating that of sand—with the possible exception of the very fine sands of the Erith varieties—will lead to trouble, as such coarse material causes the formation of large coke particles on combustion, which weakens or rots the sand, further coarse coal particles are apt to give rise to gas pockets and pockmarks.

Fine coal dust is more economical to use because it can be distributed more thoroughly throughout the sand, and volatilises more easily. On the other hand the author believes that the use of too fine a material introduces too great an amount of fines into the sand and reduces permeability. Ben Hird, in his valuable Papers[7] on the subject, states that "as a maximum requirement it should all pass through a sieve with 40 meshes to the linear inch," but it is conceivable that Hird had in mind medium and heavy castings when he made this statement. The B.C.I.R.A. recommend the following:—

For metal sections less than ½ in., all through B.S.I. 240-mesh sieve.

For metal sections between ⅛ in. and ¼ in., all through B.S.I. 200-mesh sieve.

For metal sections between ¼ in. and ½ in., 85 per cent. through 200 and 15 per cent. through 100.

For metal sections between ½ in. and 1 in., 50 per cent. on sieves between 30 and 100 and 50 per cent. through 100 and on 150.

Coal dust can now be purchased to conform with a guaranteed fineness specification which marks a very progressive movement in helping the foundryman to work to standards and eliminate guesswork.

In the malleable foundry the coal dust is added through the facing sand and in one section of the grey iron plant it is added, with the required amount of new sand, to Simpson mills, situated in the sand system in such a way that after milling the mixture passes on to the distribution belt of the system. It is a difficult matter to control coal dust additions by laboratory tests; the author has tried several methods, but they were either too unreliable or took too long to carry out to be of immediate value in the system of control, and finally it was found that a rapid loss on ignition determination gave information which enabled reasonable control of coal dust additions to be made. This test is by no means absolute, and conveys no direct information as to the amount of coal dust present, it being purely comparative, but once a standard of casting finish has been set, using a particular grade of dust and sand, a standard range for loss on ignition can be arrived at and maintained.

Foundry Sand Mixtures

It is now proposed to review briefly the physical properties of the sand mixtures shown in Table III and other points in connection with their make up and control. First it should be noted that all supplies of new sand are stored in a concrete building, 300 ft. by 15 ft. by 19 ft., which is sub-divided for the various types. The present-day practice of most mechanised foundries is to prepare all the sand so that facing sand is unnecessary; this procedure is based on the assumption that the use of facing sand as a separate mixture slows up production and costs more. The soundness of this assumption depends very much on the type of casting, the method of handling the sand and the human element. Perhaps the more correct and economic way to view this would be to state that facing should not be used unless necessary to secure a high standard of finish, or where that standard can be obtained without additions of excessive quantities of new sand to the system.

The wholesale treatment of the sand in the system with new sand has been abandoned by a number of foundries in America, as it was found, in many instances, that the all-round cost of using facing mixtures, as distinct from rendering the whole system suitable, was much lower. This is a matter worthy of consideration by all concerned.

Milling is another factor which effects the amounts of new sand additions in both mechanised and non-mechanised plants; a mechanised system which does not permit thorough milling of the sand, at least at frequent intervals, will be costly, in that excessive quantities of new sand will be required in an endeavour to maintain correct conditions, and often without success, because the green strength of any mixture is not developed fully unless it has been milled properly for a sufficient length of time. Additional milling treatment, if not excessive, will often raise the green strength by 60 to 100 per cent. or more without serious detriment to the other physical properties. Efficient milling is of vital importance to foundries using clay as the rebonding material. Morrison[8] has recorded that " samples taken from a system using clay for rebonding, after milling for 10 min. increased in bond strength from 6 to 11 lbs. per sq. in. (A.F.A. compressive green strength test), which indicates that there was considerable ineffective clay in the sand."

To ensure that full advantage is taken of the benefits of milling, Crane, Limited's control includes that of frequently taking samples from the foundries and remilling them in a small laboratory Simpson mill—shown in Fig. 4—for 2 to 3 mins., after which the green strength is measured and compared with that before remilling. By this means one can easily determine whether a facing sand has been milled long enough, and whether a system sand requires more milling or additions of new sand.

Plant control of sand mixtures to be within suitable strength or bonding power range can be achieved by applying the knowledge gained from such tests as give comparative measures of this property. The most generally used methods are those of the B.C.I.R.A. or of the A.F.A. which involve the compression test principle.

Reference to Table III will show that the "apparent density" of the sand increases with the number of rams, or, in other words, the harder the sand is rammed the greater is the weight in a given volume. The density is apparent because in this case it represents only the density of a test piece and not of the actual sand grains, whose density would be much higher. It is also noted that the permeability decreases as the ramming density increases.

In connection with that property of sand known as permeability—measure of resistance to the passage of air or gas—it may be of interest to record that Dietert and Valtier[9] were able to form the following conclusions, as the result of investigating the effect of grain structure on the permeability:—(1) Rounded grains give at least 20 per cent. higher permeability in moulding and core sands than do angular grains; (2) a ten per cent. addition of a much finer sand than the base material may cause a 50 per cent. drop in the permeability; (3) the permeability power of fine sand or silt is sufficient to control the permeability of the sand entirely if 30 or more per cent. is present;

(4) to increase the permeability of a sand it is usually necessary to add 30 per cent. or more of the coarse material. It is thus seen that fine sand or silt has a much greater unit effect on the permeability than coarse sand.

Synthetic Sand Mixtures

Both the system and facing sands used in the gunmetal foundry of Crane, Limited, are synthetic mixtures, the base material being Ryarsh silica sand and the bonding substance Colbond. The green compressive strength is maintained by the addition of from 0.5 to 0.75 per cent. by weight of bonding material to the facing mixture which consists of 88 per cent. system sand, 11 per cent. of the fine silica sand, and 0.1 per cent. approximately of coal dust.

Table III shows that this sand mixture possesses very good green strength and the texture or grain size is fine, giving a nice smooth finish to the castings, the permeability is also good. With this type of mixture one obtains all the advantages—particularly in respect of casting finish—of the Erith types of sands without the serious disadvantages of high silt and consequent low permeability.

The preparation of the synthetic sand consists of milling for five to six minutes, after introducing the required amount of water, to which a little mollasses may be added, this treatment is followed by passing the sand through a Pneulec-Royer machine. In general, the physical properties of synthetic sand mixtures are more difficult to control than the natural sands, for example, the moisture content is more likely to vary, and the effects of excess coal dust are more pronounced. The author would not advise any foundryman to adopt wholly or in part synthetic sand practice unless prepared to give it constant attention backed by scientific methods of control, frequent testing for moisture content, and the purchasing of a quick and reliable instrument for making these determinations.

Conclusions

When the author set out to write this Paper it was intended to include some considerations of sand control in the core department, but the whole subject is so large that it was soon realised that core sand and core sand mixtures control would easily comprise another Paper, and so he must conclude with a few items of interest in regard to sand, sand mixtures, and sand treatment generally, some of which apply to the more manual controlled foundry. Good castings and good tempers, the two essentials to the success of any foundry, can be more assured if real practical scientific control is applied to sands with the same measure of importance and keenness as the up-to-date foundry now applies to the control of metal.

Fig. 4.—The Technical Sand-Preparing Laboratory of Messrs. Crane, Limited.

(I) Sands should be stored under cover; if stored in the open, moulding sands not only lose bonding material but cause increased scrap losses in the foundry due to excessive moisture content.

(II) To obtain standards and properly controlled mixtures, the " shovelfuls " measure must not be permitted; a cubic foot box, or a straight sides and flat-top barrow (to enable striking off level) divided into two longitudinal sections should be used.

(III) A definite minimum milling time based on satisfactory standards found by practice should be set.

(IV) Sand dumped from moulds cannot be properly tempered immediately afterwards; this is apt to be a problem, particularly in mechanised plants; it can be minimised by efficient cooling, milling, and æration, and by the use of large capacity storage bins, in which the sand can be allowed to "temper."

(V) In general, sands of the correct grain size, uniformity, and permeability do away with the vent wire, or at least minimise its use, so saving time and very often the patterns too.

(VI) The particular requirements of the job should be found out in respect of sand, a suitable mixture arrived at and standardised.

(VII) If making light castings and scabbing troubles arise, do not jump to the conclusion that the sand is the cause; examine the patterns, maybe too much metal is allowed to enter through a single runner.

(VIII) Keep the amount of moisture as low as is consistent with the required bonding condition, necessary to give good joint lines and smooth castings. Maintain moisture control within a standard range. In mechanised foundries hot sand is often unavoidable; remember that such sand requires more water as it dries out faster on the delivery belts than heap sand.

(IX) Silt, and the troubles associated with it, are more likely to come from coal dust than from possible breakdown of normal sand grains. Silt and excess fines can be removed by means of a large volume, low-velocity suction fan; in some American foundries the fan is situated in the bucket elevator of the sand system, but for this scheme to be successful the sand must be relatively dry.

(X) Take precautions to eliminate metal-shot; this material can be the cause of a number of troubles, such as hard spots and blow-holes.

(XI) Hot sand causes rough castings and is less permeable than cold, due to air expansion and steam; aerating minimises these troubles.

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DISCUSSION

Mr. G. W. Brown (President of the Birmingham Branch) presided, and on behalf of the Birmingham members expressed appreciation of the privilege afforded them to take part in the meeting.

Mr. F. Gentles asked what varieties of Erith sand the author had used, and particularly whether he had used the medium grade and what results he had obtained. It would be interesting if the facings trade would provide a coal dust which would not give silt.

Mr. Shepherd replied that he had tried all the varieties of Erith sand but had not found any appreciable difference between them. He would not criticise Erith sand, because it was particularly useful for some purposes. Much depended upon the application of good foundry technique, venting, etc.

Minimum Coal Dust Addition Advocated

Mr. H. Winterton (President of the Institute) said he agreed with the statements made in Mr. Shepherd's Paper concerning coal dust. He recalled a Paper which he had delivered at Birmingham, in 1908, in which he had stated: "Do not use too much coal dust; very carefully calculate the amount necessary. For large castings use a coarser coal dust than for the fine castings. It is essential to measure and add exactly the same amount each time." In the past, he continued, far too little attention had been paid to the mixtures; perhaps, also, far too little attention had been paid to the qualities that had been produced, but nowadays standard qualities were produced in a scientific manner; in some works, indeed, all raw materials were subjected to the most complete analysis every time that mixtures were made. Of course, the consumer must use them in his own particular way, but founders were realising that in the handling of raw and prepared sand more specific care was necessary than had been applied in the past. The Institute had been of great advantage not only to the founders but also to those who had to supply the needs of the founders, by leading them in the right direction. He hoped sincerely that the time was not far distant when some definite standard might be arranged between the various bodies, whereby founders would be able to obtain sands to their particular requirements, as well as other ingredients, so that materially fewer wasters would be produced.

Mr. Shepherd said that the facings trade could, and did, supply materials to specification, and would be willing to co-operate with any who required specifications to suit their particular purposes. It was pleasing to note that so many years ago Mr. Winterton had warned the founders against the excessive use of coal dust.

The Silt Problem

Mr. J. W. Gardom (Past-President of the London Branch) asked if it were not possible that silt was produced, but was carried away; it was likely that at the knock-out, where there was bound to be air suction, that the silt would be removed. Some years ago he had advocated the installation of plant to eliminate silt, but nowadays he did not believe that it was necessary. He was convinced that a certain percentage of silt was essential to the making of a really good casting, for without it the contractions in the sand were such that a bad surface was produced on the casting. With regard to the air separation of the silt in mechanised foundries, he recalled the author's statement that if that separation were to be successful, the sand must be thoroughly dry, and the suggestion that a fan be used for withdrawal at the elevator. The best place for the fan, he suggested, was over the knock-out, because there the sand, with the silt in it, was hot and dry, and, further, one could improve the usually unhealthy working conditions at the knock-out.

He had recently become acquainted with a firm making driers and had persuaded them to carry out some experiments on sand drying. Regardless of the original moisture content of the sand, it could be reduced to any percentage desired. Unfortunately, this process cost a good deal of money, and he doubted whether foundries could afford the cost of it.

Controlled Moisture Content Dryers

If the contamination of moulding sand by core sand, or *vice versa*, were bad, it seemed worth while considering the installation of suitable plant for the separation of the two types of sand. The separation could be effected quite easily, provided a founder would spend the money, and he was convinced that the capital outlay could easily be recovered. If that were so, it did not seem advisable to mill all the sand used to facing quality, as the author had suggested was the case in a mechanised foundry. The best material to use for facing was a well-milled fine sand with good bond; the backing sand could be quite open, provided it would hold together. It seemed advisable to use a finer sand at the face, whatever the size of casting, and a coarser backing sand in order to secure permeability. The separation and recovery of sand in the various grain sizes used in the different parts of the mould was well worthy of very full investigation. The engineers of the Austin Motor Company had done much work in that direction, and perhaps Mr. G. W. Brown would be able to publish the figures, as they would be valuable to many foundries. The main difficulty in milling all the sand to facing quality was that of cost; in mechanised foundries using 100 tons of sand per hour, they could not afford to mill all the sand used. They were obliged, therefore, to separate the facing sand and backing sand qualities, and he did not think the time spent in making the moulds was appreciable, provided proper arrangements were made for the delivery of the two types of sand to suitable places.

In expressing the hope that Mr. Shepherd would conduct further work on sands, particularly from the point of view of the conditions in mechanised foundries, Mr. Gardom asked whether it would be possible to carry out bonding tests with various sands and mills, in order to ascertain what types of mill would produce a certain bond in a given time. The results of such tests would be of very great advantage, and he suggested that it would be best for a private firm to do this work. The rammed density of the various sands in the moulding machines was also important; questions such as whether a sand required 100, 80 or 60 bumps had an important influence on production in a mechanised foundry, and, of course, it was on the production that a mechanised foundry either paid or lost money.

Mr. Gardom agreed with the author that grain size was about the most important factor in sand testing; he did not think it was of any use mentioning the moisture content without giving also some indication of the grain size.

Knock-Out Considerations

Mr. Shepherd replied that to some extent there was air separation of the silt in the plant that he used, although no fan was used. The plant relied entirely on natural draft, using extension pieces over the bucket elevator and the casting grid. He had never determined what silt was present immediately before the casting entered the knock-out, where the suction was applied, but he had taken samples of sand from the bottom of the bucket elevator and had found no appreciable amount of silt there. The gun-metal foundry was not yet operating on the mechanised basis, and during the last few years he had not found any appreciable increase of silt. If an excessive amount of coal dust were added, there would immediately be an increase in silt and decrease in permeability.

The suggestion to place a suction fan over the knock-out for the purpose of drawing off the silt was a good one, but as the fan would be operating over very hot and steamy sand it would be apt to draw off a quantity of the sand itself. That was why he had always relied on natural draft over the casting grid. Over the bucket elevator, however, there was a possibility of using a good suction.

The ability to dry sands to definite moisture contents was important. Speaking without knowledge of the drying plant to which Mr. Gardom had referred, he said it might be necessary to employ someone on the plant to control the moisture contents of the sands with which it dealt. Possibily the man who was handling the plant could do that.

Two-Sand Developments

It seemed that Mr. Gardom had misunderstood the views expressed in the Paper with regard to facing sand. He had stated in the Paper that there was, or should be, a movement away from making all the sand like facing sand. For example, things were done on such a high speed scale in America that the mass handling of sand became a vital factor, and obviously they had sought to eliminate the use of a separate facing sand. But latterly there had been a distinct movement towards the reintroduction of facing sand in American foundries, for they had found that it paid to use a separate sand for facing instead of preparing the whole of the moulding sand to facing sand quality.

The efficient milling of the sand was essential in any system if one were to obtain full value from the system. He could speak from experience in that matter particularly, because some trouble had been experienced in connection with a unit recently installed. The engineers concerned had said that the mill should go in one place, whereas the foundrymen and the metallurgists had said that it should go somewhere else. The engineers' opinion had been followed, and a serious amount of new sand had had to be used in that system in order to maintain the quality. Ultimately the mill had been moved to a position in which it could give efficient milling. The equipment makers should market an equipment which would mill sand efficiently in a continuous plant. An attempt had been made in the United States; but the problem of cost was important, and there were limits to the amounts which even the large companies could afford to spend on sand plant.

He had done some work in connection with bonding times, and would gladly undertake to carry out further tests, possibly by taking samples at various parts of the system and running them through the mill. By that means it might be possible to find some valuable information.

The rammed density of moulds was of vital importance, and he had found that when using a certain type of moulding machine the number of rams applied was the controlling feature in the production of a good casting. He had in mind some sort of mould hardness tester, but he understood that such accessories were not yet very satisfactory, as so many variables had to be considered.

More About Silt Control

Mr. G. E. France said there had been a dearth of information relating to the effective operation of mechanised foundry plants, particularly in relation to sand preparation and handling. He hoped that as the result of the Paper other members of the Institute would be persuaded to give further information which would be helpful not only to operators, but also to designers of foundry plant. The efficient design and development of foundry equipment was very largely in the hands of the foundrymen themselves, inasmuch as the designers had to rely on the experience of the users of the plant.

With regard to the silt problem, nothing had been said in the Paper or in the discussion to disprove that excess of silt had a very deleterious effect on the efficiency of moulding sand. There were both manufacturers and users of foundry equipment who attached considerable importance not necessarily to the elimination of silt, but to the inclusion in their plant of some apparatus which would control the amount of silt, for they recognised the danger of uncontrolled silt. Much work had been done, and was still being done, in that direction. The remarks of Mr. Shepherd and Mr. Gardom concerning the methods used for the air separation of silt would suggest that perhaps they were not fully aware of late developments. The provision of an exhaust fan at the knock-out or at the bucket elevator was too haphazard. The problem of dust extraction should be tackled as a problem by itself. The dust and steam problem at the knock-out should be regarded purely as a problem of ventilation; the silt problem was a separate one, and could be tackled by the provision of proper plant, built into the foundry equipment, and which would give the user complete control not only of the quantity, but also of the quality of silt removed.

Whilst hot sand might not have a very material effect in a small foundry, it became an important factor in foundries engaged on intensive mass production by means of large mechanised plant. In a continuously operated foundry which he knew of, the plant had been triplicated during the last three years, and in each case the plants were producing continuously throughout the whole of the 24 hours—quite a considerable amount of the total capital expended had been concerned with sand cooling. Each unit was dealing with 60 tons of moulding sand per hour, and the sand was kept cool.

He said that Mr. Shepherd's Paper had confirmed a fact which was well known by the users of many mechanised foundry units in this country, that it was a simple matter to arrange for the constant milling of sand at the rate of 60 or 100 tons per hour. There was no difficulty in justifying it economically.

The Economic Aspect

Mr. Shepherd said that everybody would appreciate the indications given that a lot of time and money was being devoted to making mechanised sand handling really efficient and that there was already on the market a considerable amount of efficient apparatus. Of course, there was a limit to the amount of capital that a founder could spend on his plant. The criterion was the return on the investment, and he agreed with Mr. France that the matter must be handled from the economic point of view. He agreed that the silt problem was not so much one of complete elimination as of control of the silt, and he recalled the statement he had made in the Paper, that the amount of coal dust used should be controlled very carefully; in making that statement he had had in mind the control of the amount of silt present.

Mr. G. H. Piper, in a written communication, stated that the question of coal dust in moulding sand was an important one, and he was glad Mr. Shepherd had stressed the need for careful control, both as regards quantity and fineness, in order to avoid the extremes of burning-on and veining. The amount present could be roughly estimated from the percentage of volatile matter in the moulding sand, but he thought Mr. Shepherd would agree that the method proposed by Aptekar (Trans., A.F.A., 1934), involving carbon determinations on the sand and on the original coal dust, was the more satisfactory.

There was a need for further research on the function of coal dust in moulding sands. Experimental work by B. Hird and H. Winterton had shown that, when molten metal was poured into the mould, a smoky carbonaceous flame was produced from the coal dust, which protected the sand from the action of the molten metal. A further effect which had been found in work carried out by the British Cast Iron Research Association was that the dry strength of the sand was greatly increased after a few castings had been made in a sand containing coal dust. This was of importance in connection with synthetic moulding sands where, with certain bonding clays, the dry strength of the moulding sand was too low. In such cases control of the dry strength appeared desirable in order to avoid troubles such as sand erosion and sand washed into the mould from the bottom of the runner.

Vote of Thanks

Mr. F. J. Cook, proposing a vote of thanks to Mr. Shepherd for the Paper, said he had had the privilege of being present, as the representative of the Institute, at the meeting held in America in 1922, to which Mr. Shepherd had referred. The Americans had been very enthusiastic about dealing with the sand problem. It was pleasing to note that, due to the efforts of men such as Mr. Shepherd, we in this country were nowadays well in the forefront in regard to sand testing and evaluation.

The vote of thanks was seconded by Mr. Shotton, and carried with enthusiasm.

Mr. H. Winterton (President of the Institute) expressed the thanks of the meeting to Mr. Ellis, who had operated the lantern, and to Mr. Lockwood, Secretary of the London Branch, for the excellent arrangements he had made for the joint meeting of the London and Birmingham Branches. It had been indeed a pleasure, he added, to attend the joint meeting of these two Branches, and the visitors were indebted to the London Branch for having them to attend and for having made such excellent arrangements for their entertainment and instruction.

East Midlands Branch

Paper No. 616

PATTERNS AND THEIR RELATION TO MOULDING PROBLEMS*

By S. A. HORTON (Associate Member)

A considerable number of Papers has been presented before the various branches of the Institute of British Foundrymen on patternmaking, but the majority have been presented by patternmakers who explained methods of pattern production and various details of the craft. When reading these Papers it is somewhat surprising to find there is no record of the numerous troubles foundrymen encounter when using these patterns to produce satisfactory castings. The purpose of this Paper is, therefore, to discuss details of pattern production which are of primary importance to the moulder and patternmaker.

It should be understood that the various points of pattern production criticised in this Paper are faults which repeatedly occur in the foundry. The patterns in question are received from all parts of the British Isles, and are, therefore, representative of the type of patterns many foundries receive.

There are details in the production of a pattern which the patternmaker should consider before construction of any design is commenced. It is obvious that the following details are of importance: the jointing of the mould; the removal of the pattern from the mould; moulding taper; the weight of metal patterns; the coring of the mould; the correct allowance for metal contraction; the dimensional accuracy and general finish; and casting identification.

All these points should receive serious consideration before the production of a pattern equipment commences as they all affect the resultant casting. When moulding difficulties have been

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* The Author was awarded a Diploma for this Paper.

intelligently anticipated by the patternmaker and a satisfactory pattern equipment produced, moulding is considerably simplified.

To simplify moulding means to reduce time spent on the production of each mould, and in these days of mass production, time saved on moulding is of considerable importance. The type of labour now employed in the majority of foundries makes it imperative that a good clean mould be produced every time a pattern is withdrawn from a mould.

The opinion of a great number of patternmakers with whom the author has discussed casting production is that their responsibility ceases directly the pattern equipment passes through the patternshop door; their attitude seems to be that as the pattern equipment has been made as accurately as possible to the drawing, the moulder is responsible for the production of a satisfactory casting.

The purpose of this Paper is not to discuss pattern construction, which is a trade of its own, but to outline several troubles repeatedly noticed on patterns submitted for production which could have been eliminated if more attention were given to the problem of moulding. No doubt the various methods of moulding create their own difficulties; for example, with machine moulding, the pattern equipment is preferred as a two-part job, a pattern submitted as a three-part job, which could be quite satisfactorily produced by another method of moulding, might have to be converted into a two-part job.

It is not desired to create an impression that the points to be raised are applicable to a certain type of moulding; faults are experienced when moulding from patterns by any method, and it is the intention of this Paper to bring several of these to the notice of the patternmaker.

Jointing of the Mould

A moulder can spend a considerable amount of time producing a satisfactory mould joint when working from any type of pattern if necessary provision has not been made by the patternmaker. This operation could be eliminated on 75 per cent. of the patterns submitted to the foundry. It seems to be generally understood that it is the moulder's job to produce the mould joint, but whenever possible it should be produced in the patternshop and not in the foundry. If it has not been possible to produce the pattern in halves, the pattern taper and other details associated with the jointing of the mould should be so formed that the moulder can see exactly where the mould requires jointing.

This statement will, no doubt, bring forth the accusation that when a patternmaker joints a pattern it is never satisfactory to the moulder. This is a difficulty which is easily overcome, because when the patternshop is in doubt, the foundry executive can always be consulted.

An illustration of poor practice is the pattern of cylindrical design which, instead of being made in halves, is made solid. A pattern of this design made in halves is easily mounted on plates for machine moulding. By halves, two exact halves are not necessarily meant, but it should be sectioned in such a manner that the two portions are easily moulded—if there are any parts that will not lift they can be either accommodated by the use of cores or sanction obtained for a slight alteration to the design.

It has been personal experience that the designing departments of engineering firms are interested in the foundryman's troubles, and if moulding difficulties be fully explained, and reasons given why certain alterations to the original design are desired, in the majority of instances such details as loose bosses carried on dovetails or formed by a core would be considerably reduced, because invariably "D" shaped bosses could be incorporated in the design.

It is essential, with the type of labour now available for moulding operations, that whenever possible the mould joint should be formed by the pattern equipment. There are jobs on which this is impossible, but in a foundry producing castings on a competitive basis they must be reduced to the minimum.

Bonnet Pattern.—This pattern is made as a three-part job. It would be simpler to mould if the pattern were split along the vertical centre line, and made as a two-part job for then the joint could be produced by a flat board and there would be a considerable reduction in the moulding cost.

Casing Pattern.—This also is a three-part job, but of a different type. It is a well-made pattern and a considerable amount of thought has been used in its production, but it is not altogether a satisfactory moulding proposition. The pattern is marked to show where the mould joints must be made, and the production of the mould necessitates careful attention to detail. This will take time, and if the moulding time could be reduced by an alteration in the design of the pattern this ought to be done.

It is suggested that this ought to have been a block pattern—the sides having a substantial amount of taper, and the pattern split on the top face. The boss could then be either dowelled on to the pattern or the pattern mounted on a plate, the external shape would then be formed by four cores. The assembly of the cores would be very simple and they would be very easily produced. A pattern made in this manner would not cost much more to produce and the extra cost would more than be saved by the reduction in moulding operations.

Removal of the Pattern from the Mould

The removal of the pattern from the mould is an operation which is necessary in the production of a mould, yet on the majority of loose patterns which are submitted for use in the foundry no provision is made for this. Everybody is familiar with the result of a pattern being used in the foundry without substantial rapping and lifting plates. The moulder is frequently blamed for the rough treatment of such patterns, but it is not entirely his fault when the known precautions have not been taken.

If damaged patterns be returned in an unsightly condition to the owner, a complaint is received of excessively rough usage and inefficient supervision in allowing a moulder to abuse a pattern to such an extent. It is a moulding operation to rap and remove a pattern from the mould, and many loose patterns are supplied without rapping or lifting plates.

There is also the type of lifting plate which is much too small in relation to the size of the pattern, and instead of being flush with the pattern surface, it stands proud and is secured by four $\frac{3}{4}$-in. screws; no hole is drilled in the pattern to allow the rapping bar to be used efficiently without mutilating the pattern, and invariably, after the third or fourth time, the pattern is rapped, the screws pull out and the moulder resorts to a red hot bar. Even when he exercises special care, the pattern is usually damaged and the cost of the repairs would more than cover the cost of providing substantial rapping plates and correctly placing them flush with the pattern surface.

Excessive rapping can have a very great effect on the size of the finished casting. When recently investigating complaints of excessive weight, casting growth and variation in casting sizes of bulk quantities, it was proved that they were directly due to uneven rapping caused through the moulder using an excessively heavy bar because the rapping hole had become enlarged as no rapping plates had been provided. To prevent a repetition of this trouble, suitable plates were fitted. This, if it does nothing else, will definitely restrict the moulder's choice of rapping bars.

Moulding Taper

Ever since the author has been connected with a foundry the only interpretation of the word taper known to the moulder has been slope, and it is probable that in the past, when castings were sold by weight, the foundry owner also understood taper to mean slope, but those days are gone. With the introduction of mechanical methods of vibration, pattern taper can be controlled to the satisfaction of both purchaser and foundryman.

Gradually draughtsmen are being educated in the use of moulding taper, but there is a persistent reluctance on the part of the patternmaker to incorporate satisfactory taper in the production of a pattern equipment unless it is shown on the drawing. Half-hearted attempts are sometimes made by sand-papering vertical surfaces to give negligible amounts of taper when the pattern is ready for the foundry.

Why taper appears to be the last consideration is almost beyond comprehension, as the amount of taper required on a vertical surface to give a satisfactory lift is not an unknown quantity, and it should receive consideration when the production of the pattern is discussed. Recently, a foreman patternmaker, discussing with a workman the best method of constructing a certain pattern, dealt with the method of moulding, jointing of the pattern, strength of the pattern, size of coreprint and machining allowance, all of which were intelligently considered. Finally, the workman inquired about the taper, and the foreman replied that they would rub that on when the pattern was finished.

That remark seems to be typical of the amount of consideration usually given to the subject of moulding taper, judging by some of the patterns produced from which satisfactory castings are required. Frequently ribs 3 to 6 in. deep have only $\frac{1}{32}$ in. taper each side. For instance, a pattern on which quite a liberal amount of taper could have been used actually had only $\frac{1}{64}$ in. on each of the two sides. The difficulty the moulder has in withdrawing this pattern from the mould, unless he excessively raps it, is obvious.

This typifies the remarks regarding the absence of sufficient moulding taper. The amount of taper permissible varies with the castings produced, but there is not a single design which is seriously considered as a moulding proposition on which a satisfactory amount of taper could not be allowed.

Weight of Metal Patterns

A good lift is an essential factor in the production of a good mould, and, therefore, the weight of the pattern must be considered, because, if a pattern is easy to lift, it is easily handled and can be more accurately withdrawn from the mould. It has been personal experience that there is always a greater tendency for dimensional inaccuracy when two moulders withdraw a pattern than when one moulder withdraws it alone. It is, therefore, essential for the pattern to be as light as possible, taking into consideration the strength necessary to withstand the service requirements of the foundry.

At the present time, metal patterns are quite frequently supplied, but the choice of metal from which these patterns are made is not as satisfactory as it might be. Some aluminium alloys have proved to be very satisfactory in the foundry, their main disadvantage being that pattern alterations cannot be so readily carried out, but this is a difficulty which can be overcome.

Brass or cast-iron patterns are often made unnecessarily heavy, but when they are effectively lightened, they are quite satisfactory. Frequently they are heavier than the casting they produce, due to the addition of coreprints. Metal patterns are supplied weighing up to 3 cwts., which could be easily reduced to a quarter of this weight if they were lightened. Only a very thin section of metal is necessary apart from a slight strengthening up at the points where lifting and rapping take place.

The remarks on the weight of patterns apply chiefly to the hand moulding section of the foundry, because, if a heavy pattern is supplied for use in the mechanical section, aluminium patterns are prepared and substituted on account of the excessive fatigue repeated handling of such patterns imposes on the moulder.

Coring-up of the Mould

In these days of quantity production machining, when large numbers of castings are machined from predetermined location points, it is imperative that the cored portion of the mould be in correct relation to the moulded portion. To ensure this regularity, the correct type of coreprint is necessary, because it is impossible to maintain the correct position of the core unless there is an ample coreprint.

Considerable difficulty has been experienced from time to time with the coring of differential case castings. The two spherical faced bosses must be correct to within $\frac{1}{32}$ in. of the flange face. The flange is formed by the pattern and moulded, and the two spherical bosses are formed by the core.

Two sets of pattern equipment have been encountered, the first of which has never given the slightest difficulty in maintaining the position of the bosses, because adequate coreprint has been allowed. The core fits freely, and is held firmly in the coreprint, and there is a sufficient area of core covered by the cope to prevent the core lifting when the mould is poured.

A second casting has given considerable trouble, as the core seating is quite inadequate. The core was expected to rest on two portions of a sphere, and there was no provision made to prevent the core lifting, apart from a small centre core. After the pattern was first submitted, two rectangular strips were attached to the coreprint; these were added because it was possible for the core to be misplaced in a clockwise direction. The strips corrected that error, and also gave an improved core seating, but still a considerable amount of time was lost in coring up this job, as every core had to be set with a core gauge, and every casting to be checked at the inspection tables to prove if the moulder was using the core gauge.

All this extra work could have been eliminated if the type of coreprint associated with the first pattern had been used. It is of interest to know that the first pattern was made in the patternshop of a firm who have their own foundry, and no doubt the foreman patternmaker has learnt from experience how necessary it is when producing this type of casting to have a good core location.

Another trouble experienced is with the core, which is only supported at one end. Usually, just sufficient print is allowed to locate the core, and, when in position, the portion in the mould is considerably greater than the portion in the coreprint, with the result that the correct metal section around the core has to be maintained by using chaplets.

A personal thought is that it is preferable to have a print at least as long as the core protrudes into the casting to eliminate the use of chaplets. The extra print necessitates extra moulding box room, but it has been the author's experience that a more satisfactory casting is produced when using a balanced core than when using chaplets. The extra timber necessary is negligible when a more satisfactory casting is produced. These remarks only apply to a certain type of casting, but this trouble is repeatedly encountered.

Another problem is the pattern on which a round core protrudes into the mould; no corebox is supplied to give the correct length of the core. A mark is painted on the pattern, and the moulder is expected to mark the mould, cut a core to the correct length, and place it in the correct position in the mould.

Castings have been rejected because the length of the core was not within $\frac{1}{16}$ in. of drawing dimension, and this kind of pattern was supplied to produce the casting.

A T-shaped type of pattern illustrates a core difficulty very similar to the example just mentioned. The T-shaped core is located by a print at the base of the vertical portion, and, when in position in the mould, the T is horizontal. The width of the print is not sufficient to balance the weight of core that protrudes into the mould; therefore, chaplets are essential to ensure the correct section of metal around the core.

If prints the same shape as the core had been placed at each end of the pattern, the assembly of the core would have been simplified, and there would then have been no necessity to use chaplets.

Frequently the method of core location causes considerable difficulty. By core location is meant the type of setting strip either added to or cut away from the coreprint, which controls the position of the core in relation to the mould.

The author's firm produces a considerable number of castings for the motor industry, and invariably it is the internal portion of the casting on which the majority of the machining is carried out, and it has been their experience that machining locations are usually taken from some portion of the casting formed by the pattern; therefore, they have very carefully investigated the matter of core location.

Unless the moulder is able to see quite clearly the exact position of the location while he is coring up the mould, the location is not satisfactory; it must be understood that on the castings in question the position of the core must be controlled with limits of plus or minus $\frac{1}{32}$ in.

The commonest error is the print at the base of a core which stands vertical in the mould; a "flat" is cut across the print edge (see Fig. 1). As a core location this is, no doubt, quite satisfactory, but when the moulder commences to assemble the core in the mould he is unable to see the exact position of the core location, which is covered by the body of the core. Only a very slight misplacement is required to cause this casting to be rejected.

The most satisfactory method of locating a vertical core is to have the location strip on the outside of the coreprint (Fig. 2) and the strip to give a definite radial location (Fig. 1). Using this method no trouble is experienced, because the exact position of the core can be seen when the core is assembled.

Patterns made in halves (and this remark also applies to the majority of machine-moulded patterns), the design of which necessitates location strips on the print, give the most satisfactory result. If the strip be placed on the mould joint a core can be assembled in a radial or longitudinal position by this method of location (Fig. 3).

Frequently the strip is placed on the drag portion of the coreprint, but instead of being at the pattern joint it is at right angles to the joint. This method is unsatisfactory because the exact position of the core cannot be maintained within the desired limits.


Fig. 1.

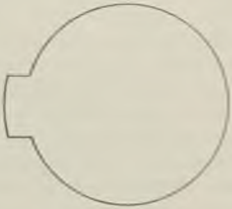
Fig. 2.

The question of core drying must also be considered. In certain instances, when the core location is either on the cope or drag portion, special precautions must be taken to prevent the location being fouled by the dryer. If the location is at the core joint the necessary clearance is very easily formed.

Core and Coreprint Tapers

A moulder should not have to dress a core to give the necessary taper before assembling a core in its print. It was no doubt common practice a few years ago for cores to be made without allowance for coreprint taper, but moulding costs do not now allow for unnecessary operations. Apart from the time lost, the location of the core is not as satisfactory with a dressed core as with a core from a corebox. It is, therefore, a definite advantage, both in casting accuracy and moulding cost, to make the corebox with the correct coreprint taper.

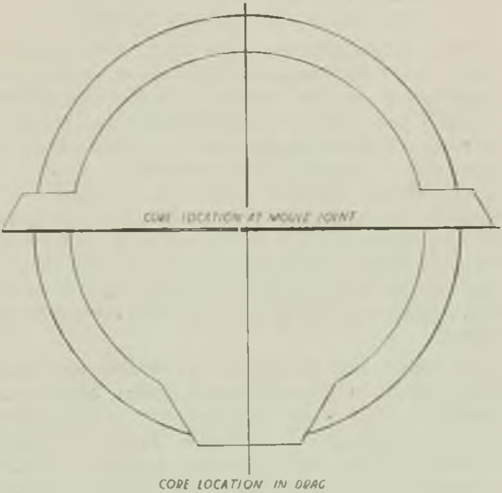

Fig. 3.

Several of the defects mentioned in this section may seem quite trivial, but repeatedly new pattern equipment has to be modified to prevent coring trouble. There are difficulties which would never arise if one moulded entirely from patterns produced in one's own patternshop, but as the faults mentioned above are experienced on patterns supplied, there must be numerous patternshops throughout the country that take little or no notice of the problem of the coring of a mould.

Contraction

Contraction does have a bearing on the dimensional accuracy of the finished casting, and although it has been stated that patternmakers always consider the type of casting the particular pattern is to produce before they fix the contraction allowance, personal experience is that very little of this forethought has been given during the years which the author has had close co-operation with several patternshops.

This experience has been that, with cast-iron jobs, $\frac{1}{8}$ in. to the foot contraction is used, regardless of size and shape. With a non-ferrous or steel job, contraction applicable to the metal is used. The argument used to substantiate this practice is that, if the resultant casting be dimensionally incorrect, the first thing to be done is to check the pattern to trace the error. If the pattern fails to have the allowance for the standard contraction, the patternshop is blamed for the incorrect casting. It is a useless argument, but it is mentioned for what it is worth.

To show the variation in contraction which takes place in the particular metal used in the foundry with which the author is associated, several examples have been taken: Castings without cores, solid plates and strips, castings contracting on to a sea-sand core and castings contracting on to a green-sand core. The castings were carefully measured, and the results have been tabulated. The outside diameter of the castings are somewhat the same, and they must all be within plus or minus the diameter of $\frac{1}{32}$ in. on the rough casting. From this list it is hoped to show that, if the same amount of contraction had been used, several of the castings would have been rejected.

In the author's patternshop there is still difficulty in getting the patternmakers to forget the standard contraction. They believe that they are making the pattern wrongly if it does

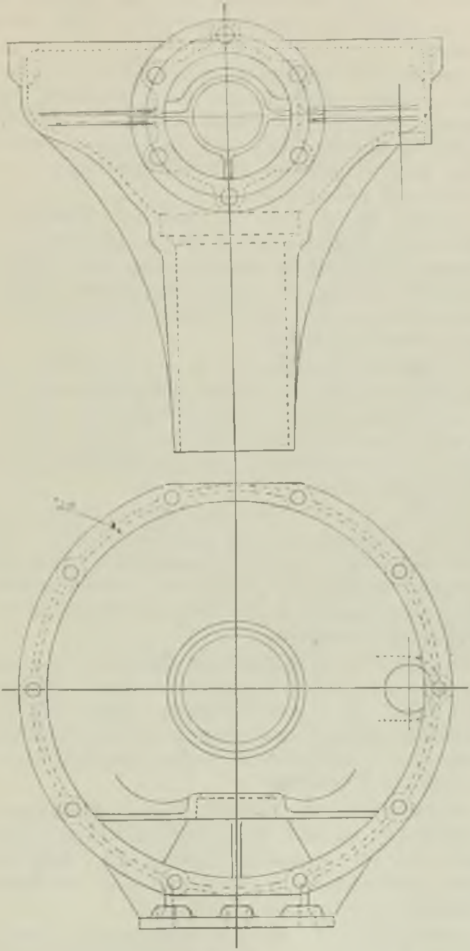

FIG. 4

not correspond to the contraction rule, and if a pattern has to be altered because the casting is oversize, it is always said that the pattern has to be made incorrectly to produce a correct casting.

Casting No. 1 (*Fig.* 4), *Rear Axle Housing.*—The casting contracts on to a sea-sand core. Pattern dia., $15\frac{5}{32}$ in.; hard casting dia., $14\frac{31}{32}$ in.; annealed casting dia., $15\frac{1}{16}$ in.; metal contraction, $\frac{3}{32}$ in.; variation in twelve castings, $\frac{1}{16}$ in.; mechanical vibration.

Casting No. 2 (*Fig.* 4), *Rear Axle Housing.*—The casting contracts on to a sea-sand core. Pattern dia., $13\frac{25}{32}$ in.; hard casting dia., $13\frac{5}{8}$ in.; annealed casting dia., $13\frac{45}{64}$ in.; metal contraction, $\frac{5}{64}$ in.; variation in twelve castings, $\frac{1}{16}$ in.; mechanical vibration.

Casting No. 3 (*Fig.* 5), *Rear Hub.*—The casting contracts on to a 4-in. dia. sea-sand core. Pattern dia., $12\frac{3}{4}$ in.; hard casting dia., $12\frac{1}{2}$ in.; annealed casting dia., $12\frac{5}{8}$ in.; metal contraction, $\frac{1}{8}$ in.; variation in twelve castings, $\frac{1}{32}$ in.; mechanical vibration.

Casting No. 4 (*Fig.* 6), *Brake Drum.*—The casting contracts on to a green-sand core. Pattern dia., $16\frac{13}{32}$ in.; hard casting dia., $16\frac{3}{32}$ in.; annealed casting dia., $16\frac{5}{32}$ in.; metal contraction, $\frac{1}{4}$ in.; variation in twelve castings, $\frac{1}{32}$ in.; mechanical vibration.

Casting No. 5, *Differential Carrier.*—The casting contracts on to a green-sand core. Pattern dia., $15\frac{11}{16}$ in.; hard casting dia., $15\frac{3}{8}$ in.; annealed casting dia., $15\frac{15}{32}$ in.; metal contraction, $\frac{7}{32}$ in.; variation in twelve castings, $\frac{1}{32}$ in.; mechanical vibration.

Casting No. 6, *Round Plate.*—Solid plate, $\frac{3}{4}$ in. thick; pattern dia., $16\frac{13}{32}$ in.; hard casting dia., $16\frac{1}{32}$ in.; annealed casting dia., $16\frac{5}{32}$ in.; metal contraction, $\frac{1}{4}$ in.; variation in twelve castings, $\frac{1}{16}$ in.; hand vibration.

Casting No. 7, *Strip.*—Solid strip: Pattern length, 4 ft. $1\frac{1}{32}$ in.; hard casting length, 3 ft. $11\frac{28}{32}$ in.; annealed casting length, 4 ft. $\frac{1}{4}$ in.;

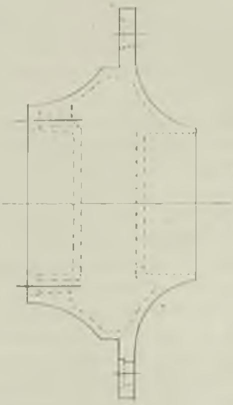

Fig. 5.

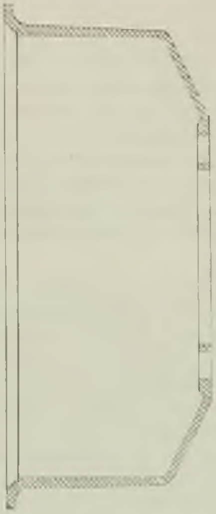

Fig. 6.

metal contraction, $\frac{25}{32}$ in.; variation in twelve castings, $\frac{1}{8}$ in.; hand vibration.

All the examples chosen are of circular design. It was purposely arranged for the shapes to be similar to make comparison easier.

It will be noticed that the sea-sand core definitely resists the metal contraction and that the green-sand core allows the normal contraction. There are many difficulties in persuading the patternshop to tabulate contraction figures for the various types of castings so that they will have reliable information from which to work in future.

This is definitely an internal problem, but it is mentioned in this Paper because it is thought that the variation in metal contraction through details of mould construction is not studied with the seriousness it demands. A certain amount of trial and error is still experienced in arriving at the correct finish size of the rough casting. With constantly changing designs, this is to be expected, but the practice ought only to be used as a last resource, because there is every facility for noting and recording the metal contraction under all conditions and when cast in innumerable varying designs. This information, carefully tabulated, would be of considerable assistance when pattern equipment was being produced in the future.

Generally, the castings produced in the author's shop are not more than 4 ft. in length or width, and their depth is 2 ft., but when the over-all sizes must be controlled within predetermined limits, and in the majority of cases intricate cores have been assembled, the correct allowance for metal contraction must be made. Although it may be a considerable number of years since the first casting was produced, it is suggested that in shops with every advantage of being able constantly to note and record metal contraction on the numerous designs of castings, only 50 per cent. could produce a tabulated contraction record if requested.

Dimensional Accuracy and General Finish

The details of pattern production mentioned in this section of the Paper are of primary importance. The majority of castings manufactured to-day are machined by quantity production methods. They must therefore be correct to a standard of accuracy which has never been demanded previously. Everybody is aware of the high standard demanded by the average machine-shop inspection department. To fulfil tho necessary requirements, rough castings must conform to drawing dimensions within unreasonable limits.

The point it seems desirable to emphasise is that although a pattern may be correct to drawing and produced to mould in what is thought to be a satisfactory manner, machinable castings are not obtained. For the purpose of this Paper a machinable casting is one which will locate in the various predetermined location points of the tooling equipment designed for the machining of this particular casting, and be correct to drawing when the machining operations are completed. What is meant can best be illustrated by explaining the difficulties recently experienced with a steering box casting. The foundry was requested to produce castings for a steering box, the jig locations being marked on the drawing from which the pattern equipment was produced. It was decided to joint the pattern through the centre line of the main bore as shown in Fig. 7. The section beneath the quadrant arm casing was cored out, and when completed the pattern was moulded on a plate and appeared to be quite satisfactory as a moulding proposition. It was noticed that the location points were on each half of the pattern, but it was expected that these could be controlled.

The castings produced were quite satisfactory and considered to be of standard finish. When machining operations commenced, it was stated that no two castings were alike, and that if machining operations were continued the machined rejections would be abnormally high.

The method of machining was as follows:—The machine, an Archdale automatic, had six stations, on each of which was a casting location jig on which the castings were located. These stations revolved and made six stops in one revolution. At each stop a set operation was performed, and when a casting had made one revolution of the machine the whole machining operations were completed. From this description of the machining equipment it will be understood that the castings had to be extremely accurate and consistent in general shape.

On the first machining run 25 per cent. of the castings machined were rejected, as the main and trunnion bores failed to clean. In an endeavour to check this high rejection figure, the patterns were inspected and found to be correct. Location fixtures similar to the machine locations were then made to gauge the position of the two bores in relation to the location points. It was proved that slight " swells " on the trunnion bore, caused by variation in ramming, and slight cross joints aggravated the two points of location on the trunnion bore, and the one on the main bore adversely affected the machining location. With these errors controlled, the rejection percentage was reduced to approximately 10 per cent. This was not considered satisfactory, and when the whole position was reviewed by the foundry executive it was decided to make new pattern equipment.

This equipment was again jointed on the main bore centre line as shown in Fig. 8, but at 90 deg. to the first pattern made. A core was placed beneath the trunnion boss and the pattern was mounted on plates. It will be noticed that now the three location points are on the same half of the plates, so that it is impossible for cross jointing to affect the location, and the possibility of " swells " on the trunnion boss are almost entirely eliminated. The castings

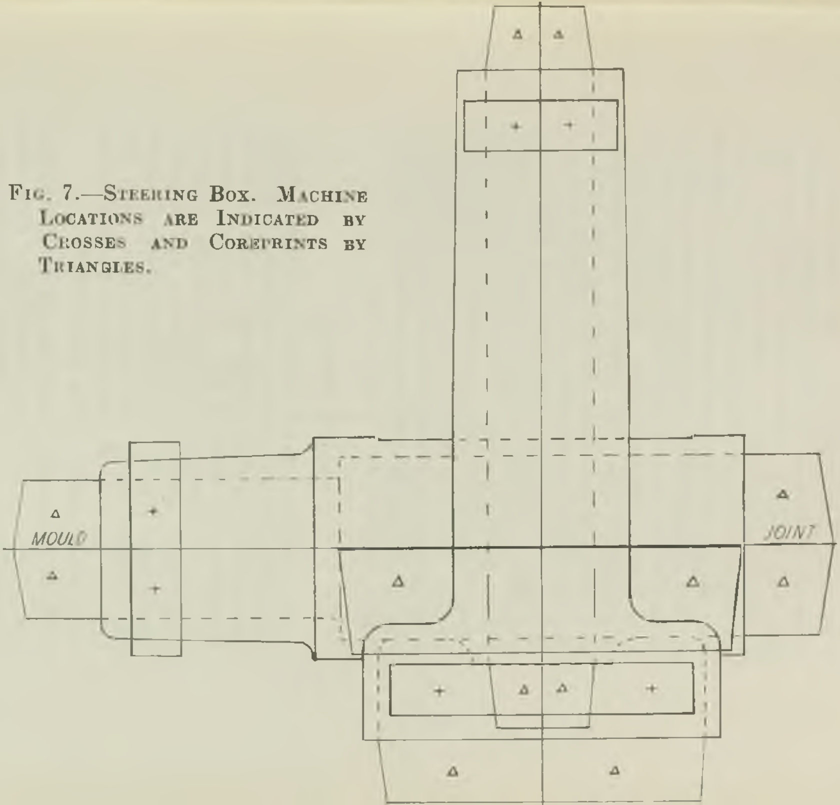

Fig. 7.—Steering Box. Machine Locations are Indicated by Crosses and Coreprints by Triangles.

from this pattern have given complete satisfaction. The error of bores not cleaning was overcome and material rejections (blow-holes) are now the only complaint.

Recently the machinist has demanded a standard of general accuracy for rough castings that the foundry cannot meet, unless the patternshop is prepared to co-operate. This calls for specialisation within the craft, and at present it appears that patternmakers are unaware of this new demand. In recent years foundry technique has advanced tremendously, but the patternshop does not seem to have advanced accordingly. Repeatedly, when a blueprint of a new design is submitted for pattern production, the patternshop is searched for patterns similar in design. If the pattern found has been made ten years, the new pattern called for is made similar to the old one. This, it is suggested, is wrong. Every new design should be intelligently studied and the foundry executive consulted. It is the casting which is the saleable commodity, and everything necessary to a successful product should be put into its production.

Spring Shackle

Fig. 9 shows another pattern equipment which has been altered to produce machinable castings. The machine shop had difficulty in maintaining the correct thickness of the rib when machining from a location which engaged in the spherical bore. Two patterns which formed the spherical bore were mounted on a coreprint; both patterns and corebox were well constructed, the core being a good fit in the print and the castings produced appeared quite satisfactory.

When the castings were located for machining the position of the two ribs varied, and when machined there was no consistency in the finished thickness of each rib. In an endeavour to overcome this defect every care was taken when assembling the core, but the machining results were similar.

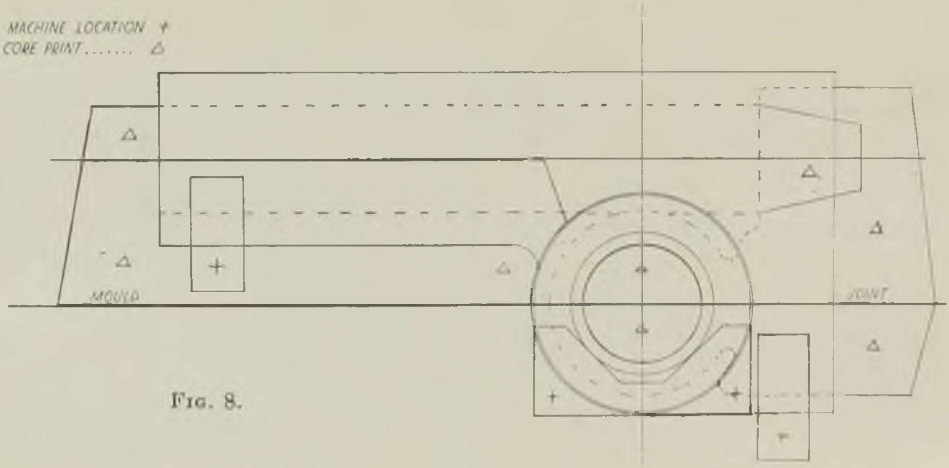

Fig. 8.

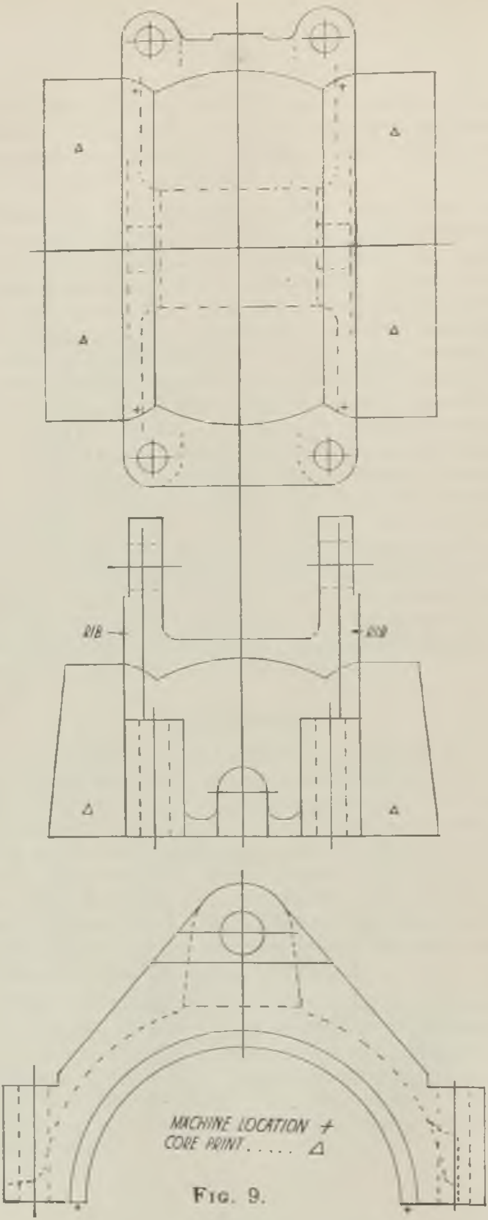

Fig. 9.

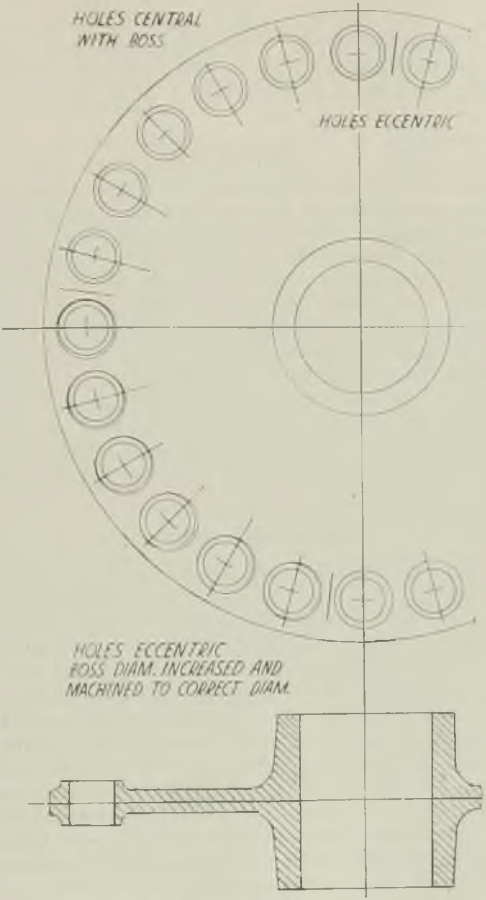
HOLES CENTRAL
WITH BOSS
HOLES ECCENTRIC
HOLES ECCENTRIC
BOSS DIAM. INCREASED AND
MACHINED TO CORRECT DIAM.

FIG. 10.

It was eventually decided to make another set of patterns (Fig. 10), the cored portion this time to be moulded. The patterns were mounted on a plate and the opposite side made to form the spherical bore. Castings produced from these patterns have given complete satisfaction, and the ribs when machined have been consistent to drawing size.

Difficulty is frequently experienced in maintaining the correct amount of material around a machined hole when there is little difference between the size of the hole and the boss facing. For example, with 1 in. dia. hole and 1¼ in. dia. boss facing, the hole has only to be slightly out of centre to create a visible error, and if there is a series of similar holes on any surface it gives an unsightly appearance. One of several factors can operate to affect the position of the machined hole. If the diameter of the boss is increased slightly the appearance of the completed casting would be improved, and, if desired, there is sufficient material around the boss diameter to allow for it to be machined to the required size.

Casting Identification

Casting identification would be considerably simplified if a little thought were used before the necessary symbols were placed on the pattern. Usually symbols are made of stamped aluminium or brass, but these materials are easily mutilated if placed in an exposed position, and frequently they are fastened on the pattern surface. It is suggested that whenever possible the symbol should be placed in a recess in the pattern surface, the top face of the symbol to be level with the pattern surface. It is then protected to a certain extent and if there be sufficient taper on the symbol, there would be a visible identication on the castings.

Frequently, when the symbol is placed on the pattern surface it becomes flattened out by moulding operations and carelessness, and when the castings are examined before despatch, it is almost impossible correctly to read the symbol as cast.

In conclusion the author wishes to thank the directors of Ley's Malleable Castings Company, Limited, for permission to use certain equipment for illustration purposes and to publish details of moulding operations.

DISCUSSION

Mr. P. A. Russell, opening the discussion, referred to the use of aluminium patterns, and asked whether difficulty through pitting had been experienced. He had found them satisfactory when new, but when they were taken from the store, say, about three years later, they were usually in a bad condition, due to this defect. Regarding the balancing of cores and the suggestion that the core-prints be equal in length, he asked if that length was sufficient. He always thought a print was required which was longer than the core projected into the mould. He suggested that the patternmaker should paint a line along the joint on the pattern, for the guidance of the moulder, and, referring to taper, his experience was that one could persuade a patternmaker to deal correctly with patterns but not with core-boxes. He instanced a cube pattern that was made to taper from 12 in. to 11¾ in. for the purposes of moulding. The core was made to withdraw from the box in an opposite direction, and the taper on the core, being in the opposite sense, did not give the correct wall thicknesses. They had the utmost difficulty in persuading the patternmaker to maintain the size, by making the core-box with loose sides so that the taper was constant. Finally, Mr. Russell referred to top core-prints. With a core that was placed in the bottom and projected in the top half of the mould, the patternmaker could assist if he made the top core-print oversize.

Mr. Horton said the aluminium patterns he referred to were never in the stores. The trouble he experienced was preventing the moulder from damaging the patterns with the vent wire. He usually used shellac for varnishing. He agreed that it would be a very great help if the patternmakers marked the mould joint, but they usually had insufficient time.

As to core-print taper, with quantity production it was essential that the core and core-print should be similarly tapered, whilst to minimise core-print crushing, he thought it was a good point to have the core-print in the top box slightly larger.

Core-Drying Distortions

Mr. T. Goodwin, referring to the differences in contraction between the oil-sand core and the green-sand core, asked if the variation was due to the rate of cooling He thought it would be advisable, with the box casting with the balancing print, to have made a casting on each end of the core, thus making it self-balancing.

Mr. Horton replied that he had only given the contraction figures to show the variation. He was not prepared to say whether it was due to the cooling effect of the core. Unless the patternshop allowed for the contraction there was bound to be some difficulty. Regarding cores balancing on a print, he said it was good practice, if the foundry could afford it, to have two patterns made.

Unused Rapping Plates

Mr. J. Lucas said he was responsible for many patterns used in many different foundries. A large number of patternmakers had never seen the inside of a foundry, and one had to contend with that factor nowadays. No two foundries used similar methods, and where one foundry would agree that a pattern was satisfactory, another foundry would condemn the same pattern. Patternmakers were reproached because they did not put rapping plates in the correct position; but patterns which had been returned to him showed clearly that the rapping plates had never been used. As to contraction allowances, he had sent patterns to one foundry, and the resulting castings were too large; yet the same patterns, when sent to another foundry, gave the opposite effect; but the patternmaker was blamed in both cases.

The lecturer had mentioned core drying, and Mr. Lucas asked if he had had any experience of a dried core being different in shape or size from the core-box. His own view was that in many cases a core, when drying, did sometimes change in size. A patternmaker could not be expected to make a pattern to suit every foundry. He thought that a jobbing foundry should say to each customer what it expected from the castings ordered and what sort of patterns they should supply.

Mr. Horton agreed with some of Mr. Lucas's remarks. The patternmaker should ask the foundry for suggestions how the pattern should be made, as every foundry carried out various alterations. He, personally, had usually found that variations in core sizes after baking were attributable to a faulty drier, which had allowed the core to take the shape of the drier.

Pitting of Aluminium Patterns

Mr. J. F. Driver appealed for greater collaboration between various departments, and he suggested that there was too much working in water-tight compartments. His definition of a working drawing was " a method of representing an object," and if it was a perfect drawing, a skilled workman would then be able to make the object without any difficulty. A draughtsman had no idea how a job was to be cast, but if it was designed with that knowledge, it would be more helpful.

Pattern drawings should be such that the taper was not left to the whim of a moulder or patternmaker, but was shown on the drawing, and, of course, designed by someone who was an expert. One would then obtain uniformity. He asked whether aluminium was not too soft a material, and if an aluminium alloy was used.

Mr. Horton said he used an aluminium alloy and found it an advantage, as he had experienced a certain amount of pitting with the aluminium alone.

Mr. C. B. Hallam said a patternmaker was very often asked to make a pattern as cheaply as possible; therefore insufficient time was expended upon it, to the detriment of everybody.

Mr. J. Gerrard said he was glad to hear Mr. Goodwin suggest that small castings should be made as two castings instead of one, to effect balance of core.

Unvarnished Patterns

Mr. H. Reeve said the varnish on certain patterns he dealt with was a source of dissatisfaction. The number of patterns reaching the foundry unvarnished was remarkable. Often a pattern took perhaps an hour to mould, and by the time the pattern was stripped, the mould would crumble to dust, as the unvarnished wood had absorbed the moisture in the sand. Naturally, some firms required patterns to be made too cheaply and too quickly.

Mr. R. H. Buckland, speaking with regard to quoting for new jobs, said a customer would often prefer to supply the pattern, probably on account of cost. He thought in such cases it should be stated, when the price was quoted, that the pattern was to be made in a specified manner, and if possible a sketch should accompany the quotation.

Mr. G. L. Harbach thought there should be a move on the part of the Institute to insist that all engineering apprentices should have some experience in the foundry. A draughtsman should also go through every department of a works.

Lifting Straps

Mr. H. Bunting (Branch-President) said that one point not mentioned in the discussion was the removal of the pattern from the mould.

With large patterns it was common to find no lifting straps on the pattern. One particular job he had in mind was about 3 ft. deep, 1 ft. square, and only ¼ in. thick, yet the pattern was provided without straps. Naturally it was very difficult to strip such a pattern from the mould. Another important point, especially in the larger type of work, was the small core print, for a core entering into the side of the mould usually had only from 1 to 2 in. of print. It was ridiculous to deliver such a pattern. A moulder would have to cut away a large amount of sand to insert the core and to make it a workable proposition. He failed to understand Mr. Lucas's remarks on rapping plates. It might be that with the pattern in one foundry the rapping plates were easily accessible, but in another they might be covered by the box bars. These were points that the patternmaker should attend to when discussing with the foundry foreman how a job was to be made.

Vote of Thanks

MR. C. W. BIGG (Vice-President of the Institute), proposing the vote of thanks, said there were many points in the Paper that should be considered very carefully by them, not only as foundrymen but as members of the Institute. The part which appealed to him first was the necessity of co-operation between the patternmaker and the foundryman. Mr. Horton had said that a new standard was being set for castings, and that was what he tried to emphasise with regard to all patterns. Heavier demands were being made on the foundrymen on the whole, and it followed that all departments in the foundry should make a larger contribution to the result. Another speaker had remarked that many patternmakers had never been inside a foundry, but this state of affairs was altogether wrong. A patternmaker, to be efficient, could not produce a pattern unless he understood the difficulties under which that pattern was to be used. Many patternmakers did not understand the first essentials of sand manipulation, and he advised all the young patternmakers to learn the fundamentals, and give the moulder a finished article.

Mr. R. Spriggs seconded the vote of thanks. The question of co-operation between the drawing office, patternshop and foundry, was very difficult, he said, and the larger a firm grew the more difficult this question became. They did co-operate more than they used to, but they still had a long way to go.

Lancashire Branch and Falkirk Section

DEVELOPMENTS IN THE PRODUCTION OF INGOT-MOULD CASTINGS*†

Paper No. 617

By R. BALLANTINE (Member)

Considerable interest has been aroused in recent years on the subject of ingot-mould castings for use in steelworks, and when Dr. T. Swinden and Mr. G. R. Bolsover, in a Paper‡ presented to the Sheffield Conference of the Institute of British Foundrymen in 1935, put forward data of inestimable value and importance, the steelmaker's case was admirably presented. Arising from the discussion which followed, it was felt by foundrymen that a Paper of a practical nature showing developments in the production of ingot-mould castings would allay the fears of the steelmakers and prove that research and progress in this branch of foundry work is moving forward as rapidly as in other phases of foundry activity.

Those foundrymen trained in other branches of ironfounding naturally visualise the manufacture of ingot-mould castings as being very simple. They are, apparently, heavy pieces of metal of simple design, with uniform sections, in the manufacture of which one might expect ease in every operation; they seem, in fact, from the foundry point of view, to be all that one could wish for. Yet "things are seldom what they seem."

In the first place, these castings must conform to definite standards, and are subject to exacting service. They must withstand extreme variations in temperature and heavy usage, especially when "stickers" require removal. They must be strong enough to undergo hose

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* The Author was awarded a Diploma for this Paper

† See also "Additional Data on the Manufacture of Ingot Moulds" by the same author, page 167.

‡ Proceedings, Vol. XXVIII, page 192.

spraying with water, for cooling when exceptionally hot, and coupled with these qualities the internal finish must be good. The quality of the skin on the inside is important, with a direct bearing on the ultimate lives of ingot moulds.

Uses of Ingot Moulds

Ingot moulds may best be described as permanent moulds for the reception of molten steel, which, on solidifying, is extracted in the form of ingots. The " permanency " will undoubtedly be questioned if the moulds give way early in life. In the Mossend Works of the Fullwood Foundry Company, Limited, specialisation is practised in the manufacture of these castings. Compared with general foundry standards these works may be described as a quantity-production foundry operating on heavy work. The weight of castings made ranges from 2 to 50 tons.

The lay-out of the Works† lends itself exceedingly well for a continuity of operations. All movements are so arranged that overlapping in their respective cycles does not occur. From receipt of the raw materials until despatch of the finished castings, reasonable control is exercised.

Mould Types

Two types of moulds are manufactured: (1) the common or ordinary, and (2) the inverted. In the first type the top area of the mould is smaller than the bottom, and in the second the top area is larger, as shown in Fig. 1. The 5½-ton mould drawing on the left is that of a common mould with semi-closed top, and the 14-ton mould on the right is of the inverted type. Designs are extremely varied in both cases, and range from the square and rectangles to fluted octagonals and duodecagonals.

Fig. 2 shows a 17-ton inverted mould weighing 26 tons, with the ingot of steel beside it; it is of the duodecagonal type. Fig. 3 shows an octagonal ingot of steel of about 30 tons weight after removal from a mould.

Cores

From the summary already given it will readily be agreed that first-class cores are essential in this type of work. Starting from the shake-out, castings remain inside the foundry from two days to over a week, according to size and weight, so that early chilling of the casting is avoided. After stripping, the castings are loaded up and removed by the work's locomotive to the fettling shop. This covered-in building is a substantial structure suitably equipped with overhead travelling cranes.

The removal of ashes in the cores is the first operation. Internal barrels are not used. The castings are then transferred to the coring benches for removal of the sand and gratings which make up the main core. Pneumatic hammers with long chisels make the removal of core sand a comparatively simple operation. This sand is reclaimed from either end of the casting and falls through diamond-meshed gratings on to a conveyor belt before being elevated to a storage hopper. A travelling hopper takes the used sand by monorail to the core-making department, where it is again stored after the fines have been removed by fan to a settling tank.

A modern plant specially designed for the economic production of cores has been installed, and the only sand used is Scottish rotten rock. A ratio of 5 parts of old to 1 part of new sand is the usual practice. There are no additions of proprietary binders, nor of coal-dust, saw-dust or other ingredients. Only water is added to give a moisture content averaging 6 per cent. The milling time is 5 min., after which the sand is aerated, and again elevated to a feed hopper, which deposits on to a conveyor belt feeding direct into the corebox on a 20-in. jolting machine.

It is interesting to note that the green strength of the core sand is low at 4 lbs. per sq. in. A test-piece 2.256 in. in height and 1.128 in.

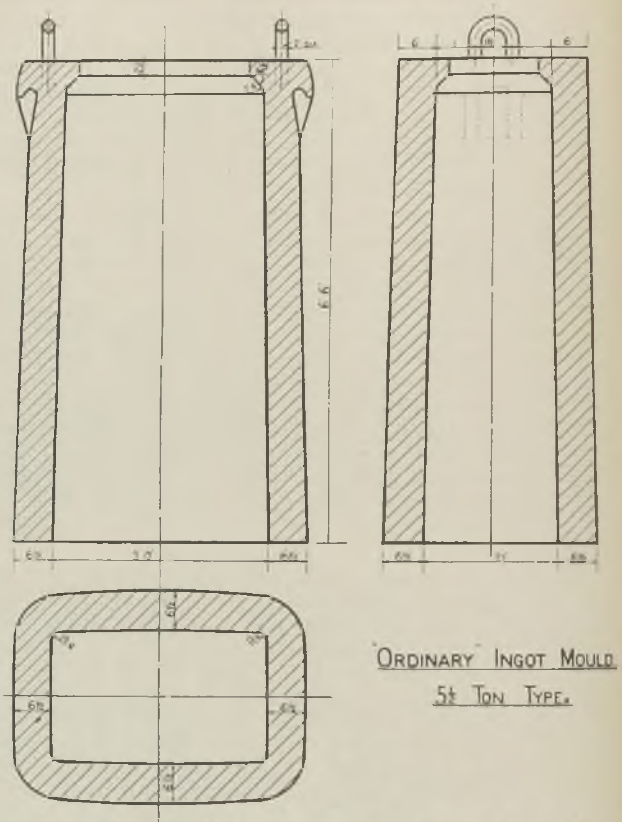
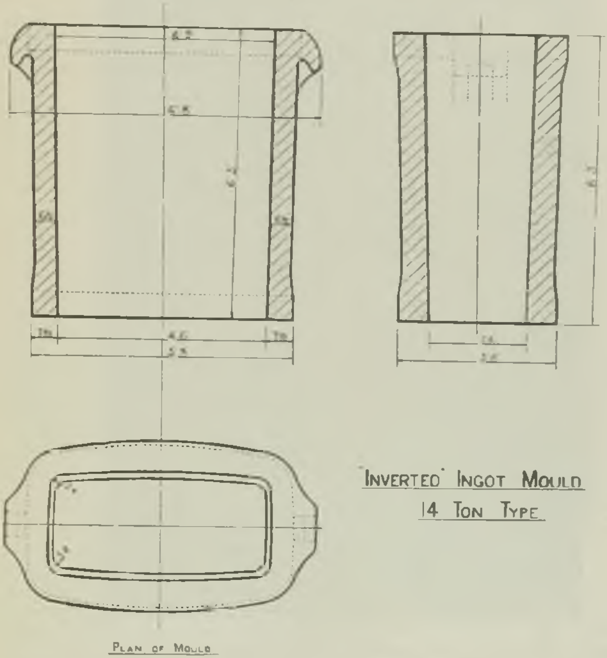


Fig. 1.—Ordinary Type of 5½-ton Ingot Mould



AND AN INVERTED TYPE OF 14-TON INGOT MOULD.

dia. rammed in the Buchanan double-compression apparatus and broken by ordinary spring balance gives this figure (2.1).* For determining dry strength a similar test-piece is used, baked for 2 hrs. at 200 deg. C. and allowed to cool to normal, giving an average strength of

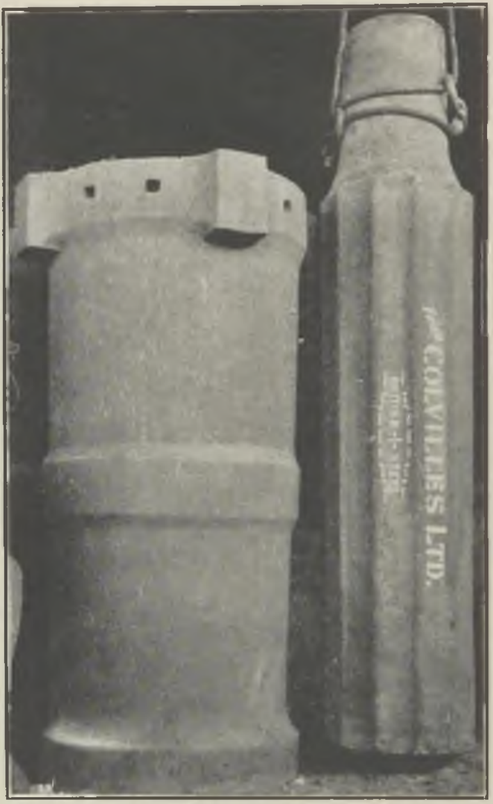


FIG. 2.—INVERTED MOULD WEIGHING 26 TONS, WITH ITS INGOT.

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* Check figures by Buchanan show wide variancies are permissible.

24 lbs. (16 lbs.).* The importance of permeability is outstanding in good core practice for ingot-mould work.

By the modified Richardson apparatus in which the test-piece is rammed and kept in the corebox, the back pressure set up and noted on the water gauge registered 14 in. On the B.C.I.R.A. apparatus the time taken for 2,000 mls. of air to pass through the test-piece in the corebox was $4\frac{1}{4}$ min. (A.F.A. 126).* On the sieve test, after agitation for 1 hr. the aver-

Fig. 3.—Octagonal Ingot of Steel Weighing 30 tons.

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* Check figures by Buchanan show wide variancies are permissible.

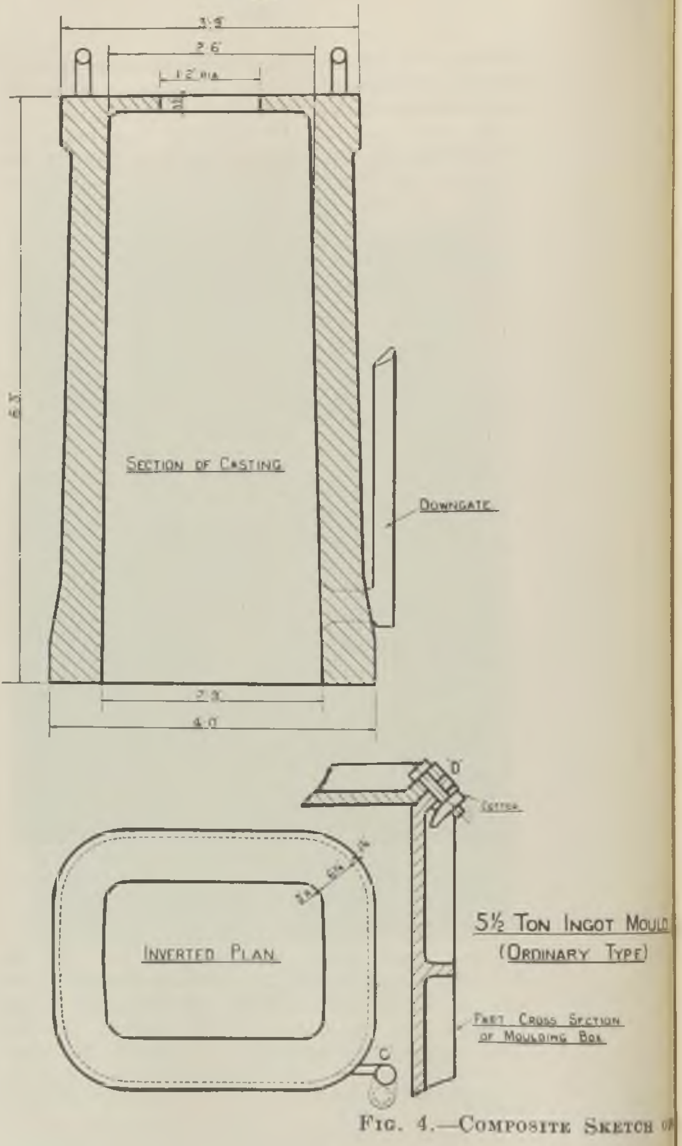
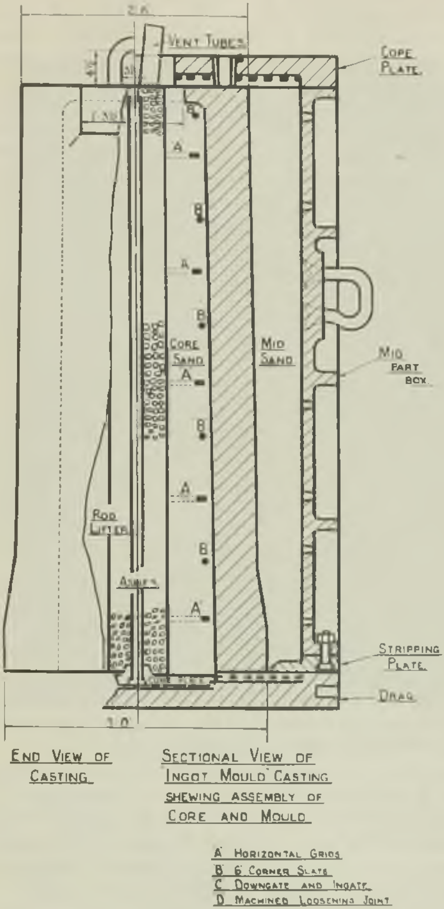


FIG. 4.—COMPOSITE SKETCH OF



Ordinary Type $5\frac{1}{2}$-ton Mould.

age percentage of sand deposited on the respective sieves was as follows:—

Sieve ..	20	40	70	100	Pan
Per cent..	8	31	42	10	9

Moisture content is checked by Speedy moisture tester on samples taken entering the core-box on the jolter.

Fig. 4 shows a composite sketch in that it gives the lay-out and assembly of the mould and core in part section. A detailed description of core manufacture is essential. The corebox, either in wood or iron, is placed on the jolter, and a bottom lifting plate put in position. The bottom plate takes the contour of the core shape, allowing a slight clearance, an adjustable lifting rod or rods being carried to the top. A suitable tube is then slipped over, and filling with sand commences. At intervals, as shown at A, horizontal grids are placed, these being comparatively light in section and made of steel for re-using. From four to six grids are inserted according to the height of the mould. Frequently, if the body of sand be large, an auxiliary row of short metal cuttings 6 in. long is inserted at the corners and between the gratings.

Perpendicular reinforcements are rarely used. (The inverted core seen in Fig. 5 has not an upright iron in it, and neither have the others). When the core-box is filled with sand, the jolting operation begins. Using 90 lbs. per sq. in. pressure a definite fall in sand is registered. The filling and subsequent operations are repeated, but prior to the finishing jolt, ashes are inserted inside the tube before it is removed.

The effect is most beneficial, the sleeking action of withdrawing the tube is overcome by the settling of the ashes by final jolting. The core-box is slightly opened after a top hand ramming is given, and either the core or the box is removed, dependent on the mould type.

Fig. 5 is a good example of the core used in the first mould shown. As already mentioned no uprights are used, nor is sprigging allowed on any of the corners. This core is not jolted, but all the others are. Great care is exercised in the finishing of these cores. Trowel sleeking prior to blackwashing is not encouraged, but after a liberal supply of blackwash is applied to fully $\frac{1}{16}$ in. sleeking takes place. The final process is a brush-down with water and plumbago additions.

Fig. 5.—Core for a Duodecagonal Ingot Mould.

While on this subject of blacking it should be noted that consistency in analyses should be maintained, but blacking of the following approximate analysis, allowing reasonable margins, is highly satisfactory: Moisture, 0.52; volatile matter, 1.48; ash, 8.05; fixed carbon, 89.95; and total sulphur, 0.78 per cent.

A small gum addition is beneficial due to its adhesive qualities.

Good blacking is not in itself enough; its preparation and application is vital. A dual tank mixer, directly coupled to a centrifugal pump, is installed. The tanks are filled with water from the mains to a given capacity, and dry blacking is added. A recent development in controlling clay additions has been introduced by additions of clay in powder form. Clay is dried and mechanically pulverised, then added in ratio to the blacking used. Variables in manufacture are a bugbear, and their gradual elimination is desirable if progress is to be maintained.

Fundaments for Core Production

There are certain features in core manufacture for this class of work which should be noted if satisfactory castings are to be produced:—

(1) The sand must be permeable, otherwise flaking in corners occurs in the larger moulds, due to back pressure into the mould cavity. Ordinarily, release of gas should be through the core into the ashes, gas escaping as the metal rises. The artificial pricking of corners does not appeal as a means to assist venting or to counteract the scaling in corners. Were it convenient to do pricking from the inside of the core to the corners, then the advantages would be apparent.

(2) A liberal coating of blackwash eliminates the tendency to fuse where there are heavy metal thicknesses.

(3) It has been proved in practice that if these cores be dried throughout, the best results are not obtained. Cores dried inside usually lose virtue outside by overheating. Consequently, a curling on the caked blackwash occurs, leaving indentations which must be levelled in the finished casting.

Core Drying

From a study of Fig. 6, which shows a batch of 18 cores being placed on a stove carriage, it will be seen that the question of drying is very important. A normal amount is 20 on one carriage. The cores enter the stove at 10 a.m., are slowly baked for three hours, rising to 450 deg. Fah. (230 deg. C.), and this temperature is maintained until 4 a.m., when the cores are cooled off for removal of the carriage at 6 a.m. for closing and casting. It is the author's experience that cores manufactured with a minimum of handling, and a minimum of disturbance in transit, give the best results. More trouble is caused by strains set up in the cores when in their green state, prior to entering the stoves, than is credited.

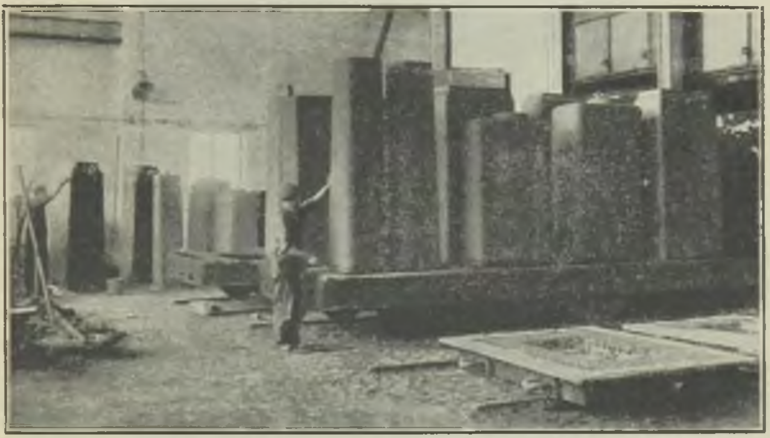


Fig. 6.—Batch of 18 Cores Entering the Drying Stove.

Forced drying has been dispensed with in all six stoves. A single fan installed at the chimney base has proved most effective. As a result of inducing a current of hot air through the stoves, fierce drying is not encountered. The effect is observed in a nicely baked core and a cleaner foundry atmosphere. Temperature control is effected by six thermographs of the latest dual-type, giving pen and pointer readings.

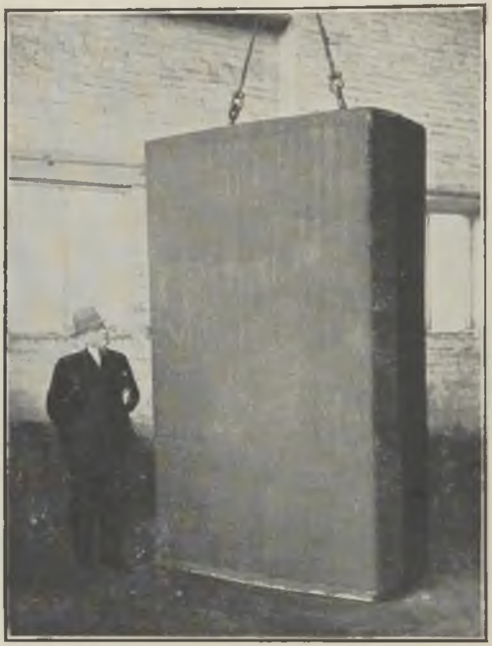


FIG. 7.—INVERTED MOULD CORE FOR A 34-TON CASTING.

Fig. 7 shows an inverted mould core (all sand) for producing a 34-ton casting. It has no uprights, and the approximate weight of sand is 4 tons. The sides and ends are slightly cambered, and, moreover, the core is top heavy. Fig. 8 shows a core and mid-part for a 30-ton ordinary mould casting. The mid-parts are of old types, which are being worked out. As in other cores, there are no upright reinforcements. In both cases the drying is from Friday at 5 p.m., and casting takes place about mid-day on Monday.

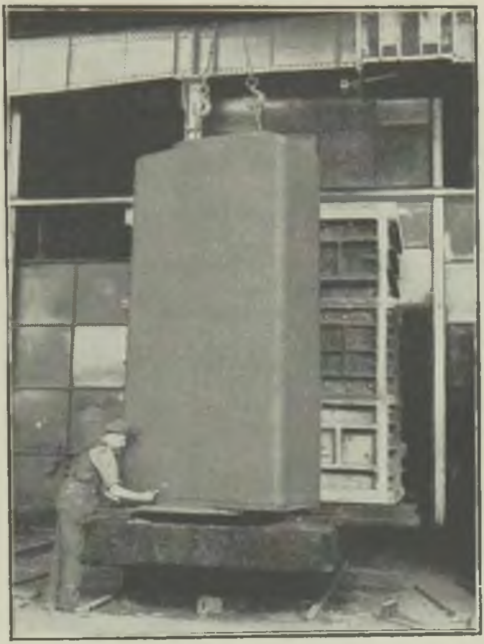


FIG. 8.—CORE FOR A 25-TON NEW DESIGN.

Moulding Boxes

The question of satisfactory moulding boxes is most important, and considerable experiments in design have been carried out. The mid-parts are made up of four separate plate castings with all joints machined. The perpendicular flanges are angled to 45 deg. Three of the corners are bolted, and the fourth is held by cotter bolts. This method releases strains and facilitates removal of the casting. A machined stripping plate is fixed to the underside of mid-parts, and is in two parts, split at alternate corners. This ensures carrying of the mid-part sand, and has the advantage of being easily replaced in case of alteration to design.

Copes and drags are of a semi-permanent nature and carry provisions for clamping, gating and flow'ers, the facing medium being loam. Joint faces in both cases are machined. Objectionable features, such as loam stamping, which softens the mould face near the drag, are eliminated, and the ever-present danger of run outs is counteracted. Moreover, fins which have a habit of solidifying rapidly, and causing endless trouble, are non-existent when machined boxes are in use. In the quest for further developments it was borne in mind that cast-iron boxes had their disadvantages, first in being easily broken unless of very heavy section, and secondly because the extra weight retarded jolting capacity. A fabricated steel box was evolved and introduced which allowed a 20-ton casting to be jolted successfully.

Fig. 9 clearly indicates the box under actual working conditions, with a 16-ton casting being removed. The box is a surface-table built job and is not elaborately reinforced. It is all-welded with riveted fixed corner angles. The casting is being removed after 60 hrs., and the absence of sand is most noticeable. Cotter bolts have been removed from the flange at the left-hand corner, and it is interesting to record that an opening averaging 5 in. occurs, making the removal of the casting a simple operation. There is rather a reciprocal peculiarity about this box, for the foundry supplies castings for the making of steel, and the steelmakers in turn supply steel plates for making the boxes in which some of these castings are made.

Fig. 10 illustrates a newly designed cast-iron box for making all types of large mould castings.

When the copes and drags are included the weight is 22 tons in cast iron only. It will be observed that cross membering of stiffening ribs is introduced. The length of the box in this instance prohibited the machining of upright angle flanges, but the standard practice of all machined joints is evident.

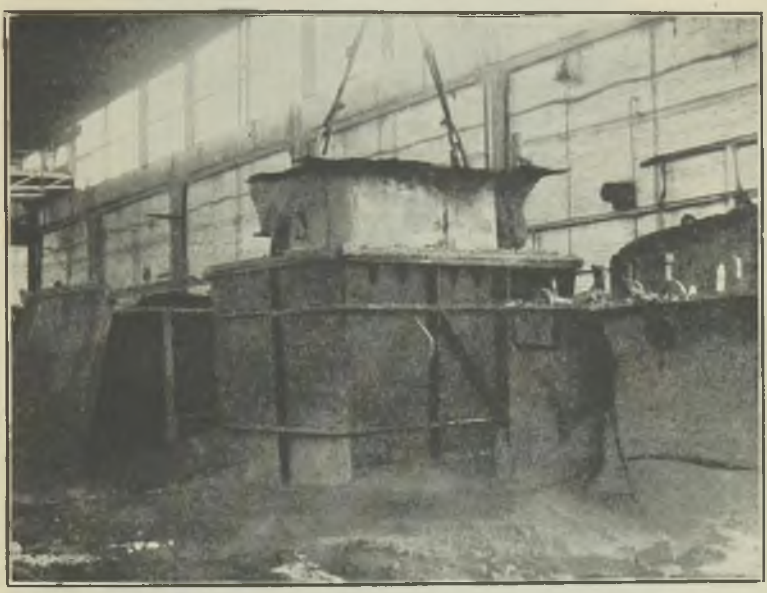


FIG. 9.—SHOWS A 16-TON CASTING BEING REMOVED FROM THE MOULD.

Fig. 11 shows the mid-part and core for the 34-ton inverted mould casting being placed on stove carriage.

Mid-Part Jolting

The larger moulds are jolted on a 32 in. machine at 100 lbs. pressure. When the pattern is set in the mid-part, a layer of sand covers the stripping plate. Downgates are inserted, and at regular intervals sand and rod stiffeners are added in a similar manner to the coremaking methods. The number of downgates is determined from actual practice, and ranges from one in the smaller moulds to four in the larger. Immediately after removal of the pattern the mid-parts are transferred to the finishing benches for ingate cutting and blackwashing, prior to entering the stoves. The number of ingates inserted, like the downgates, is determined from results obtained in practice.

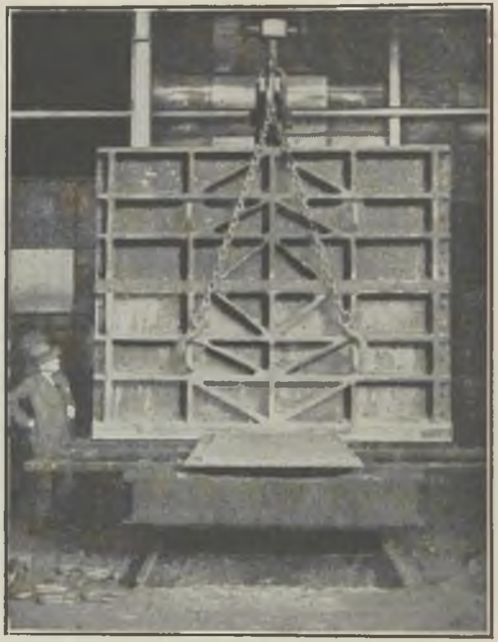


FIG. 10.—SHOWS TYPE OF MOULDING BOX USED.

Fig. 12 shows the mid-part for the 30-ton (ordinary) type ready for removal to the drying stoves. The four downgates are shown, and also the loam gutter recess for stopping the flow of metal at the cope parting.

Closing and Casting

The assembly of cores and moulds prior to casting is a specialised job allocated to experienced employees. The closing movements are carried out in sequence, so that casting operations follow, allowing a reasonable margin of safety for the closing squad. The proper skimming of ladles has long been practised, and is an

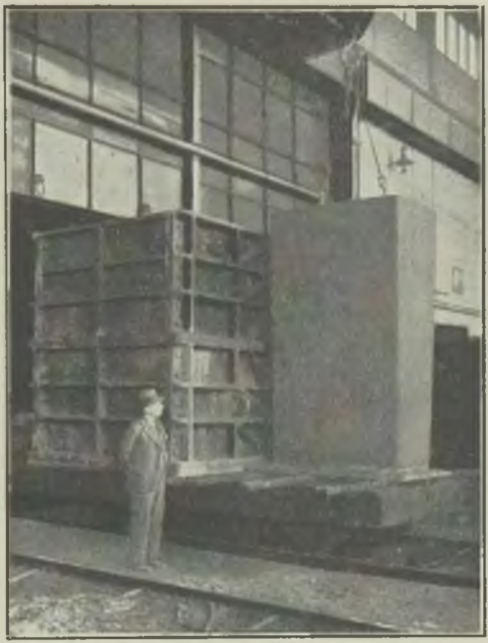


FIG. 11.—MID-PART AND CORE FOR A 34-TON INVERTED MOULD ENTERING STOVE.

essential operation. The question of teapot and bottom-pouring ladles has been considered, but the present system has much to commend it for adjusting the rate of flow, in keeping up heads and in easy sculling and fettling of the ladle.

Gating, Risers and Feeding

All ingot-mould castings are run by down-gates and the ingates are formed in the mid-parts. Top pouring by pencil gates has been discarded in favour of the former system. Opinions are divided as to the best methods of running any casting, but the author's experience is that for this type of work made in dry sand the results show much cleaner tops and internal surfaces than by the drop-gate method. Whether or not to feed a casting is a question which evokes a great deal of controversy, but it has never been found necessary to feed these castings either by feeder rod or feeding head. At the same time, one is justified in asking where the 4 cwts. or more of metal used in feeding goes. But is not there something advantageous in its absence?

The metal thicknesses in ingot-mould castings are reasonably uniform, and it would appear the necessity for feeding does not arise. An examination of fractured mould castings reveals an open metal structure in place of a denser structure in the wall centre. When expansion of the mould takes place in service, it is very probable that the initial shock of rapid change in temperature is counteracted by a resilient or cushioning effect resulting from this phenomenon. This effect possibly tends to hasten the crazing of internal surfaces, but, at the same time, it lessens the possibility of discards by major cracking and consequent losses through split ingot moulds in service.

Patterns and Coreboxes

The production of ingot-mould castings in sand necessitates special care in the making of patterns and core-boxes, especially when operations are on a mass-production basis. Substantial bridging, internal cross membering, and cleating in pattern construction are essential if successful jolting is to be accomplished. Even more exacting service is demanded from the core-box due to the alternate corner splitting, which is so essential to easy removal of the core.

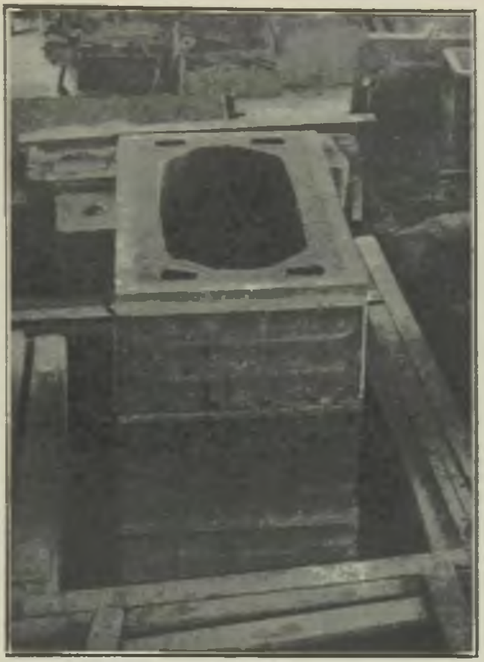


FIG. 12.—MID-PART FOR 30-TON TYPE READY FOR DRYING.

Fig. 13 illustrates a 20-ton ordinary-type pattern and corebox, with an 8-ton octagonal inverted pattern on the ground level. The 20-ton pattern is plain but massive, and the corebox is reinforced with 5 sets of 4-in. by 3-in. by $\frac{1}{2}$-in. angles fixed on 11-in. by 3-in. cross beams. Upright stiffeners are inserted to counteract the jolting shock. Special care in finishing both patterns and coreboxes is the rule. Three coats of special varnish paint are given. The benefits of this procedure can be assessed by clean pattern withdrawal and cores which do not require patching. All patterns are painted in orange colour so that the contrast when pneumatic ramming takes place is dominant.

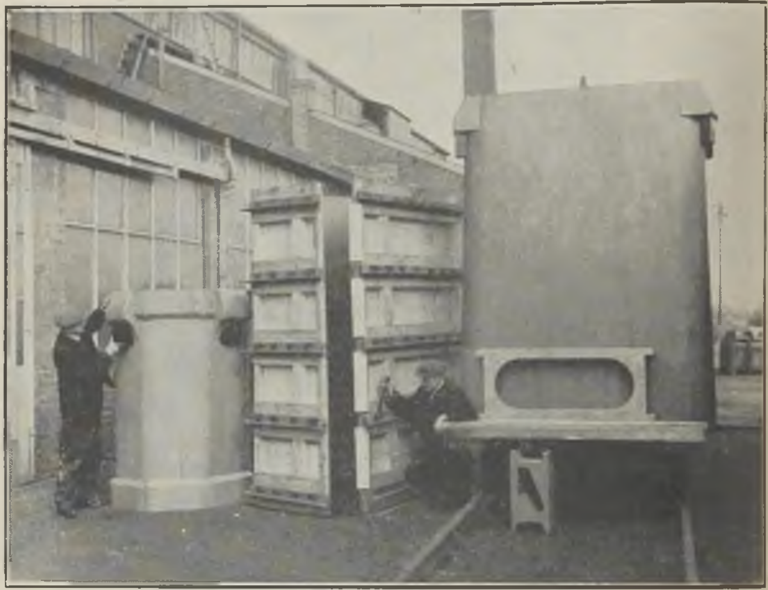


Fig. 13.—Pattern and Corebox for 20-ton Ingot Mould.

The coarse nature of the sand used has a high abrasive action on the varnish paint, but periodical repainting maintains the good drawing qualities. The contrast is most marked when the pattern and corebox of an older type of mould, which is not painted, are compared. As manufacturing by the loam method is not practised, it is advisable at times to use makeshift methods for a one-off job, and in the following is an example.

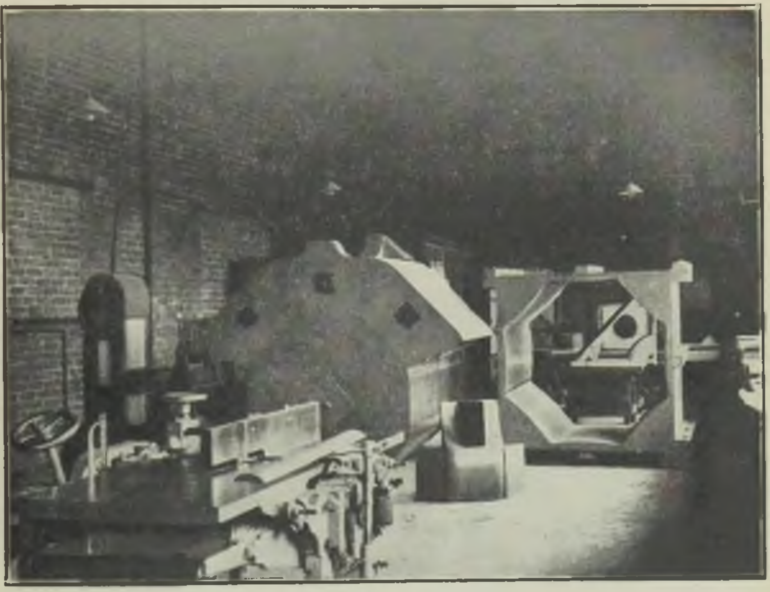


FIG. 14.—PATTERN FOR A LARGE OCTAGONAL MOULD.

A large type of octagonal mould is shown in Fig. 14. An existing pattern was used and a series of three movable sides added. Ramming operations were started on the three eke parts which, in turn, were withdrawn from the sand and replaced at other parts. The corebox was constructed on a one-off basis, but was rammed by pneumatic rammers, being unsuitable for jolting.

Iron patterns and coreboxes are extensively used, and one is assured of a true-to-shape casting resulting from their use. There are two objections to them however: they do not lend themselves to easy alterations, and the sweating effect on the surface, when they are in daily use, has a tendency to "start" the sand if excessive rapping takes place. On the other hand, patterns and coreboxes made in wood, and suitably reinforced, give a fine job, are easier to alter and rarely adhere to the sand. Their upkeep, however, is costly as they require constant inspection and adjustment.

Analysis, Manufacture and Usage

So much has been written about analysis for the ideal ingot mould, that it is with a certain amount of hesitancy that this subject is introduced. Careful scrutiny of the various investigators' findings leaves the author looking for some definite indication of analysis. Equally good lives have been obtained from ingot-mould castings with fairly wide variance in composition.

Dr. T. Swinden and G. R. Bolsover give: T.C, 3.5 to 3.75; C.C., 0.3 to 0.6; Si, 1.9 to 2.3; Mn, 0.6 to 1.0; S, 0.03 to 0.05, and P, 0.03 to 0.045 per cent. They state in addition there is a tendency to limit the silicon to 1.7 or 1.9 per cent. with a higher manganese content of 0.9 to 1.1 per cent.

Other investigators, including Legrand, Shiokawa, Kruska, Leonard, Shaw and Blakiston, confirm the view that fairly wide variances are permissible, and this coincides with the author's view. Silicon at 1.8 per cent. and manganese not exceeding 0.9 per cent., with minimum sulphur and phosphorus, give good results. Blakiston in a Paper he presented to the Middlesbrough Branch of the Institute, advocated the need for research on the actual manufacturing side. He also suggested that, as an initial step, the internal core barrel should be eliminated. The author fully agrees with this statement regarding rigid core barrels.

Two objectionable features still have to be considered, for if the barrels are left in the cores strains are set up in the casting when cooling; alternatively, if they be removed the red-hot ingot-mould castings must be handled roughly to remove the internal barrel. On the other hand, a sand and ash centre core with a minimum of iron reinforcements allows for easy

Fig. 15.—End View of a 26-ton Casting, the Core for which was shown in Fig. 5.

contraction of the casting. Compression of the core takes place, but as a unit. The ash centre relieves the sand compression when contraction takes place. It is felt that the method of manufacture coupled to subsequent use in the steelworks has a greater bearing on the lives of ingot moulds than that of analyses. In addition, the salvage value to the steelworks of discarded ingot-mould castings must be considered.

Design of Moulds, Weight Ratios and Lives

No attempt will be made in this practical Paper to summarise design, weight ratios and lives. There is such diversity of opinion in the various steelworks, all ably backed by actual experience, that definite standards in design are difficult to obtain. A mould design may be most satisfactory from a foundry point of view, but out of the question for producing a satisfactory rolling ingot. Again, there is experience of certain ingot-mould castings with objectionable features in design, as affecting the foundry, which give first-class rolling ingots and splendid lives.

Castings are supplied in accordance with the designer's conception of what is necessary to meet their service; but the tendency is towards weight reduction, as in general engineering castings. A comparison of weight ratios makes for interesting commentary. Ratios from 0.8 of the ingot weight to 1.5 are quite common. It is questionable if a stipulated ratio can be worked to, giving the best results unless local conditions of usage are studied.

W. J. Reagan has given results* of experiments on small octagonal moulds with a ratio as high as 2.5 of the ingot weight. A study of the graph given by Reagan reveals superior lives at this high ratio, with a maximum 250 casts. In personal records interesting comparison can be made. Standard 21 by 20 in. open-ended

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* "Iron Age," October 29, 1936.

common moulds give average lives of 160 casts, with individual lives as high as 230.

Another example of the variation of life of ingot moulds can be cited. Ingot mould castings, weighing approximately 8 tons, for producing standard slabs, were sent to two steelworks. The design was standardised, the analyses within limits were similar, and the castings were taken from common stock. In the case of works A, there was an average life of 55 heats, and an individual life of 62—a very consistent record.

Fig. 16.—Shows the Casting shown in Fig. 15 in Vertical Position.

On the other hand, works B obtained an average of 110 heats, with individual lives as high as 176 from similar castings. In this instance the foundry cannot be questioned, and in fairness neither can the designer nor the metallurgist. One must look for something appertaining to local conditions in the steelworks to provide a solution.

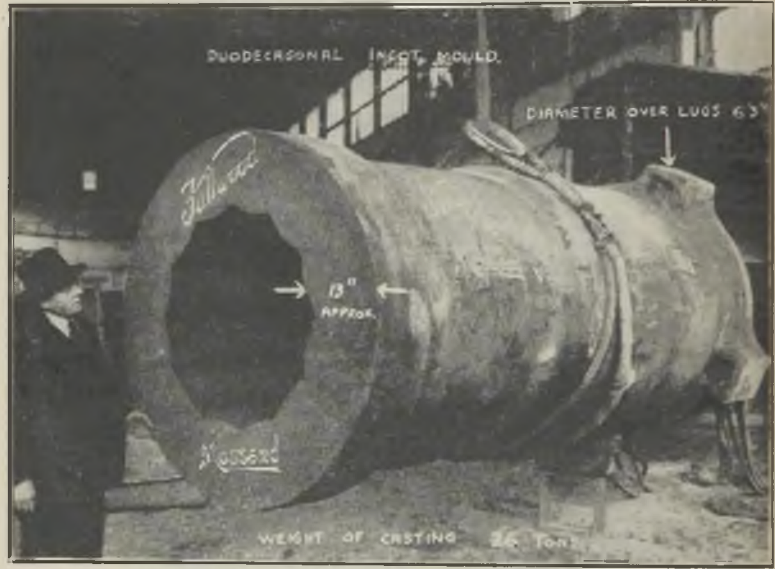

Fig. 17.—Indicates the Cross Sectional Thickness of a 26-ton Ingot Mould.

Good ingot-mould lives can be obtained by a combination of three vital factors:—(1) In the foundry, by having good coremaking practice, and by paying attention to apparently trivial safeguards. (2) In the design, by having a safety margin in wall thickness. (3) In the steelworks, by having reasonable attention and usage.

The lives of ingot-mould castings have increased very rapidly in recent years. At works B, for example, within the last 10 years these same 8-ton ingot moulds have risen from average lives of 43. Better metal, better treatment in steelworks, modified designs, co-operation, and improved foundry technique all add their quota towards better lives from these castings.

FIG. 18.—SHOWS A VIEW OF THE MAIN BAY OF THE FOUNDRY.

Metals and Melting

Hematite irons are exclusively used in manufacture. Discarded moulds are rarely used; only shop returns, such as gates and risers, are added to the pig-iron charges.

Casts as high as 182 tons in one day and from one cupola have been made, and daily casts of from 150 to 160 tons are quite common. Three cupolas of the solid-bottom type are installed. They are used in turn. The diameter of the cupola shells is 84 in., but with standard bricks and auxiliary scone brick linings the melting zone diameter is 60 in. Two rows of tuyeres are incorporated, a bottom row of four and a top row of three. There are no outstanding modern innovations attached, but very effective service from these home-made melting furnaces is obtained.

The melting rate averages 14 tons per hour. It may be pointed out that the casting temperature is very low, at 1,175 deg. C., but the phosphorus content of the metal is likewise low at 0.03 per cent. On a cast of 150 tons, the consumption of coke per ton of metal melted averages 155 lbs., inclusive of the bed charge. The coke ratio to iron melted averages 1 to 14.

Care is taken to keep the tuyeres clean, and periodically to clean the wind belt, so that consistent melting is maintained. It is interesting to record that erosion to a depth of 8 in. in diameter is shown on examination of the melting zone after particularly heavy casts, but rarely is this amount exceeded.

Supplementary Illustrations

Fig. 15 shows an end view of the 26-ton casting actually made from the core shown on Fig. 5. The fluted effect is very distinct. In Fig. 16 the casting is shown in an upright position, the overall dimensions being clearly marked, whilst Fig. 17 is an angled view with metal given at 13 in. and conveys some idea of the exacting conditions to which the sand in service is subjected. Fig. 18 is an interior view of the main bay taken some years ago, whilst Fig. 19 shows a stock of approximately 2,000 tons of various ingot-mould castings in the stock yard ready for despatch. This photograph conveys a great deal more than one at first realises. The systematic stocking makes for easy despatch, and creates a tidy atmosphere. Moreover, the effect on the employees when they observe a minor operation well done is most effective.

When one bears in mind that 500 tons of castings can be made before defects in production become apparent, it will be recognised that every care must be exercised in manufacture. Fortunately, this position rarely arises. Ingot mould castings may be called heavy pieces of metal by those who are ignorant, but who will say that chilled or grained rolls, both plain in design, are other than high-class castings, subject to severe service?

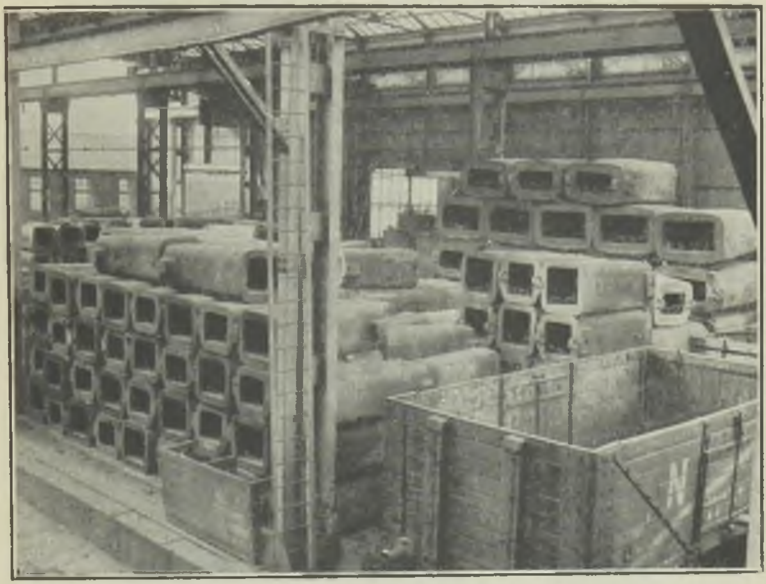

FIG. 19.—SHOWS A STOCK OF ABOUT 2,000 TONS OF INGOT MOULDS.

In conclusion the author desires to express his indebtedness to the directors of the Fullwood Foundry Company, Limited, for granting him permission to prepare this Paper, and he sincerely trusts that the younger men may be induced to give of their very best by contributing Papers to the Institute of British Foundrymen.

DISCUSSION

Mr. H. V. Grundy, in proposing that a very hearty vote of thanks be accorded to the author for his interesting Paper, said that ingot moulds were required to be absolutely perfect. Probably a thin shell scab, $\frac{1}{16}$ in thick, a little depression on the core, or a little projection on the mould, would be quite sufficient to scrap the casting. In addition to this some buyers imposed very fine compositional tolerances, frequently of the order of 0.03 per cent. S and 0.02 per cent. P as the maximum. Straight pig-iron was necessary, and steps had to be taken to counteract the sulphur pick-up. The lecture was an unusual one for the Lancashire Branch, and it had been listened to with very great interest.

Phosphide and Flaking

Mr. E. Longden, seconding the vote of thanks, remarked that, as had been anticipated, Mr. Ballantine had prepared an extremely practical Paper dealing with the application of moulding to ingot mould production and practical metallurgy. Although he, the speaker, had made ingot moulds up to 50 tons, he had nevertheless learned a great deal from the Paper, particularly in regard to cores and the unusual methods of constructing them in order to avoid many imperfections which occurred on ingot mould castings.

It was very interesting to think of some of the attempts to describe why ingot mould castings flaked and scabbed. One investigator who examined the flakes or scab metal found, on analysis, a high percentage of phosphide, and declared that the phosphide had influenced the scabbing of the cores, which was nonsense. The practice should be to prevent gases passing easily off the surface of the cores at the corners. By venting the corners from the outside and making an easy passage for the gases, the cores would not scab when pouring the casting.

Such points should be impressed upon the minds of all foundrymen. He had tried to prevent moulders polishing the faces of moulds before they put on the blacking, as a far better casting could then be obtained. A wide range in the analyses used had been presented. He was not alarmed about sulphur content if it was below 0.12 per cent., but certainly phosphorus should be kept at the lowest point.

The ideal sought was a metal which was really uniformly open-grained. Reference had been made to feeding, and Mr. Ballantine had explained the reason why he did not resort to feeding ingot moulds. The great amount of carbon precipitation counteracted the metal shrinkage. One could employ hematite iron, and it would illustrate very forcibly the compensating effect of carbon precipitation on liquid shrinkage and the feeding of castings. If a mould of any description was produced to his instructions, he would guarantee to produce castings without the ordinary liquid shrinkage cavities when made in grey hematite irons without feeding.

The vote of thanks was carried unanimously by acclamation.

Low Scrap Losses

Mr. R. Ballantine, responding, said that as far as he was concerned analysis did not really worry him very much, simply because he had to consider the salvage value of the ingot moulds back to the steelworks. They purchased the hematite to a definite analysis, but they never got the broken ingot moulds back to use in the cupola. What he was concerned about was the manufacture of the core—to allow for the natural contraction of the casting. The firm with which he was associated made something well over 22,000 tons of ingot moulds last year, and they had only 3 castings scrapped in the foundry. Therefore, he thought they were very successful in the process they were using.

Sheffield Practice

Mr. J. Roxburgh (President of the Sheffield Branch) had very great pleasure in conveying greetings from the Sheffield Branch to the Manchester members. He had had the pleasure of visiting Mr. Ballantine's foundry, and could support everything which that gentleman had said. Mr. Ballantine was, however, definitely in an advantageous position. He was making his ingot moulds for one particular steelworks, and was doing about 600 or 700 tons per week. Therefore, it was possible for him to specialise in the manufacture of ingot moulds.

In Sheffield they were particularly interested in the manufacture of ingot moulds, but they worked on an entirely different basis. Some of the steel firms had their own foundries; but, in the majority of cases, iron-founders were supplying the ingot moulds to the steelworks, which was quite a different matter. The only way in which they could tell whether the ingot moulds were satisfactory or otherwise was by the number of "lives" that were obtained, and yet they were to a great extent, as Mr. Ballantine had said, dependent upon the steelmaker. A great deal of harm could be done to the ingot mould in the steelworks. There had been instances, as Mr. Ballantine was aware, of moulds of similar capacity which had done well at one works and badly at another. When the matter was investigated from the foundry point of view it was discovered that they had been manufactured in an identical way. Therefore, it was felt at times that if the steelmaker paid more attention in a scientific way to the treatment of the moulds, better results would be obtained.

The sand was of vital importance in the manufacture of ingot moulds. Ingot moulds were manufactured in different parts of the country, and therefore it was necessary to explore the possibilities of the local sands. Mr. Ballantine had the advantage of the Scottish rotten rock sand. In Sheffield there were available for small moulds the Worksop red or sands of the red variety. Therefore, they endeavoured to get the best results out of the local sands, which was rather an important point in the case of the small moulds. It would appear that the sand Mr. Ballantine used was a coarse-grained sand, uniform in texture, and very permeable, and he had the advantage of a continuous sand preparing plant. Therefore, he could get rid of all his dust and silt, and control his sand in a very scientific way.

Sand Mixtures

In regard to his, the speaker's, particular foundry the output of ingot moulds would probably amount to 25 per cent. of the total output. Therefore, they were really jobbing founders. As a contrast to Mr. Ballantine's practice their cores for the small moulds were made as weak as possible. The mixture would be, approximately, a barrowful of black, and six shovelfuls of red sand. To that mixture they added a riddle-full of sawdust, which was passed through a one-sixteenth mesh sieve. It was not milled at all, but was simply mixed with a shovel. Thus, he regarded it as a particularly weak sand.

With regard to core barrels, they actually cast a small diameter core barrel on to the bottom core plate and round the core barrel they wound a straw rope. When they were ramming the core up they inserted four tubes opposite each corner, which were extracted, and then, contrary to Mr. Ballantine's practice again, they pricked the corners so as to make sure they were vented.

The procedure with regard to the mixing of the blacking was similar to Mr. Ballantine's method. In the case of small moulds they brushed the cores over with a plumbago wash, using a camel-hair brush. The inspection to which the moulds were subjected in Sheffield was particularly rigid. The moulds had to be very smooth inside and free from any defect. His own particular firm could ram with sand ingot moulds up to 12 or 15 tons. That was as far as they had gone with this practice, because, on the one hand, they could not afford to make a full pattern when it was a one-off job or even a two- or three-off job. The result was that in the case of the bigger moulds they had to make a skeleton pattern. This meant that above that weight they had to rely upon loam moulding.

Loam for Ingot Mould Making

MR. ROXBURGH said he had made ingot moulds up to 120 tons in weight in loam, but in his own particular foundry, at present, they could only manufacture castings up to 60 tons in weight. The manufacture of ingot moulds under those conditions, using loam moulding, was quite a different matter. In that case, too, they vented the corners, and counteracted the contraction stresses by building grids with dabbers into the cores and packing the bricks to the dabbers. They also made use of clamp bricks, and loam bricks to take care of the contraction stresses. Spaces were left at the corners, which were rammed with core sand, and pricking through into the centre with a vent wire was carried out.

Mr. Ballantine had mentioned the number of down-gates that he used, he also cut his in-gates, but he did not state the exact position of those in-gates, which was definitely a very important point. In Sheffield the practice was different from that adopted by Mr. Ballantine. They endeavoured to impart a spin to the metal, and the in-gates were run tangentially in the same direction. In Mr. Ballantine's foundry the in-gates were so placed that the metal was running in opposite directions.

The level of the in-gates was very important, for instance, if he had a 25-ton ingot mould to make he would have a down-gate on the one side with two in-gates, one in-gate would be placed about 1 in. from the bottom and the other about 7 in. above halfway; the down-gate from the opposite runner would enter about halfway up, just under the top in-gate of the other runner. It was contended that when the metal was spinning as it was rising, it was tending to lag when it got to the level of the top in-gate, and this latter in-gate helped to speed up the metal.

With regard to the feeding of the casting, he did not quite agree with Mr. Ballantine. If the ingot mould had to be machined on the top without any feeding head, he thought that defects would be shown. In Sheffield they laid particular emphasis on the fact that they must have level surfaces; they specifically precluded any flash on their ingots, and so forth. The result was that in many cases with big moulds they machined both ends, and it was insisted that they cast a head on the ingot moulds. From experience, he found that 9 in. of head was required to be cast on an ingot mould, so that when it was machined off, the casting was solid. Hematite was very liable to drawing. If there was no provision for feeding and a certain amount was machined off at the top, one would probably find a large draw-hole.

Type of Metal to Use

To a certain extent, manufacturers of ingot moulds were limited in the type of metal they could use, as there was the salvage aspect of ingot moulds to be considered Apart from that, they would probably all agree that in order to deal with the repeated expansions and contractions an iron with a high total carbon content was necessary.

Various opinions prevailed respecting silicon and manganese. Some people went so far as to recommend a 1.5 to 1.75 per cent. manganese iron, but for his own particular practice he used an iron of about 0.6 per cent. manganese. He would recommend 1.6 per cent. silicon for larger moulds, and for smaller ones about 1.8 or 1.9 per cent. He felt that manufacturers would probably all agree that the ingot mould must have low sulphur and low phosphorus contents. In Sheffield they were allowed to reach 0.07 per cent. sulphur and phosphorus, unless salvage was essential. He wondered whether a closer grained material would assist to lengthen the life of the ingot mould.

In Sheffield the ingot moulds would have a very low combined carbon content, probably as low as 0.3 or 0.5 per cent. He thought that experiments might be undertaken with a view to ascertaining the maximum combined carbon content which was permissible, and also the degree of fineness of graphite that could be obtained to give better results. If research work could be undertaken in that direction, in conjunction with better treatment in the steelworks, some useful knowledge would probably be acquired.

Feeding the Castings

Mr. **Ballantine**, speaking personally, said that machining the top of moulds was not necessary: he thought that feeding moulds was not advantageous. Taking mould section, he found there was a definite open matrix in the wall centre, yet there was no inner local defect showing due to lack of feeding. The wall section was quite definite, and showed the same characteristics in any other part of the mould. He believed the part showing the open matrix had a beneficial effect on the life of the moulds, simply because there was a cushioning effect.

The tendency towards moulds splitting in service was objectionable, and the very fact that they were not fed had proved beneficial. Mr. Roxburgh was manufacturing under entirely different conditions from those at the author's foundry.

Mr. **Roxburgh** said that usually it was an inverted type of mould when the head was cut off and the top surface was machined, which meant that the top side came to the bottom when in service.

Mr. Ballantine agreed, but said that he cast the other way.

Mr. Roxburgh observed that the point was that they took the top part of the casting as cast, then turned it over, and all the pressure was at the bottom.

Mr. Ballantine said that the inverted type of mould was cast in a similar way to that described in the Paper. He did not agree with the suggestion that the down-gates chased each other, and he asked if Mr. Roxburgh was referring to the duodecagonal type.

Mr. Roxburgh said he was referring to the big moulds. In the case of small moulds he only ran them from the bottom, and in such cases the gates would not chase each other.

Mr. Ballantine said that he stepped the gates. He thought the gates chasing round created a swirling action, which tended to disturb the twelve points on a core of this type.

Mr. Roxburgh said that with a small mould they had a grip cut in the bottom. He wished to mention that he blacked all his cores in the green state and not in the dry state; because in the green state the sand was able to absorb the blacking better.

Mr. Ballantine said that was also his practice. His point was that the sand core had very great advantages as contrasted with loam moulding with bricks. He was still of the opinion that the corner flaking could be eliminated. If it were possible to vent by means of a pricking rod from the inside to the outside, this would assist scaling. Owing to the very fact that bricks were not used, and the sand was of a definite texture, this trouble of scaling rarely arose. He had had a peculiar experience some time ago, when he was called to a works to see an 8-ton casting. The foundry wanted an allowance for the job. A complete shell came from the inside of the casting, adhering to the steel, and he learnt that this casting had run out when poured, and had been filled up again!

Size of Gates

Answering another speaker, Mr. Ballantine said he did not include the sizes of down-gates and in-gates, because every particular mould had different ratios. He was very pleased that the speaker had brought forward the point respecting the amount of sand. He always liked to have a safety margin in sand. Some of the older boxes gave 2 in. of sand, which was useless. In the case of any new boxes that were designed, there was a minimum of 5 to 8 in. of sand.

In the case of the large box, he believed there was a margin of 10 in. sand, which gave a very good cushioning effect. A binder was not required at all. If there was a fair margin of sand to work with, a great deal of trouble was eliminated.

He had found some fairly wide variations in regard to combined carbon contents. The fundamental necessity in any foundry practice was care in manufacture, quite apart from the metal used. The finest metal ever manufactured, if put into an inferior mould, would produce a defective casting, while quite ordinary metal put into a first-class mould would produce a serviceable casting.

Mr. Roxburgh, referring to combined carbon, said if a casting was to be maintained at a continuous temperature throughout its life, he thought that one could even use an iron with a mottled structure because there was no shock to contend with. When casting ingots in ingot moulds, if they were repeatedly cooled down and heated up again, the conditions were entirely different. In his opinion, for an ingot mould a low combined carbon content was definitely better. Perhaps the percentage could be increased a little more with a view to giving increased life. For continuous service he had made irons which had been quite mottled, where the combined carbon had been 1.5 or 2 per cent., and the life in service had been over two years.

MR. J. E. COOKE spoke with regard to the drawing of core boxes which had been jar rammed. Mr. Ballantine had emphasised the importance of the varnish. There was a tendency at the present time to attempt to save both time and money by the use of inferior varnish, in which gum or resin content impeded drying. Did Mr. Ballantine use the best quality varnish, and had he ever tried any substitutes for varnish on the coatings for the surface of his core boxes?

MR. BALLANTINE replied that he bought the very best varnish paint possible to obtain. He was not content with giving one coat; he gave three. He could effect considerable economies in production by the application of good quality varnish paint, and the patterns stripped easily. It was not an economic proposition either to put inferior varnish on the patterns or to scamp the timber. If he put good timber on, 2½ in. thick, he used good varnish paint.

Sheffield Branch

Paper No. 618

THE MANUFACTURE OF IRON AND STEEL CASTINGS IN GREEN SAND*

By C. J. DADSWELL, Ph.D., B.Sc., T. R. WALKER, M.A., and F. WHITEHOUSE (Members)

The reason usually advanced for the manufacture of castings in green sand, instead of in dry sand, is that there is a saving in cost when green sand is adopted. This is generally true, but in certain instances there are other factors which influence the choice of method. In any case, any advantages green sand practice may possess are not obtained without careful study; special precautions must often be taken, and the process has inherent disadvantages which limit its application.

Advantages Shown

The first important advantage is that moulds need not be dried. This saves the cost of drying equipment, and also the cost of drying, which includes not only fuel, but the time and wages of stove attendants. It also liberates the space otherwise required for drying equipment, and enables the space to be usefully employed for other purposes. There is an additional saving in the time normally occupied in the drying operation. In consequence the capacity of the foundry floor for moulding and for putting down boxes is increased, so that if the capacity of the melting unit is adequate, the output of the foundry may be increased. Alternatively, for a given output of castings, fewer moulding boxes are required, since they are returned to the moulding bay in a shorter time than when making dry sand castings. This is of particular importance in the quantity-production of castings, when moulding machines are being employed

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* The Authors were awarded Diplomas for this Paper.

which should be kept fully occupied. In some cases green sand castings have a sharper outline than those made in dried moulds, that is to say, more detail is reproduced.

The fact that the mould material has comparatively little strength gives increased freedom from pulls or hot tears, and brackets can frequently be eliminated which are required when castings are made in dry sand. Owing to the reduced tendency to tear, less easing of the castings is required. These last remarks, of course, apply almost entirely to steel castings. Fig. 1 is an example of a thin steel casting about 5 ft. long successfully made in green sand without tears and with a good finish.

Fig. 1.—A 5 ft. long Steel Casting Made in Green Sand.

The cost of closing moulds is less than for similar jobs made in dry sand, as the cores can be fixed into their prints with less filing and fitting. This is because the green sand prints give way slightly and adjust themselves to any small irregularities in the cores. The fact that the cores fit closer into green sand prints means that less flash is produced, so that the cost of fettling is reduced. In addition, the way in which the green sand prints can be, to some extent, distorted, allows cores to be set up by gauges in the mould, producing greater accuracy in the subsequent castings. This distortion, however, may also lead to inaccuracies in the castings, since the fact that the prints are not rigid means that unless gauges are used it is very easy for cores to be misplaced. Fig. 2 shows an automatic railway coupler and its components. This is an example of the accuracy which can be obtained in green sand steel castings as all the working parts are assembled in the coupler body without machining.

Fig. 2.—Automatic Railway Coupler Cast in Green Sand and Assembled without Machining.

Horseshoe nails and special chills can be inserted in the moulds at chosen points during closing without the mould surface being damaged. Finally, for some types of steel castings it is possible to use the same sand for both facing and backing purposes, which leads to a saving of time when machine moulding is being carried out.

Disadvantages

The first disadvantage of green sand moulding is that the weakness of the moulding material limits the size of the casting. Castings can be made in green sand only if they do not involve a high ferrostatic pressure or very heavy sections.

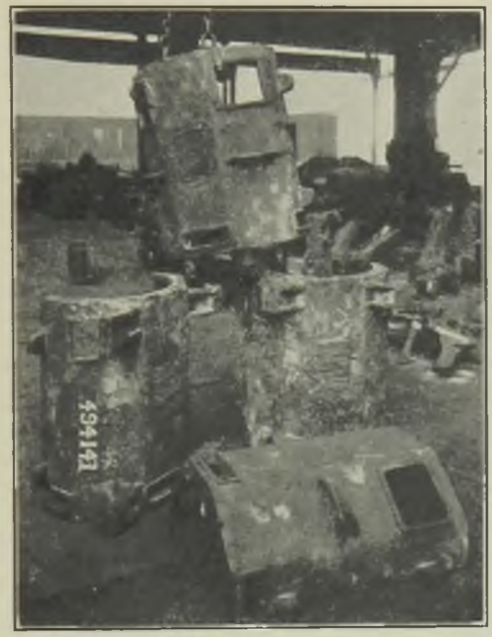

Fig. 3.—Defects and Swellings which may Occur on Green Sand Steel Castings.

The mould surface is weak and easily washed away in front of the runners unless precautions are taken to avoid this. Nailing can be adopted, or inserts of either dry sand or oil sand can be used, but these devices naturally increase the cost of the process. In addition, the weakness of the surface of the mould is liable to give rise to sand inclusions at, or underneath, the surface of the castings.

Green sand moulds naturally require more careful handling during closing than dry sand moulds do, and they are also more easily crushed. Green sand castings are more liable than dry sand castings to such defects as swellings, scabs and blowholes, owing partly to the weakness of the sand and partly to its water content. Swelling and scabbing may be minimised by hard ramming of the mould. Fig. 3 illustrates the defects of swelling and scabbing which are prone to occur in certain types of green sand steel castings.

If green sand moulds are not cast within a certain time, any nails or chills inserted in the moulds tend to condense on their surfaces a layer of moisture which causes small blowholes in the castings. Similarly, unless the core compound in use is of a type which will resist the action of water, the moisture in the mould will soften the oil-sand cores, if moulds are allowed to stand for too long after closing and before casting. In such circumstances, if it is not possible to cast closed moulds on the same day, so that they are left over until the next day, it is often possible to keep them in good condition by lifting the tops and packing them above the bottom parts with, say, pieces of brick.

Since green sand moulds are not so hard as dry sand moulds, the core prints are not always strong enough to prevent the lifting of cores during pouring. Chaplets cannot be used satisfactorily between the cores and the mould surfaces, since the chaplets would penetrate into the relatively soft mould surface instead of stopping the cores from lifting. This trouble may be eliminated in several ways, for example, by packing the prints from the box bars. Fig. 4 shows a steel dredger bucket cast in green sand and weighing about 15 cwts. In this case a heavy core was used which had to be supported in the green sand mould by packing from the box bars.

In green sand repetition work, accurately jigged boxes are required, and good fitting pins must be used. Metal "carrots," sand buttons and sockets are useless in this case, since they have no rigidity and will not register the top and bottom parts with any accuracy.

Sand Practice

For successful results in green sand moulding, it is necessary to devote some care to such modifications of ordinary dry sand moulding practice as are demanded by the different nature of the moulding material. Patterns for green sand work should have a very smooth surface, in order to obtain a good draw, since patching and rectifying the surface of the mould are more difficult and less satisfactory in green sand than in dry sand, particularly for steel, and often lead to the occurrence of scabs and other surface imperfections in the castings.

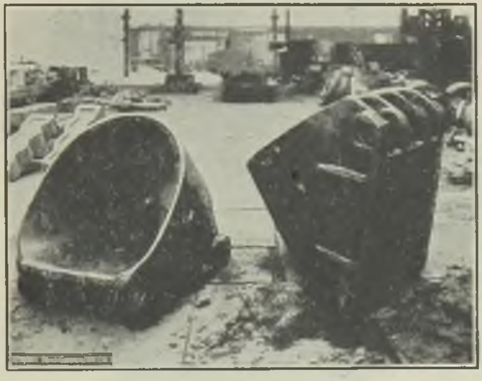

Fig. 4.—Dredger Bucket Cast in Green Sand. The Core is supported from the Box Bars.

The moulding boxes must be rigid, particularly those used for moulding top parts; neglect of this precaution may lead to the dropping-out of the mould during lifting or transfer from one part of the floor to another. In the case of steel castings, especially those run from bottom-poured ladles, sufficient depth of the bottom part is necessary to prevent the steel bursting out at the bottom. For the same reason bottom parts must be well rammed, and if they are moulded on machines must be properly flat-rammed between the bars. During pouring, the boxes must be fitted on good level beds of dry sand, or other adequate means must be used to support the bottom box.

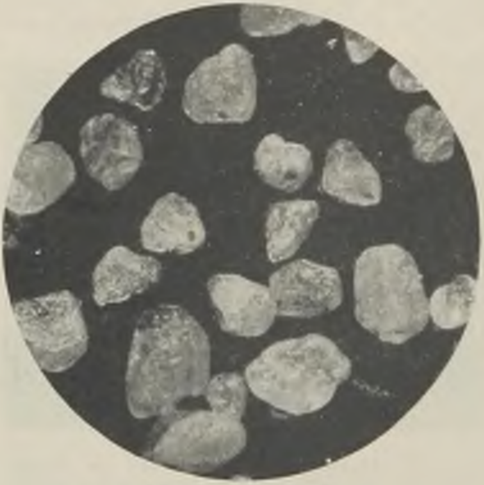

FIG. 5.—ROUND-GRAINED SILICA SAND.
× 25.

Gating Modifications

The provision of gates also requires consideration. Moulded gates are better than gates afterwards cut in green sand moulds, as they are stronger and have a stiffer surface. An alternative is the use of oil-sand cores in which the runners have been moulded.

A point of particular importance in green sand steel castings is the position of the runner, since the mould material is not able to withstand very much washing of the liquid steel over its surface. Often the normal practice of bottom running gives satisfactory results, but in many instances this is not so good as running at the joint, or even from the top of a casting. The adoption of bottom pouring for a deep casting means that a large amount of liquid steel has to be forced up the sides of the mould, whereas running at the joint means that some of the steel falls downwards and the rest is forced upwards. In some cases top pouring can be carried out successfully if the liquid steel is allowed to fall on a core in the bottom of the mould placed there for this precise purpose, or alternatively on one of the cores which is a normal component of the mould.

FIG. 6.—NATURALLY-BONDED ANGULAR-GRAINED SAND. × 25.

Down-gates for steel castings should be made of fireclay, since green sand will not withstand successfully the wash of the steel. For the same reason, runner bushes are commonly made in dry sand.

Green Sand Cores

An obvious extension of green sand moulding is the use of green sand cores instead of either dry sand or the much commoner oil sand cores. This is a matter in which steady progress is being made, this progress being more marked and more rapid in iron foundries than in steel foundries.

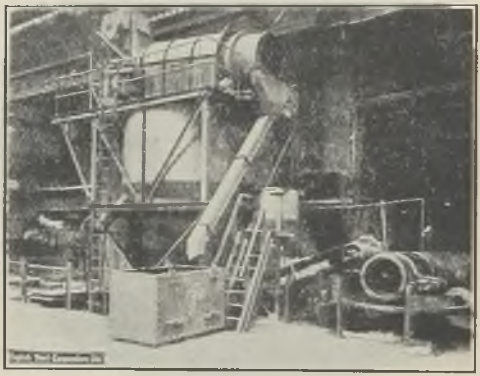

Fig. 7.—Sand Mixing Plant.

The first important advantage in the use of green sand cores is that the core mixtures are very much cheaper than mixtures of silica sand with core compound. Just as in the case of green sand moulding, the cost of drying equipment and of the drying operation is eliminated. This means, of course, that the capacity of the core shop is increased. An advantage in using green sand cores is that they diminish cracking and hot tears, since they give way readily to the forces of contraction owing to their low mechanical strength.

There are, however, distinct drawbacks to the use of green sand cores which offset the advantages referred to above. In the first place, the low mechanical strength of the core does not permit of much overhang, so that this at once limits the application of the method. In the case of small and medium-sized cores, only such

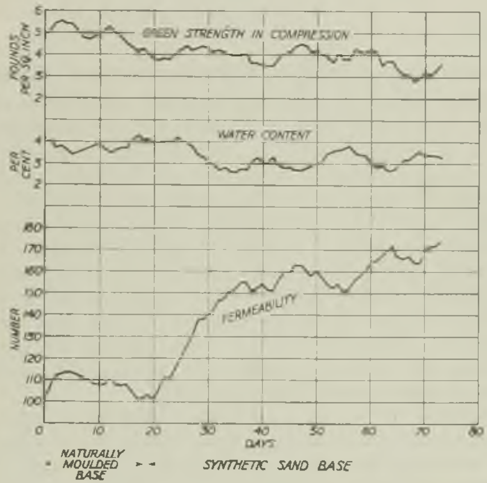

Fig. 8.—Varying Properties of Knocked-out Sand before Treatment.

cores can be used green as can be safely conveyed from the core table and placed in the mould without sagging. Green sand cores are more fragile than green sand moulds, in that green sand moulds have the support of their box, in the bottom part at any rate.

Generally speaking, green sand cores are less refractory than oil-sand cores, which on strong heating are reduced essentially to silica sand. This means that green sand cored castings often involve more sand blasting, which is more difficult to carry out in recesses than it is on the outside of the casting. It is possible to use larger green sand cores when floor or pit moulding is being carried out, since the cores can then be built up *in situ*, and do not have to be handled or conveyed to another part of the foundry.

Although in the manufacture of green sand castings in iron and steel there are many principles which are, in general, applicable to both materials, there are some points which affect the manufacture of castings in only one of them.

Properties of Steel in Relation to Green Sand

In the case of steel castings, the properties of the liquid steel are of importance in obtaining success in the foundry. Though no particular change in chemical composition need be made when changing from dry sand to green sand moulding, the method of steel manufacture sometimes needs modifications if success in making green sand castings is to be obtained. From a foundry point of view, steel should have a low content of dissolved gases. If its gas content is considerable, then gases will be evolved when the steel is cooling in the mould, and blowholes of some kind will result.

This point is of particular importance when green sand castings are being made, since steam is evolved from the mould when the steel is poured into green sand moulds, and the passage of such steam through the steel is liable to cause the evolution from the steel of dissolved other gases which, without being disturbed in this way, would not be evolved.

The other important property from a foundry point of view is the life of the steel. It should remain pourable over a considerable range of temperature, and should be sufficiently fluid to fill every part of the mould however intricate this may be. Although this property is desirable for all castings, it is most important when the castings are small, light and thin in section, or intricate in shape. This is precisely the type of casting usually made in green sand; hence the importance in green sand work of having a steel with a considerable life.

One method of manufacturing basic electric steel suitable for green sand steel foundry practice was described by two of the present authors in a Paper* last year, and this point need not, therefore, be further elaborated.

Sand Control

The properties of the sand used in a steel foundry for green sand work have an important effect on the results, and attention to this point is essential if success is to be achieved. Given suitable raw materials, the sand mixtures leading to successful results must usually be discovered by trial. When once they are found, uniformity in the sand supplied to the foundry floor must be maintained, especially when machine-moulding is adopted. This uniformity is secured by testing batches of sand immediately after mixing. Whether this testing is carried out with apparatus giving numerical values for such properties as the water content, permeability and green strength, or by "Old Bill," who relies on sight and feel, is a matter of no great consequence, unless "Old Bill" falls ill.

Sand for green sand moulding in steel should have a high permeability, and should, therefore, be fairly coarse in grain with as uniform a grain size as can be obtained. Its water content should be as low as possible, but a minimum amount of water is, of course, necessary to develop sufficient green strength. The high permeability will assist steam and other gases to escape from the mould, whilst the low water content will minimise the amount of steam generated during casting. Green sand casting has the advantage that during the pouring process a less proportion of the sand is heated to such a high temperature that its bond is permanently destroyed, and consequently a greater proportion of sand is re-usable than in dry sand

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* Proceedings, I.B.F. Vol. XXIX, page 537.

work. It follows that with green sand moulding the percentage of make-up, whether of new sand, new binding material or both, is reduced. In spite of this economy, the surface of green sand castings is often at least as good as that of similar castings made in dry sand, since the refractoriness of the green sand mixture is at least as great as that of the dry sand mixture.

The property which is most liable to sudden variations is the water content, and differences in the amount of water present affect both the permeability and the green strength, so that it is essential to carry out frequent determinations of the percentage of water present. To obviate any troubles due to variations in water content this should be maintained constant within half per cent. For the same sand mixture too little water gives moulds which are weak and have a friable or murly surface, whilst too much water easily results in such defects as scabs and pin holes. It is advisable, therefore, to mill the backing sand as well as the facing sand in a green sand steel foundry, since without milling it is almost impossible to obtain uniformity in the sand mixtures. If the backing sand contains more water than the facing sand, water will move forward towards

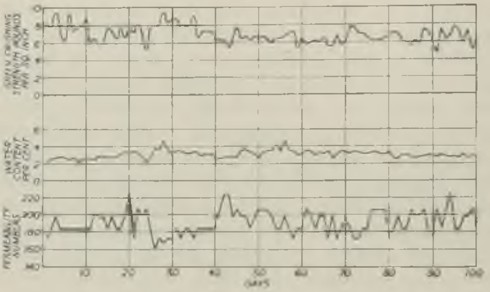

Fig. 9.—The Result of Control in Sand Preparation.

the surface of the mould when the moulds are standing, especially after closing, when the water vapour cannot readily escape from the interior of the mould. It is thus desirable that the backing sand should contain less water than the facing sand.

Synthetic Sands

In foundries in this country an increasing use is being made of sand mixtures consisting of silica sand milled with clay. In such mixtures the characteristics of both the sand grains and the clay are important. Sand grains which consist exclusively of silica are spherical in shape and have a smooth surface, and are the most refractory. Owing to their shape they touch at a minimum number of points, which is good for permeability but bad from a strength point of view, whilst the smoothness of their surfaces means that any coating of binding material put

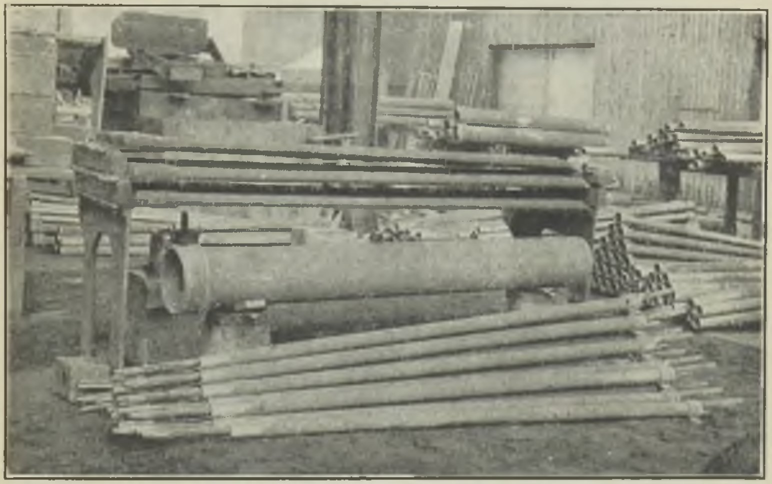

FIG. 10.—A RANGE OF PIPES ALL OF WHICH CARRY GREEN SAND CORES.

on the grains will not be held very firmly. Fig. 5 illustrates a silica sand of this type in which the grains are well rounded and have a smooth surface. If the grains are more angular the permeability is somewhat diminished, but owing to the greater area of contact between neighbouring grains the mechanical strength obtained by milling the sand with clay is improved. If at the same time the surface of the grain is rough, or if the grains are coated with a thin layer of tenaciously-held natural binding material, then any additional binding material milled with the sand will form a firmly-held layer round each grain. Fig. 6 illustrates a sand of this type in which the grains are sub-angular and are coated naturally with a thin film of clay, which is very difficult to remove.

Fig. 11.—These Castings have been Cast with Green Sand Cores.

Though any kind of clay may be used as a binding material, the ideal clay for this purpose would be both very refractory and highly plastic. Such a clay has not yet been discovered, and it is therefore necessary to adopt a compromise. Since the clay is less refractory than the silica sand, as little clay as possible should be used, so that the clay chosen should be highly plastic, with as great a refractoriness as can be secured.

In this country the two clays commonly used are bentonite (a very plastic American clay) and ball clay (from Devon or Cornwall).

Table I gives the properties of sand mixtures made from the sand shown in Fig. 5, with different additions of bentonite and ball clay, whilst Table II gives the same information regarding mixtures of the sand shown in Fig. 6 with the same proportion of the same clay.

TABLE I.—*Sand with Smooth Well-Rounded Grains.*

Clay addition. Per cent.		Water. Per cent.	Permeability number.	Green strength. Lbs. per sq. in.	Dry strength. Lbs. per sq. in.
Ball clay	1½	1.0	216	2.0	7.7
	2½	1.25	200	2.5	25.3
	5	2.25	188	5.5	51.3
Bentonite	1½	1.5	216	1.5	20.3
	2½	1.75	200	2.5	30.0
	5	3.0	178	4.75	55.7

TABLE II.—*Sand with Coated Sub-Angular Grains.*

Clay addition. Per cent.		Water. Per cent.	Permeability. number.	Green strength. Lbs. per sq. in.	Dry strength. Lbs. per sq. in.
Ball clay	1½	2.0	178	3.75	26.7
	2½	2.4	178	6.0	43.7
	5	3.2	144	9.25	82.7
Bentonite	1½	2.1	188	3.75	27.4
	2½	2.8	178	6.25	58.0
	5	3.75	138	9.0	78.7

These illustrate the fact that with the same sand the two clays give almost the same mechanical strength. With the more angular sand, possessing a thin film of bond, however, the mechanical strength is substantially greater with the same clay content than for the smooth grain sand. The permeability of the mixture with the smooth rounded grains is rather greater than for the other sand. In any complete comparisons of clays it must be emphasised that besides the green strength in new mixtures there are other points of importance such as the length of useful life in repeated use, the nature of the surface developed on moulds, and the rate of loss of bond strength on heating.

FIG. 12.—IRONS FOR GREEN SAND CORES. ONLY THE BOTTOM HALF IS REINFORCED.

Influence of Milling

In green sand practice of the type now being considered the silica sand is milled with the requisite amount of clay and water, the properties of the batch checked by testing, and the sand passed to the foundry floor for use. After the castings are knocked out, the sand is recovered and converted into backing sand with any necessary addition of new clay. Fig. 7 illustrates a typical installation for this purpose.

The knocked-out sand arrives on a conveyor, and any contained steel or iron is removed by a magnetic separator. The sand is screened and transferred to a hopper, from which it is fed to a rotary mill, where it is mixed with new clay and water, and is charged into a skip, ready for use. The knocked-out sand naturally varies considerably in its properties, but after the treatment outlined the backing sand produced is uniform. Fig. 8 illustrates a significant change in the properties of the knocked-out sand during one period in the steel foundry referred to.

FIG. 13.—BECAUSE OF THE FEW CASTINGS REQUIRED, THE CORE IRON IN THIS CASE IS BROKEN FOR EXTRACTION.

In order to eliminate the effects of wide daily variations in properties, and to emphasise instead the general trend in properties, the figures in the graph are shown in the form of a moving average curve of five days. During the first 18 days considered, the sand had a naturally bonded base, and its permeability number was about 105. Trouble was experienced in the foundry with defective castings, and it was decided to increase the permeability of the sand substantially. For this purpose progressive additions of a synthetic sand mixture were made, and the permeability number rose steadily to a figure of about 165, with very little change in either water content or mechanical green strength. With this change trouble in the foundry was eliminated.

The facing sand used is prepared from the above backing sand, milled with new sand and with fresh clay. To ensure uniformity the properties of every batch sent to the foundry floor are determined. Fig. 9 shows the results of 100 consecutive days' examination of this facing sand. It can be seen that the sand supplied to moulders day after day is reasonably uniform, and can be expected to give similar results repeatedly when used in the same way.

Type of Steel Castings Made

From what has been said already, it will be evident that some types of steel castings can be more readily made successfully in green sand than can other types. In this country, until recently, much larger green sand castings have been made in iron than in steel. The technique of making green sand steel castings up to about one ton each in weight is still not very widely known, though the number of steel foundries now making small green sand castings is rapidly increasing. Small castings suitable for repetition work lend themselves particularly well to green sand production in the steel foundry. Examples are castings for railway locomotives, carriages and wagons, colliery work, and castings for motor cars and lorries.

In the case of steel castings up to, say, one ton in weight, it is only when a foundry specialises in particular lines that they are manufactured in green sand, as the amount of special tackle required to make such castings in green sand is considerable.

Green Sand Iron Castings

The remarks already made regarding the economies to be secured by the adoption of green sand methods apply equally well whether the castings are in steel or in iron, and need not be further discussed. Green sand moulding has been practised in iron foundries for many years, and there is no need to do more than draw attention to castings which are not universally made in green sand, or which illustrate points of importance in the iron foundry. The economic advantages associated with green sand moulding are applicable to an even greater extent when the process is utilised for the production of cores, and this is a very promising field for development in the iron foundry. It is, of course, not practicable to make every core green, but it is easily possible to extend the use of green sand considerably.

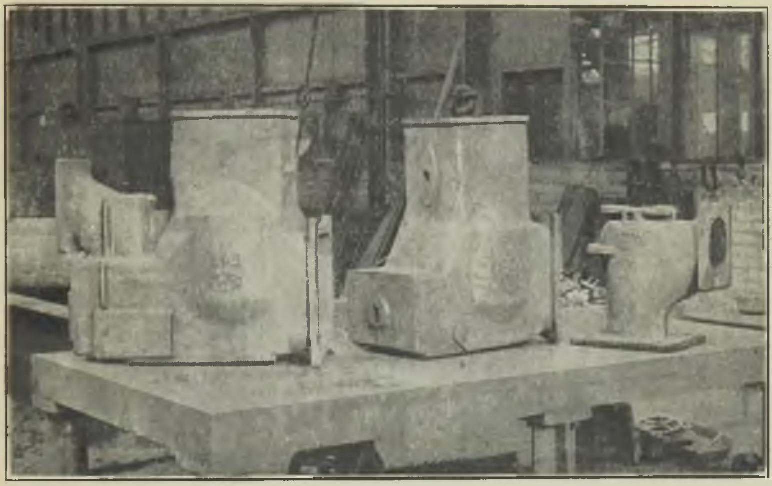

FIG. 14.—INTRICATE CASTINGS MADE IN GREEN SAND.

The greatest opportunities for the use of green sand moulds and cores are found in the light iron castings foundry. Fig. 10 illustrates the production of pipes in such a foundry, and demonstrates the range of sizes dealt with. Each pipe mould, of course, must contain a core. If all these cores had to be dried the equipment required would be considerable, whilst the time occupied and the handling involved would create problems which do not arise when the cores are used green.

Three castings which are often made with dry sand cores, and sometimes with dry sand moulds also, are shown in Fig. 11. They consist of a 12 in. sluice valve weighing 3½ cwts., a gas valve weighing 2½ cwts., and a gas offtake weighing 3½ cwts. All these are required to be perfectly sound and of good finish, all are machined to close limits, and in each case slight defects on the valve seats are sufficient to involve rejection of the castings. In the foundry under consideration all these are regularly made in green sand throughout, the wasters over a period amounting to no more than 2 per cent., so that for such purposes the use of green sand cores is no longer in the experimental stage. Some details of the methods of making and using such cores are given below.

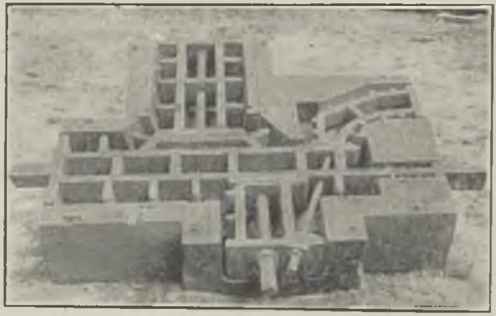

Fig. 15.—Core Box and Irons used for one of the Castings shown in Fig. 14.

Core Irons

The essential principles in green sand core-making, namely, the form and construction of the core iron, are illustrated in Fig. 12. The basic idea is that only the bottom half of the core should contain an iron, and that iron should be so fabricated that it can be used repeatedly, even if a thousand castings are required. The iron in Fig. 12 is in three parts, which are fastened together by two screws. Soon after casting, the screws are loosened and the separate parts of the core iron are taken out of the casting. The pieces are then re-assembled and the iron is ready for use again.

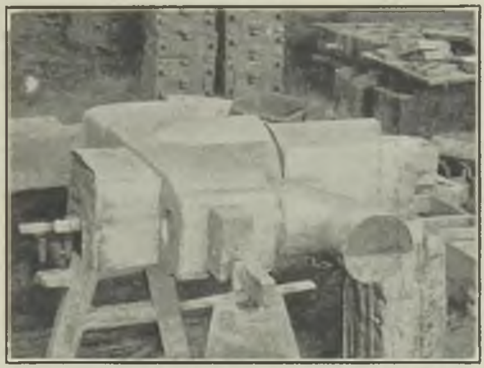

Fig. 16.—The Core Ready for Insertion in the Mould.

In this way practically all the core is removed from the casting whilst it is still in the foundry and whilst the casting is still red-hot, which means that not much sand is destroyed by heat and not much lost by going to the fettling bay. This effects an important economy. A further point with these core irons is that the end bars, at the extremities of the core, are slightly larger than the rest. They sit on the bottom of the core box, whilst the remainder of the bars are

½ in. to ¾ in. from touching. These end bars are used for supporting the core as it sits in the mould, and usually come directly over a bar put in the moulding box for that purpose. The core box is a normal one.

The objection that can be raised to this manner of manufacture is that it involves the provision of a core iron that can become elaborate and therefore costly, and this point must be taken into account. There is a minimum quantity of castings required which warrants this kind of core iron, and the precise number in any given case is obviously governed by the cost of the core iron, which is different in each job and maybe from one shop to another. However, nothing slipshod will serve the same purpose; the iron must be well-fitted, and truly rigid when assembled, and incapable of slipping or twisting.

Fig. 13 shows the core box and iron of the sluice valve seen in Fig. 11. Here the core iron is in one piece and must be broken out of the casting each time. The reason for forsaking the principle of making a fabricated core iron is merely that the number required was too small to warrant the cost of fitting it up, and there is no object in saving money on a core to spend it on tackle. In this case the only money saved was by eliminating handling and drying.

A further group of castings made entirely in green sand, larger and more intricate than the previous casting, but still subject to the same specification regarding finish and cleanliness on machined surfaces, is shown in Fig. 14. Fig. 15 illustrates the core box and core iron for one of the castings. This time there are more pieces to the core iron and more screws to hold them together, but the principle is the same. In this case the core box has loose sides, the purpose being to get the core out of the box without undue damage, a concession to green sand practice. Fig. 16 shows a core ready for dropping into the mould.

None of the sand used is milled, no facing sand is used on the top half of the core, and only very little on the bottom. The procedure is to line the bottom of the box with about 1 in. of sand (which consists of a mixture of a little Worksop red with the floor sand), and then bed-on to this the iron which has previously been clay-washed. The bottom half is rammed to the level of the box joint and then vented. Bars

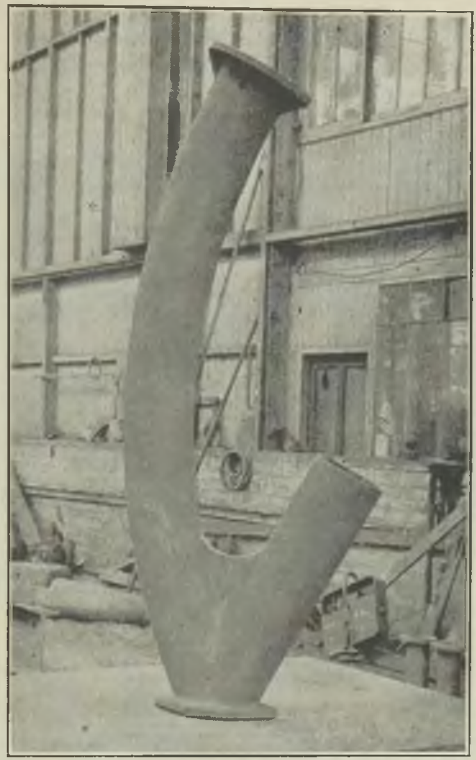

Fig. 17.—An Arch Pipe Casting Made from a Skeleton Pattern.

are laid on to bring off the air at the centre, and the top half of the box is put on.

The sand for this half is riddled floor sand and the ramming is done by packing sand in at the ends of the box, after which the top half of the box is lifted off, the core made good where necessary, and vented down to the vent bar in the centre. Now the core is lifted out of the core box and the final finishing and blacking done. After blacking, a little oil is put round delicate edges to preserve them, and the core is ready for use. No chaplets are needed, because of the rigidity of the core iron, and none is used.

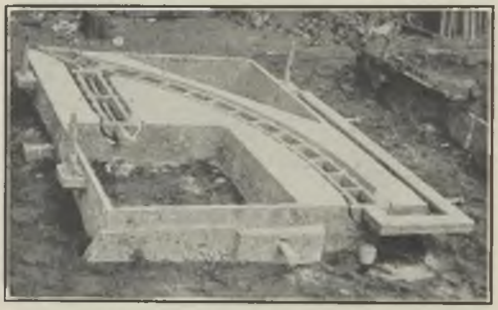

Fig. 18.—Skeleton Pattern of an Arch Pipe in the Mould. Note the Core Suspension.

This core takes about two hours to make, and there is no additional cost, apart from the items which have already been mentioned. The moulder makes his own core on his own floor, and the method described is probably the cheapest which could be found for making such a core.

Figs. 17 and 18 illustrate an arch-pipe made out of a shell pattern, utilising the same principle. The core iron is of the same type except that it has an arm extension, the purpose of which is to balance the core and serve as a means of preventing either sagging or lifting. This is done by packing to projections on the moulding box and so avoiding the use of chaplets. The core here was formerly made in loam, and the gain in time, material, new core irons, and a more uniform weight of casting obtained by the method described is evident. Here, too, it is easy to observe the manner in which the moulding box is cut out to receive the end bar of the core iron, and to provide a means of support.

Fig. 19.—Semi-Bend Pipe Casting.

Fig. 19 shows a semi-bend pipe weighing 1 ton. Fig. 20 shows the core iron for this casting, and Fig. 21 shows the core ready for dropping into the box. The principles involved are precisely the same as those already referred to, but the shape and size of the casting are different. Many other examples of similar work could be given but they are unnecessary, since the same principles are utilised in every case.

Method of Production

Although the properties of sand used in an iron foundry are important, there is no central control of the sand in the foundry where the castings illustrated above are made. Each man makes his own mixture from new sand, floor sand and coal dust without milling. No doubt the properties of each man's sand are slightly different, but the effects of such variations are corrected by differences in ramming, in the use of the vent wire and oil-can, by alterations in the position of the gates, or by pouring at a rather higher or lower temperature.

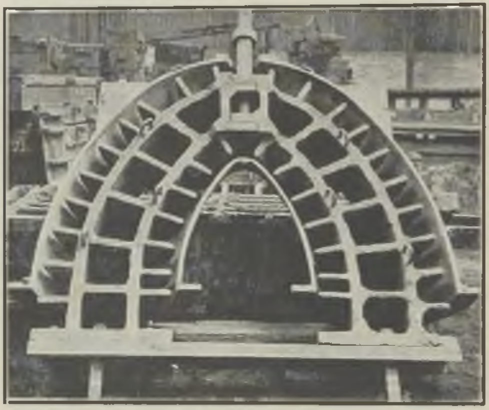

Fig. 20.—Core Iron Used for the Casting shown in Fig. 19.

Each man pours his own casting and decides for himself what is the best pouring temperature. The gating of such castings is also a matter of importance. Gates should be arranged so that the mould can be filled quickly and quietly without the stream of metal striking a green sand core directly. At times, however, these conditions, though desirable, cannot be obtained.

It will be evident that in the foundry referred to, success in making iron castings of the type described, using green sand moulds and cores, has been obtained entirely from practical experience. Individual workers are to be admired for their craftmanship, but it must be admitted that any depletion of their ranks would have a very serious effect on the output of the foundry in such castings. This affords a good example of the truism that for certain types of work foundry practice is still an art, not a science. On the other hand, many iron foundries engaged in repetition green sand work, especially for the automobile and similar industries, find it necessary to control the properties of their sand mixtures by actual testing, on the same lines as the steel foundry referred to earlier in the present Paper.

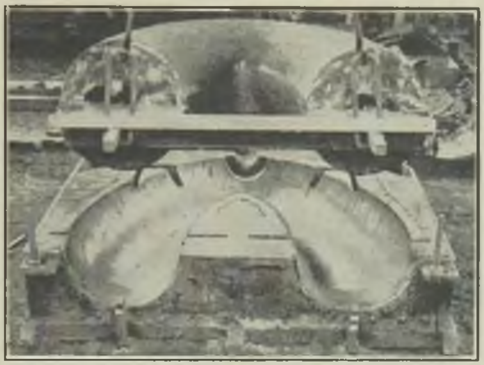

Fig. 21.—Core Ready for Inserting in the Mould.

DISCUSSION

Limitations of Green Sand

Mr. J. Roxburgh (Branch-President) said there were definite limitations to the number and the nature of castings that could be made in green sand. In the foundry with which he was concerned, where high-class engineering castings were made, it was found that, except with small castings and repetition castings, they could not use green sand to any great extent. They did use green sand in some cases, but with high-class engineering castings it was essential to melt the metal at as high a temperature as possible, and in the majority of cases to cast as hot as possible. With the majority of their castings it was found necessary to make them in dry sand. In the iron foundry they had to have a particularly skilled man to ram a job up in green sand as the question of ramming in the iron foundry was particularly important. He wondered if the density of ramming and the variation of ramming from one particular job to another were as important in the steel foundry as in the iron foundry. The task of finding skilled moulders used to green sand was a very difficult one, and during the past few years many ironfounders had changed over to dry sand for the better class of work, whereas, in steel foundries, they seemed to be reverting in many cases to green sand. Mr. Whitehouse had remarked that his foundry was a jobbing foundry, but the illustrations of the boxes and fabricated core irons he used, and the wide application of his green-sand cores, indicated that what was being done was definitely on a repetition basis. This had to be considered in relation to the suitability of green sand for a particular job. If Mr. Whitehouse was in a jobbing foundry and had to make one-off it might have been a very different matter. He also knew that the fabricated irons were made use of in mechanised plants. He presumed that as Mr. Walker's mixture was a synthetic sand he was able to add a definite amount of water, but a similar position did not arise in iron foundries where they had to accept the sand sent to them, whether it contained a large or small percentage of water. He had understood from the Paper that sands used in the steel foundry were under complete scientific control.

Central or Individual Sand Control?

Mr. J. B. Allan agreed with Mr. Roxburgh that it did not seem to be completely jobbing work which the authors had described because of the amount of special tackle, such as shell patterns, special core irons, and fabricated core irons which were used. He had wondered how this was done where there was apparently no sand control by mechanical means, the control, therefore, being completely dependent on the skill of the individual moulder. However, Mr. Whitehouse concluded by saying that it did depend on the skill of the individual moulders. In the iron foundry with which he was connected they had to exercise the most rigid sand control to enable them to make their castings with unskilled labour. With proper sand control they could obtain quite remarkable results both in steel and iron.

Mr. F. Whitehouse, in reply, said that the question of what constituted a jobbing shop was rather difficult. They found that 12-off or even 10-off warranted a fabricated core iron on certain jobs, because they lent themselves to such cheap production. The question of the quality of the castings was also very difficult to assess, because definite standards were rather elusive, and finally the customer had to decide. He manufactured the castings in the manner described because at the present time it was the cheapest way he could find, and the castings had satisfied the customer. As soon as sand control was introduced, they began spending money, and they might spend more money than they saved. If they wanted to make sure of a job, they did not turn at once to stricter sand control; they simply dried the mould.

Unexplored Aspects of Sand Testing

Mr. E. Wharton said the points which Dr. Dadswell and Mr. Walker had made in regard to technical control were extremely important, and in supporting Mr. Allan's remarks he agreed that skilled men were becoming more scarce in the industry. Mr. Whitehouse was fortunate to be in a works where the men were artists at their particular jobs. Everyone was not so fortunate, however, and, where skilled men were not available, it was necessary that technical control should be exercised. There were still a few interesting aspects of sand testing that required to be more fully explored. One of these was the question of the plasticity of bonding clays, and they also required a method of measuring the "toughness" of the sand which was not shown by a green sand compression test. Many people who were interested in sand control would be glad to know of some method for measuring such properties, and if Mr Walker could indicate how he made such a determination, it would be of great service to members.

Rapid Tests Essential

Mr. T. R. Walker said, with regard to Mr. Wharton's last point, that batches of sand must be tested before they were sent on to the foundry floor. In this testing no method was suitable which could not be carried out in a few minutes, as it was not desirable to hold up the batches of sand for the foundry. This meant that any determinations of strength could only be those of green compression strength. It was unfortunately true that they did not yet know the nature of all the properties of sand which governed its successful employment in the foundry. There was still a great deal of fundamental research which must be done before that state was reached, and even when it had been done, it was very doubtful whether the fundamental properties could be tested in the foundry by quick methods.

Consignments of sand were tested before being made up into mixtures for use in the foundry. In this case, if they started with materials which from previous experiments they knew would give successful results, then they only had to see that different consignments had the same properties. For the investigation of fresh raw materials he was afraid that at the moment all they could do to choose between different raw materials was to adopt some form of shop test. For example, they could make slab moulds, either green or dry, of a fixed size and fixed section, fill them with liquid steel and examine afterwards the surface of the castings obtained.

A great deal had been said during the discussion about the control of sand. He thought that Mr. Whitehouse was not working without the control of his sand, but was having it controlled in fifty different places by fifty different men, each man controlling it so that it gave satisfactory results when used in his individual way. In a repetition steel foundry technical control of sand was necessary since every moulder was expected to treat the sand in the same way. It did not matter in the least whether the testing was done by a boy with a permeability apparatus or by some of the experienced moulders who relied on the feel of the sand. The judgment of a man who had had sufficient experience could be relied upon, but if he fell ill and there was no other person with similar experience the foundry would probably suffer, whereas boys could be trained in a very short time to give very similar results when using the apparatus to which he had referred.

Regarding the fact mentioned by Mr. Whitehouse that much of his sand on the floor was not milled, it was a fact that by treading sand or kneading it and rubbing it together they could get better mixtures and quite as good uniformity as in most types of modern mill.

Mr. M. Brown said stress had been laid on the limitations of green sand moulding, but he wondered whether the limitations applied so much to the green sand as it did to the manipulators of the sand and their lack of experience. An iron foundry which he knew did a considerable amount of machine-tool work, which called for a very high degree of finish, and although he would not like to say definitely what their limit was, he had seen 6- or 7-ton castings in green sand. He was specially interested in the dredger bucket that Dr. Dadswell showed, and he asked for some indication of the weight of the bucket, whether all the cores were in green sand, and if any chills were put in for any special crossings. In regard to Mr. Walker's 100-day test, he noted that they started off with naturally-bonded sand and experienced much trouble, but by using silica sand much improved results were secured. Would Mr. Walker tell them whether, when he started on his naturally-bonded sand, he began his experiment with sand that had been in the foundry for a considerable time? This would mean that when the first sand went through the re-conditioning plant he would remove a different percentage of moisture each time, probably until his sand reached a constant condition. This would help him when he started on the silica sand.

Synthetic Sands

Dr. C. J. Dadswell said that for some time they had been experimenting with synthetic sand. Whilst he was on the Continent he saw the good results that were being obtained in green sand, and he also knew that in the United States similar work was being done to that which was done at the foundry with which he was associated. He knew the foreign founders were using synthetic green sands and he was determined that his firm should try similar sands. When changing over from one sand to another they did not take away all the sand but gradually made additions of the new type of sand. Generous additions of the new type of facing sand were made until it was found that there was an excess of backing sand and after this so much of this sand was thrown away every week. As a matter of interest he tried to work out mathematically how long it would be necessary to carry on with the large additions of new sand before the complete nature of the backing sand was changed. Eventually they came to a point when they could reduce the amount of facing sand added. The bucket to which Mr. Brown had referred had a dry sand core. They had to try several runners before they could find one that was satisfactory, both from the point of view of washing the mould face and cracking troubles. Finally satisfactory results were attained and the buckets were made without cracks, whereas in dry sand cracking always occurred. The weight of the bucket was about 14 cwt.

Density of Ramming

The question of the density of ramming in the steel foundry, mentioned by Mr. Roxburgh, was of considerable importance. In fact, the best results in green sand were obtained by machine ramming because uniformity was obtained. Belgian sands, of course, were suitable for green sand work but at the same time it had to be remembered that on the Continent their cost was much less than it was in this country. In the United States many developments were made in the use of synthetic sands. At one time they used large quantities of Belgian sands, but during the war it became difficult to get them and they developed synthetic sands. Mr. Roxburgh had mentioned the question of the sand arriving wet in wagons. That problem had to be overcome by drying the sand if the percentage of new sand used was sufficient to make it impossible to get the final sand mixture of the requisite moisture content.

Mr. J. H. Pearce said he gathered that from the point of view of solubility a steel could be satisfactory in dry sand and not in green sand. Perhaps Mr. Walker could tell them a little more about this, and as he had his sand under control, it seemed to him essential to have the steel under control as well. Perhaps Dr. Dadswell, who had mentioned that green sand moulds could only stand with safety a certain length of time before casting, because of the moisture collecting, could give him an idea as to how long a mould could reasonably be expected to stand in green sand.

"Irritant Centres" in Green Sand Moulds

Mr. T. R. Walker said that steel for any foundry purpose should be fluid and should have a low gas content. This applied equally well whether the moulds were green or dried. The important point about green sand was that it evolved a great deal of steam, some of which passed through the steel and very often disturbed the gas already in the steel. It could be compared with heating some water in a perfectly clean flask. This water would reach the boiling point and would not boil until heated to a higher temperature, when there would be a sudden evolution of steam. If, on the other hand, a piece of pipe clay was put in the flask with the water, any sharp corners on the fracture of the pipe clay would promote the formation of bubbles, and there would be a steady evolution of steam at the boiling point. In the same way they often had what was called in the foundry irritation in a green sand mould, and the evolution of steam, combined with the effect of small points in the mould acting as irritant centres, which tended to evolve gases in the steel which would not otherwise be evolved.

Vote of Thanks

Mr. H. Winterton (President of the Institute), proposing a vote of thanks to the authors of the Paper, said he had enjoyed both the reading of the Paper and the discussion. He contended that the old practical moulder of many years ago was really a technician, and had gained his knowledge through practical application and by carrying out his work correctly time after time through years of practice. He could not tell them why he obtained certain results; he could not supply technical names, but year after year he carried out the work accurately. The man who might be described as working by rule of thumb was really a technician, and he felt they wanted more of such men. Now that there were additional educational facilities, they ought to insist on the younger men taking the lessons that were now so freely given and which in the old days were never at the disposal of the moulder.

The vote of thanks was seconded by **Mr. A. Whiteley** and carried.

Lancashire Branch

Paper No. 619

A SMALL OIL-FIRED ROTARY FURNACE AND ITS PRODUCTS*

By E. W. WYNN (Member)

It was intended to enter into detailed descriptions of the types of alloys which can be produced in this furnace, but a description of the furnace and its operation will occupy the major portion of this Paper.

Fig. 1 shows the exhaust end of the furnace and the sling on the left of the illustration is used for removing the shell when a new lining is required. The shell is placed on end in the pit, which is just visible on the left, whilst the exhaust elbow, which is mounted on wheels, may be pushed along rails, away from the furnace, this enabling the end of the furnace to be opened up for charging purposes. It was found onerous to keep the rails and elbow in very good condition, and it is almost impossible to keep the bottom of the exhaust elbow and the down-take flue level, owing to the expansion of the bricks, whilst the slag, running down the elbow, spoils the joint, unless the elbow is removed immediately the heat is turned off. This, of course, is impossible if any time is required for casting. In order to overcome this difficulty, the elbow is lifted with the crane, which was installed for removal of the furnace shell, and when this method is used, a sand seal can be made between the bricks of the exhaust elbow and the down-take flue, and the life of both materially increased. The hinged steel sheet, resting against the elbow, is simply a cover for the down-take flue, when the elbow is removed. These furnaces are designed to melt up to 3 tons per heat, but the one used by the Audley Engineering Company is designed to melt 30 cwts., and when the

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* The Author was awarded a Diploma for this Paper.

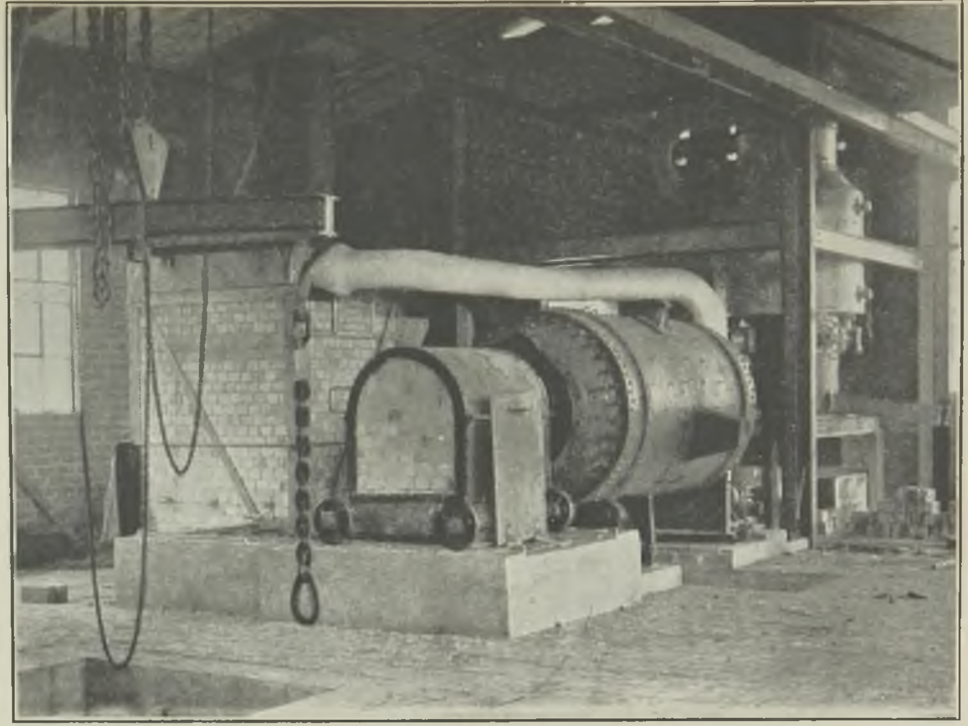

Fig. 1.—The Exhaust End of the Furnace. The Sling on the Left is for Removing the Shell of the Furnace when a New Lining is Required.

lining is worn it usually melts 35 cwts. to 2 tons, which is more economical.

The furnace consists essentially of a welded steel cylinder with a cone bolted to the cylinder at each end. Lead washers are used to allow for lining expansion. The teeming spout is separate from the furnace shell, and held in position by four lugs welded to the steel cylinder. The whole shell is perforated with $\frac{1}{4}$-in. holes, on approximately 12 in. centres, to allow the escape of moisture from the green lining.

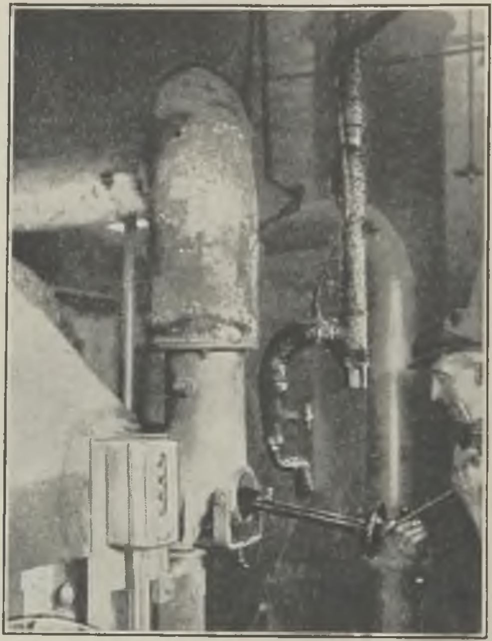

FIG. 2.—THE BURNER BEING INSERTED INTO THE BURNER ELBOW.

The furnace revolves at approximately $1\frac{1}{2}$ revs. per min., on steel tyres bolted to the body. The

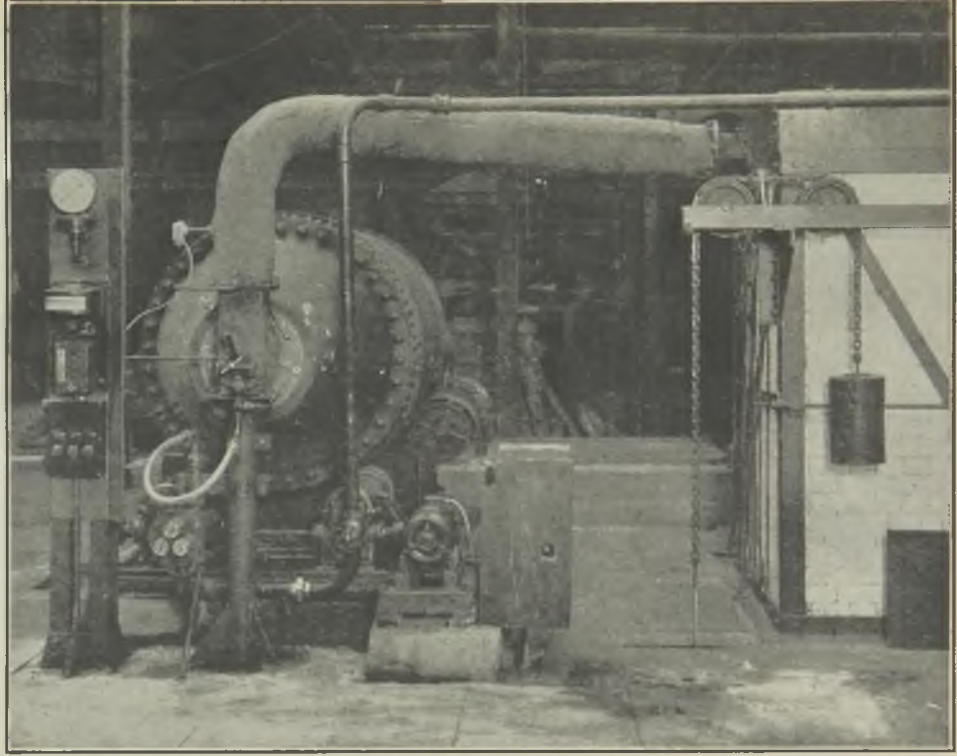

FIG. 3.—THE FURNACE CONTROLS.

drive is effected by friction rollers through a gear box driven by a 2-h.p. motor. The motor is controlled by push buttons, which are so placed as to allow the operator a full view of the spout when pouring the metal from the furnace. This control allows rotation in clockwise and anti-clockwise direction, and inching in both directions.

The burner is of special design, and works with an air pressure of 0.86 ozs., while the oil is fed by gravity from a tank placed about 10 ft. above the horizontal centre line of the furnace. The burner is composed of a tube, on one end of which is welded a disc which seals the air elbow, and the other side is recessed to form an oil-tight joint with the movable oil supply pipe. On the other end is fitted an impeller which contains the oil jets. This impeller is loose on the tube, and during firing is rotated by the air supply. Air is controlled by a simple butterfly valve, and is directed past the impeller by a small cylinder, which fits inside vanes cast integral with the elbow, and secured by a set screw at the side. The remainder of the air passes outside this cylinder and is given a rotary motion by the special shape of the vanes previously mentioned. The outside stream of air, and inside stream of atomised oil and air are thus intimately mixed and ignited just inside the body of the furnace. The length and shape of the flame is largely controlled by the length and position of this small cylinder. The original elbow was adversely affected by heat and furnace gases, so it was decided to replace the original one by one cast in an austenitic alloy (the patent rights of which are held by the Audley Engineering Company). This elbow seems to be giving much more satisfactory service. A seal between elbow and shell is made with a series of stepped rings. Here again the austenitic rings give better service than those originally incorporated.

Correct setting of the elbow (which is adjustable) and stepped rings is very important in order to prevent furnace gases and flame escaping outside the furnace, and yet allow the furnace to rotate. The oil supply is controlled by

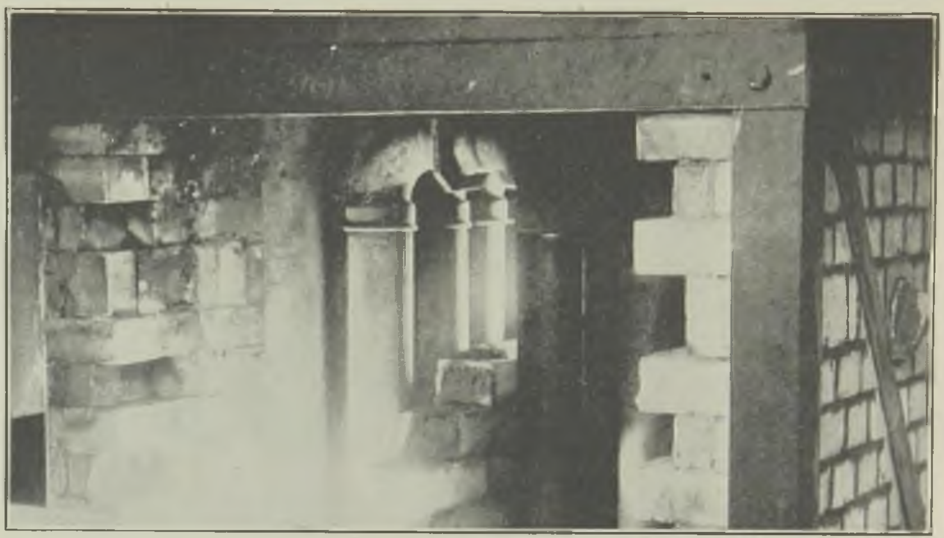

Fig. 4.—Interior of the Recuperator consisting of Four U Pipes with a Dividing Wall between Each.

an ordinary ball seated valve in the supply pipe. Either Shell or B.P. 200 secs. oil is used, and electric immersion heaters are placed in the oil line to facilitate starting up. Careful control of air and oil is essential for the economy of metal, minimisation of metal losses and ensuring a high quality of product. The best indication of correct flame control is obtained by careful observance of the colour and shape of the flame issuing from the exhaust end. A dark smokey flame obviously indicates excessive oil. If the flame is thin and reduces in diameter from the furnace to the elbow, furnace conditions are oxidising; if parallel, neutral, or if slightly expanding, reducing.

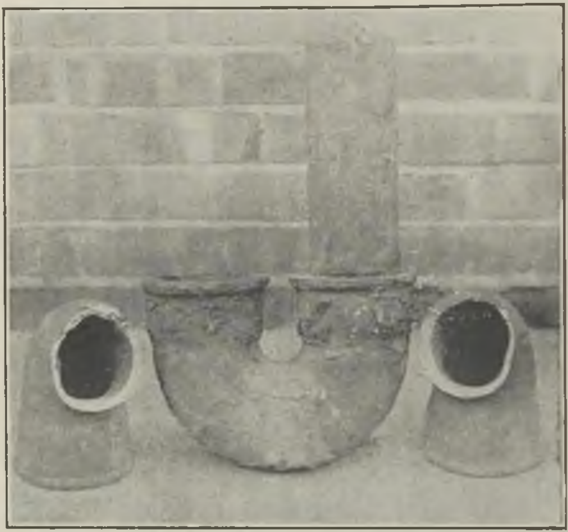

Fig. 5.—The U Pipes after Two Years' Service.

Fig. 2 shows the operator putting the burner into position in the burner elbow. The impeller previously referred to can be seen, as well as the electric immersion heater in the oil supply pipe,

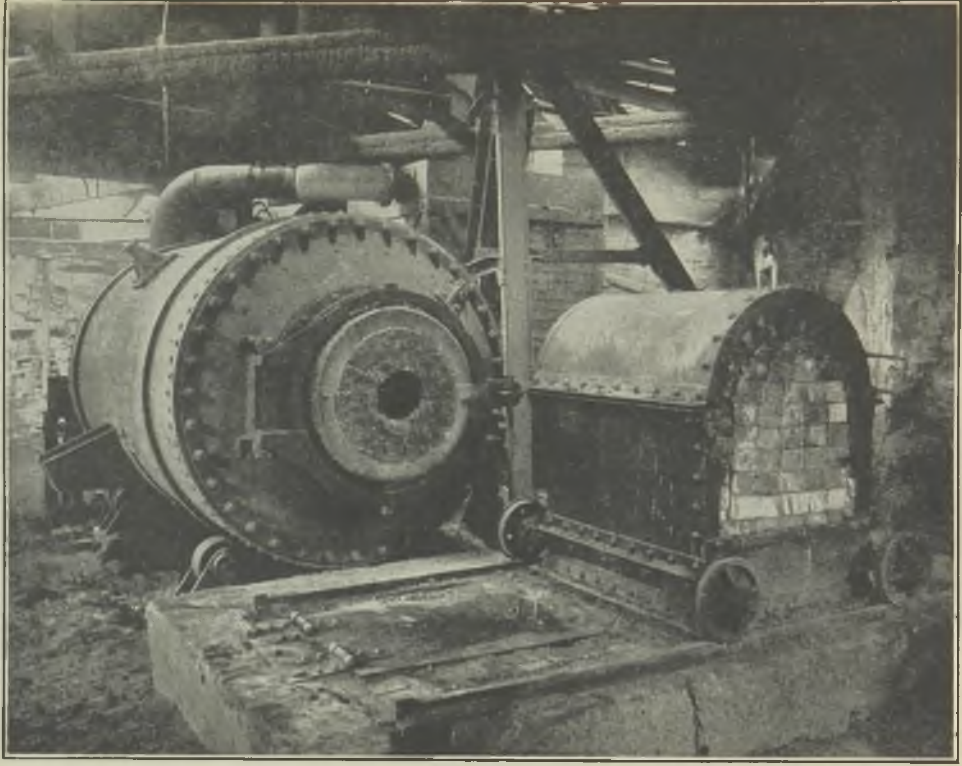

Fig. 6.—The Furnace with Exhaust Elbow Removed for Charging.

oil control valve, and swivel elbow which is clamped against the burner elbow by means of the yoke and screw, which can be clearly seen attached to the burner elbow. The push-button control can also be seen in the left hand corner.

Fig. 3 shows all the furnace controls, such as the indicator pyrometer, the oil control valve, the exhaust and recuperator dampers, etc. Heated air is supplied by passing through a recuperator under pressure from a fan, which is driven on the 30 cwt. capacity furnace by a 7.5 h.p. motor. In order to prevent overheating of the recuperator tubes a thermocouple is placed near them. Air temperature is controlled by manipulation of dampers in the recuperator and exhaust flues. A pyrometer tube is also placed in the hot air supply pipe near the burner elbow, and these form the basis of the furnace control. The hot gases from the furnace are taken into the recuperator by means of a bricked elbow. There is a gap between the exhaust elbow and the furnace, which allows cold air to be drawn in with the flame, and prevents overheating of the recuperator, etc., but allows complete combustion to take place in the elbow when the furnace is operated improperly.

Fig. 4 shows the inside of the recuperator, which consists of four double U pipes with a dividing wall between each four sets of U bends. The tubes are suspended from the top of the recuperator, and are therefore allowed easy movement during heating and cooling which reduces distortion to a minimum. Waste gases pass outside the tubes, which are heated by radiation from the containing walls, and not by direct contact with the waste gases, and are thus partially insulated by a stagnant layer which remains round the tubes. This accounts for the long life obtained from the mild steel tubes, and malleable elbows of which the recuperator is built. The original recuperator tubes lasted approximately two years, but they would have had an even longer life if the elbows were more securely fixed to the tubes, and if they were moulded in such a way that the metal thickness was even, or, in other words, if the core had not been allowed to float.

The actual elbows and tubes after two years' service are shown in Fig. 5. The mild steel tube is obviously in good condition, but was taken out due to failure of the screwed joint. The replace tubes were drilled through the screwed portion, and a half-inch steel peg driven through to prevent failure at this point.

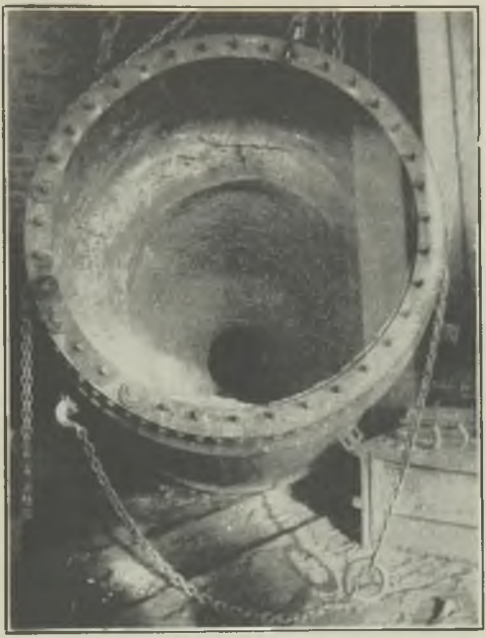

FIG. 7.—THE CONE REMOVED FROM THE BURNER END AND THE SHELL STRIPPED TO THE TAPPING HOLE.

Fig. 6 shows the exhaust elbow removed for charging. The furnace is charged after the elbow has been removed and the door of the furnace opened. Mechanical chargers can be used, but in most foundries the charge is thrown in by two or more men, and when the furnace is full the sheet-iron cover is removed and the exhaust elbow placed over the entrance to the exhaust flue. The furnace lining is rammed into position around formers and, in order to facilitate lining, the shell is placed on end in a pit. The composition of the lining is approximately 96 per cent. silica, bonded with alumina. There are various brands of siliceous linings marketed, but all require great care in ramming and initial firing. The most frequent cause of early breakdown is due to spalling before a smooth glazed surface is formed. In order to avoid this trouble the material must be evenly rammed, properly vented and dried before actual glazing. The general method is to place a bucket fire under the rammed shell for approximately six days. Once drying is commenced the temperature of the lining should be gradually increased to about 250 deg. C., then placed on the friction rollers, and a wood or charcoal fire kept going for three to four hours. The furnace should be turned through 90 deg. every few minutes to avoid local overheating. At this stage it is advisable to slack off the end bolts about a turn to allow for the expansion of the material. About 5 to 6 cwts. of cupola slag is then thrown in, and the furnace lit up. The flame should be as soft as possible until the furnace is at bright red heat, when full heat should be applied, and the furnace rotated for about 40 minutes, after which the slag is run out and the lining ready for use. Rapid changes in temperature should be avoided as far as possible throughout the life of the lining, which is largely within the control of the user (provided it is in the first place suitable for the type of metal being melted).

It is difficult to make definite statements regarding the actual numbers of heats obtained. The furnace under review usually obtains 120 to 180 heats, and about 60 after patching. In fact, the shell has not been completely lined for twelve months. The shell now in use has had the burner-end patched three times, and it appears to be possible to patch it many more times. Lining loss occurs between the burner end and the tap hole, whilst the other end retains almost its original diameter.

Fig. 7 shows the cone removed from the burner end, and the shell stripped to the tapping hole. It is then placed on end (exhaust end down), and formers are placed in position and rammed up level with the bolt flange. The precautions taken in ramming a new lining are, of course, observed in ramming the patch.

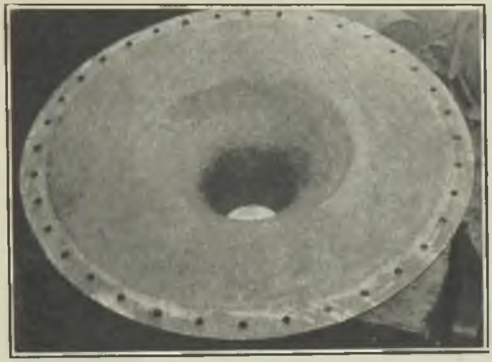

Fig. 8.—The Rammed-up Cone stretched Level.

Fig. 8 shows the cone rammed up and strickled level. It is then turned over and placed on the patched cylindrical shell of the furnace, and bolted up. New lead washers are placed between nut and shell to allow for expansion, and the whole is glazed as previously mentioned. A ring of bricks is usually required in the charging end of the shell before firing. It is estimated that the cost of lining is about one shilling when the lining is patched, per ton of metal melted, whilst the oil consumption has been determined accurately by measuring the depth of oil in the supply tank over given times, and is fairly constant at 27 galls. per hr. under normal working conditions.

Fig. 9 shows a record of a day's run taken on the actual pyrometer recorder by which the furnace is controlled, and shows actual melting, charging, casting, and preheating times. Costs, shown in Table I, have been taken from this record, and the figures can be checked against the heating and cooling curves shown.

Table I excludes overheads, power, depreciation, etc., which are too variable to be of interest here. No attempt has been made to compare the costs of melting in a rotary furnace against a cupola, because the rotary furnace will melt alloys which are very difficult or impossible to produce in the cupola, but a personal opinion is that there are still many advantages to be gained by using the cupola when making grey iron castings. It is also personal experience that cheaper material, that is, steel, can be used more extensively in the cupola than in the rotary furnace, but again comparison should not be made. In the cupola a 50 per cent. steel charge will give iron containing 3 per cent. carbon, but, of course, if a 50 per cent. steel charge was melted in the rotary furnace the carbon would probably be 1.7 per cent., and therefore no longer cast iron. Percentages of Si, Mn and C can definitely be controlled within very small limits, but some experience of the furnace is required before this

TABLE I.—*Melting Cost per ton.*

Oil (at 5d. per gall.), starting from cold (32 galls.), 13s. 4d.

Oil starting hot (27 galls.), 11s. 3d.

Oil for first malleable heat (39 galls.), 16s. 3d.

Oil for grey iron heat (18 galls.), 7s. 6d.

Oil for second malleable heat (25 galls.), 10s. 5d.

Cost of labour and control for charging (15 hrs.), 15s. (approx. 2s. 1½d. per ton).

Cost of lining (150 heats, or 32 cwts.), approx. 2s. 1d. per ton.

Direct cost of melting, 17s. 6d. per ton.

exact control is possible. Losses in Si and Mn up to 40 per cent. and carbon reaching 20 per cent. have been known, but with some experience these elements may be controlled within the limits of the raw material used. Silicon control is better if sand or some other siliceous material is added with the limestone, and carbon is also more closely controlled by adding coke-dust simultaneously. This precaution cannot, of course. be used when making malleable or any other low carbon alloys. The rotary furnace is very suitable for making black-heart malleable iron, owing to the fact that the sulphur can be kept as low as the material used, and low carbon metal may be melted with ease. As special irons are not required, the raw material is relatively cheap.

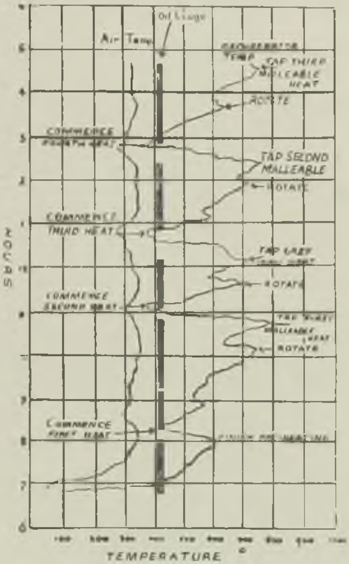

FIG. 9.--A TYPICAL DAY'S RUN.

Metal temperatures over 1,500 deg. C. are obtainable which give fluid metal with carbon down to 2 per cent. This accurate control of metal enables economy to be effected during the annealing of black-heart malleable, and reduces the quantity of rejected castings, whatever type of alloy is being melted.

Fig. 10 shows some spanners which were annealed in 48 hrs.,—the actual cycle being:—10 hrs. up to 900 deg. C.; 10 hrs. at 900 deg.; 9 hrs. cooling to 720 deg.; 6 hrs. at 690 deg., and cooling to 500 deg. C. in 12 hrs. It is not suggested that this is a very scientific test although it is a very effective selling test to the unscientific, and serves in this case to illustrate the malleability of material annealed to the above cycle. The approximate analysis and actual results obtained on test-bars cast and annealed with the spanners are set out in Table II.

TABLE II.—*Data on Spanner Test-Bars.*

Bar No.	Max. strength Tons per sq. in.	Elong. Per cent. on 2 in.
1	28.1	7.5
1	26.8	8.0
2	22.4	7.0
3	25.4	6.5

Analysis.—T.C, 2.36; Si, 1.00, and Mn, 0.38 per cent.

Heat-treatment.—10 hrs. up to 900 deg. C.; 10 hrs. at 900 deg.; 9 hrs. cooling to 720 deg.; 6 hrs. at 690 deg.; and cooling to 500 deg. C. in 12 hrs.

These test figures are above the B.S.I. specification, but generally the elongation is slightly lower, and the tensile higher than that obtained from malleable using a longer cycle, but the yield point of the short cycle material is definitely over 60 per cent. of the ultimate tensile, which in the author's opinion increases the value of any material used in engineering.

Fig. 11 shows a micro-section revealing an all-ferritic ground mass structure of this short annealed malleable and Fig. 12 shows a section of malleable iron which is mainly pearlitic and was annealed for 24 hrs. The latter type of material has many applications due to its high yield point, and a tensile strength of about 30 tons per sq. in. associated with an elongation

Fig. 10.—Spanners Annealed for 48 hrs.

ranging from 2 to 4 per cent. The silicon is generally higher than in the iron shown in Fig. 11, but the carbon is lower. The annealing cycle is shorter due to the fact that the furnace can be cooled very much quicker through the Ar$_3$ range. Definite control of material, casting temperature, etc., is essential if any success in the production of either of these irons is to be obtained, and its analysis must be based on the cross-sectional area of the casting to be made, otherwise it will contain primary graphite, which,

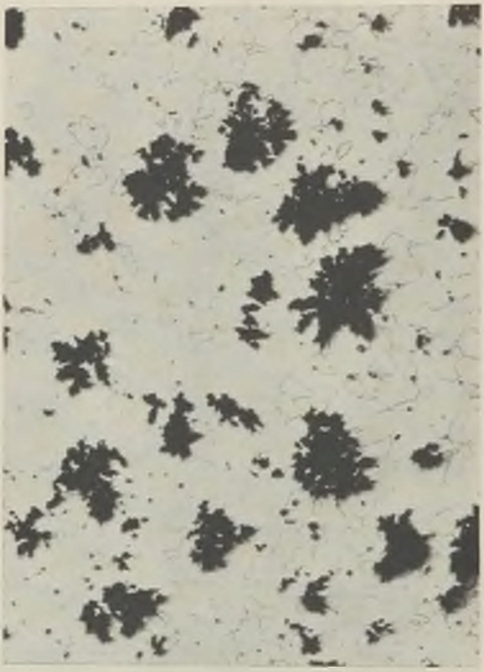

Fig. 11.—Short-cycle (48 hrs.) Annealed Malleable Iron, showing Ground Mass of Ferrite. Etched. × 90.

of course, results in weak porous castings with little malleability. High-strength grey iron can be produced with regularity, and tensile strengths of 18 tons per sq. in. can be considered as normal.

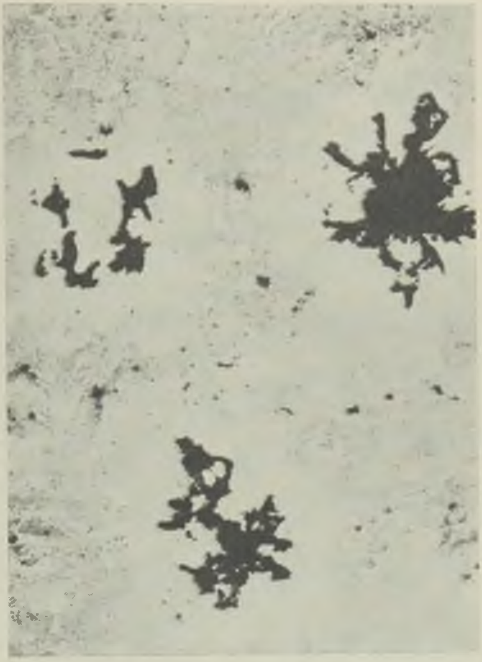

FIG. 12.—SECTION OF MALLEABLE IRON AFTER ANNEALING FOR 24 HRS ETCHED. × 90.

The specimen for the photomicrographs (Figs. 13 and 14) was taken from the centre of a heavy section of a grey iron casting, and shows regularity of graphite, size and structure. Its high strength, however, is usually obtained by reducing the total-carbon content, which, of course, increases foundry problems, and moulding and fettling costs. Thus although when properly made, a very sound casting is obtained with a structure which gives a regular Brinell hardness throughout, it will very often fail in service due to brittleness. These results can be obtained by alloy additions to cupola metal, but this method is more expensive.

Fig. 13.—Section from a Heavy High-Strength Grey Iron Casting. Unetched. × 60.

A photomicrograph of an iron of the Emmel type containing 2.5 per cent. Si and 2.5 per cent. C "hich was melted in the rotary furnace and which had a tensile strength of about 18 tons per sq. in. is shown in Fig. 15. This iron is easily made in the rotary furnace, and has many applications, such as for housings, slides, tables, bases, etc., and for the machine-tool industry. It machines easily having a steel-like finish; has good wear-resisting properties; an even hardness of about 210 Brinell can be obtained without using chills, and it can be made free from hard edges, but here again foundry costs and brittleness are increased.

Fig. 14.—The Same Iron as shown in Fig. 13. Etched. × 400.

High-quality acid-resisting 15 per cent. silicon iron is easily produced in this type of furnace, and Fig. 16 shows a photomicrograph of such an iron, which contains pure silicide with fine graphite. The main trouble with this material when produced in the cupola is the presence of large graphite which segregates at all heavy sections and corners, making an already brittle material even more fragile. The quality of the material shown in the photomicrograph would, it is presumed, be produced in any

FIG. 15.—EMMEL TYPE IRON CONTAINING 2.5 PER CENT. SILICON. ETCHED. × 150.

melting unit where it was not melted in contact with carbon, but it is doubtful if any melting unit, where this was possible, would melt as cheaply as the rotary furnace. The reason for melting out of contact with carbon, is because

Fig. 16.—Acid-Resisting, 15 per cent. Silicon Iron. Unetched. × 60.

the liquid solubility of a high-silicon iron for carbon, increases with increasing temperature, and therefore as the temperature decreases the excess of carbon quickly separates out in large flakes. It is obviously desirable that the percentage of carbon in the molten alloy should be less than the alloy will hold in solution when it is 20 deg. C. above its melting point. Some experience is necessary before this alloy can be successfully made in the furnace. The method is to melt a solid charge made up of 10 per cent. silicon pig and 90 per cent. steel. When this is molten sufficient 50 per cent. low carbon ferrosilicon is added to bring the silicon up to between 14 and 15 per cent. By this method the carbon can be kept well under 1 per cent. The foundry difficulties associated with this metal are appreciated by most foundrymen and need no elaboration.

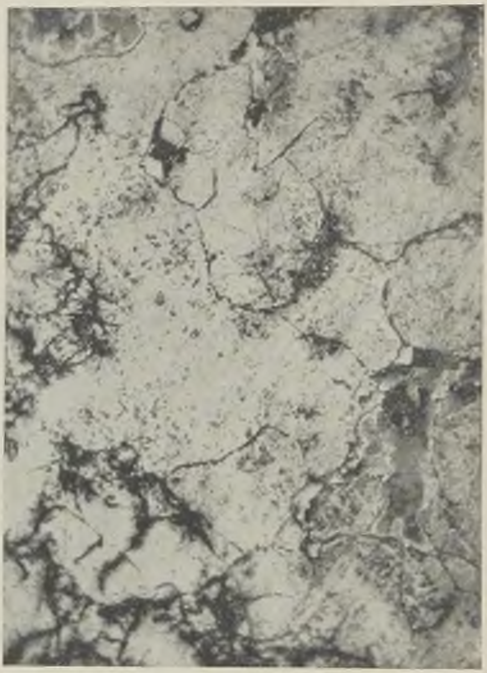

FIG. 17.—AUSTENITIC ALLOY FOR CORROSIVE SERVICE. × 400.

Fig. 17 is a photomicrograph of Audcoloy, which is an austenitic alloy used for corrosive services. This material is much more sound and consistent in structure when produced in the rotary furnace, as against pot-melting due to the more thorough mixing of the metals and higher melting temperature so easily obtained, whilst the reduced cost as against pot-melting or cupola melting is obvious. Other types of austenitic iron can be produced quite as well and as cheaply as Audcoloy. Personal opinion of this melting unit is that it is useful for producing special types of iron cheaply and is easily controlled and cheap to run. Its main advantage is that the charge is economically melted out of contact with carbon, and therefore enables more accurate chemical control and what is more important accurate control of grain and graphite size. The fact that small batches of metal can be melted is also an advantage to a small foundry having to make castings in very different ferrous alloys.

The author is especially desirous to thank the directors of the Audley Engineering Company, Limited, for permission to publish this Paper; Stein & Atkinson, Limited, for the loan of some of the illustrations, and those members of the staff of the Audley Engineering Company, who in any way have helped towards the production of this Paper.

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Paper No. 620

SOME FACTORS INFLUENCING THE PRODUCTION OF SOUND CASTINGS

By E. W. WYNN (Member) and D. HOPE (Associate Member)

In this Paper it has been decided to deal with *some* of the factors influencing the production of sound castings. To discuss *all*, or even *many* factors would require too much space. It is intended to mention superficially some factors to which many workers have already devoted much time. In the main the authors wish to deal in detail with the results of personal experiments undertaken to give some proof of their opinion on the effect of manganese on cast iron. This opinion has been formed by practical experience, which is that absolute control of the manganese content is essential, if any control of the graphite flake size in the cast product is to be effected.

It will be gathered that only metal having a manganese content in excess of that which is necessary to satisfy the so-called sulphur balance equation has been considered. This equation is: $S \times 1.7 + 0.3 =$ minimum percentage of Mn. Other workers have done much on irons of low manganese content, particularly in relation to sulphur, and have also stressed the graphitising action of Mn in such metal. It is not intended to stress this effect of Mn, but to emphasise the effect of this element on the graphite size of grey iron.

It was noticed that castings having the same percentage of silicon and total carbon had large variations in graphite size when the only other variable was the Mn content. Increase of this element gave increasing unsoundness in heavy sections as judged by pressure testing. Modern machine-tool makers insist on receiving castings which, after machining, show no openness of grain, and appear perfectly smooth and unmarred by the pitted appearance associated with large graphite.

Fig. 1 shows a 14-in. Audco valve tested to 250 lbs. per sq. in. for use on services up to 150 lbs. per sq. in. It was found, after casting a considerable number of these valve bodies, that although the silicon, total carbon and phosphorus remained the same in each case, the tendency towards porosity at heavy sections, such as occur at the throat, and particularly at the junction of the ribs, increased with increas-

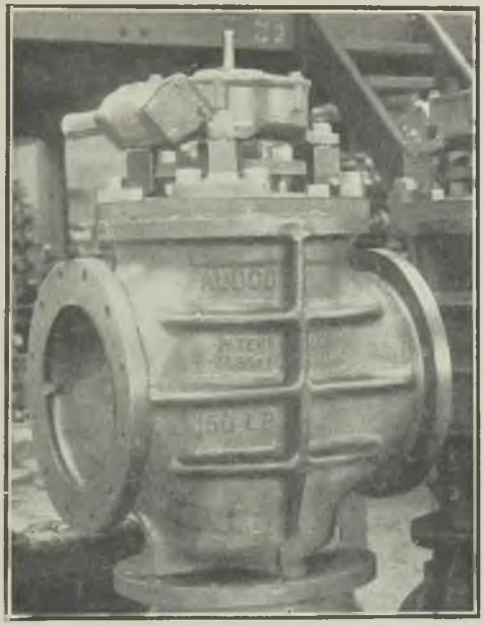


Fig. 1.—Fourteen in. Guide Valve.

ing Mn content. Even if the porosity were not sufficient to allow seepage of liquid through the metal, the appearance of the bore was very open after machining. This was due to the formation of large graphite flakes at the positions already mentioned. The sectional thickness of this casting varies from 1 to 3 in.

Sand

Sand plays a very important part in the production of castings, and is responsible for many wasters because of lack of permeability. Permeability can be increased by judicious venting, but few moulders seem able to use a vent wire properly, and therefore sand should, where possible, be graded and mixed to give the desired permeability without resort to this practice. Lack of permeability is the chief cause of scabbed castings, broken moulds, sand inclusions and like defects.

Lack of refractoriness is responsible for poor appearance and machining troubles, due to sand adhering or fusing to the surface of the metal. This increases machining difficulties and fettling costs rather than being a cause of unsoundness.

Control of moisture content is also essential in order to avoid blow-holes and loss of permeability. It is also possible seriously to affect the structure of the casting, as gases, generated by the contact of hot metal with the water in the sand, pass through the casting. Excess moisture is frequently the cause of chilled edges, etc. Control of moisture content is not nearly so important if the mould be dried before casting. The use of the Speedy moisture tester offers a very accurate and simple method of routine sand control. Care should be taken in ramming the mould, and is generally done more efficiently by machines.

Runners

Runners are frequently contributory causes of unsoundness, and require skilled and careful judgment in their design and location. No exact formula has yet been devised which is applicable in all cases. It is frequently desirable to fill a mould from one point, but lack of crane capacity, or adequate ladles, etc., forces the foundryman to use two or more runners.

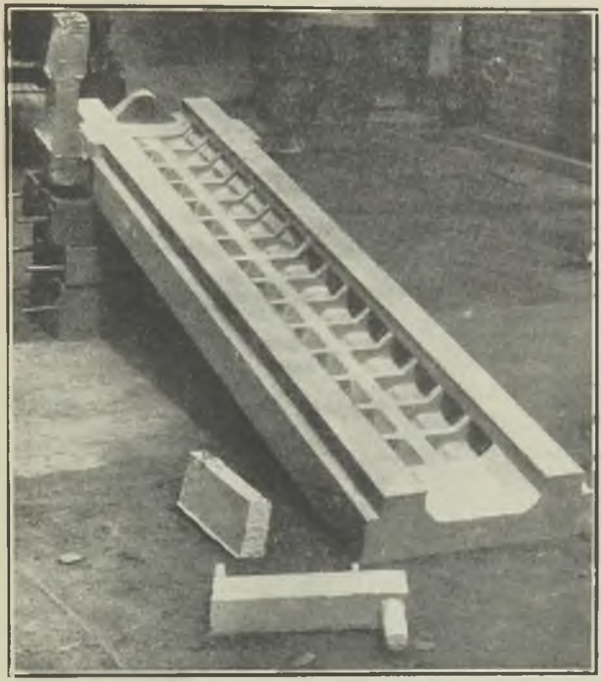


FIG. 2.—MACHINE TABLE.

The functions of a runner are to form an entry for the molten metal to the mould and to prevent access of slag, sand, etc. The correct speed which is controlled by the area of downgates and in-gates is determined by such factors as size of casting, thickness of section, composition and temperature of the metal, etc. This important part of the mould is very often left to the discretion of the moulder, but it has been found that a large number of faulty castings can be avoided, if runners are definitely fixed to the pattern and designed by a responsible official.

Various types of runners, such as spinners and strainers, have been designed with the intention of preventing access of sand, slag, etc. These are too commonly known to warrant much discussion in this Paper, but an interesting example of a runner which was the deciding factor in the successful founding of a very difficult casting is shown in Fig. 2. The weight of this machine table casting is approximately twenty-five cwts., its length is 8½ ft., the width is 2 ft., and the thickness is 10 in.

The section varies from 1 to 6 in. The casting was fed by the two feeders shown at the top, and although this might not appear to be the most advantageous position, it was the only possible location in this case. The runner can be seen at the front of the illustration, and slag inclusions can be seen on this portion of the runner at the left-hand side. This runner is a block of 5 in. by 3 in. by 30 in. long, and is connected to the casting by four in-gates at the base of the block; each in-gate has an area of approximately ¾ sq. in. Two down-runners were placed on top of the block, one inch from each end. The total area of these down-runners was 4 sq. in. Previous to the adoption of this type of runner most of these castings showed slag inclusions on the top face. The casting has to be machined on the top side and bottom faces, and slots 1⅛ in. deep cut in the bottom face. The casting will not pass inspection if the bottoms of the slots are more open than the face of the table.

Feeders

The correct design and positioning of feeders is of vital importance, if they are to function as a reservoir from which the casting will receive metal when contracting during solidification.

Lack of feeding is a frequent cause of open structure and cavities in the centre of heavy sections.

Fig. 3 illustrates a feeder which was properly designed and placed, and gives some idea of the size of the hole which would have occurred in the casting, unless adequate provision had been made for the reduction in volume.

FIG. 3.—SECTIONED FEEDER.

Fig. 4 shows a casting which was not properly fed, resulting in the formation of a very large cavity. This defect was not discovered by the user of the casting. It looked perfectly sound, but was rejected for sand and slag inclusions under the surface, which were exposed on machining. Owing to the very nature of shrinkage cavities, the defect is usually only discovered after a considerable amount of work has been done on the casting, or after breakdown in service. It is sometimes only possible to feed a casting through a passage kept open by the movement of a steel rod, thus allowing molten metal to run into the casting from the reservoir above. This is a very undesirable method, and should only be resorted to when self feeders are not practicable.

Fig. 4.—Casting Exhibiting a Hole with Extrusions.

Most moulders forget that it is impossible to push liquid iron down a 1-in. hole with a $\frac{1}{2}$-in. rod. The result of their pushing is that the bottom surface of the mould or cores, immediately under the reservoir, is broken by contact with the feeding rod. Frequent additions of metal to the reservoir are necessary. Often metal of different composition is used, which may result in open porous spots under the feeder. If rod feeding has to be resorted to, many wasters can be avoided by teaching the moulder that the movement of his rod is only to prevent the solidification of metal in the channel between the casting and the metal reservoir.

Solid Contraction

Provision must be made during the making of the mould and cores against the possibility of warped and cracked castings, caused by the contraction of the metal after solidification. If it be impossible so to construct the cores and mould to allow of this, the casting must be freed by removal of the cores, or mould, or both, as soon after pouring as possible. This practice, however, generally increases production costs. Modern core-sand practice and metallurgical developments have enabled foundrymen to make castings which are very liable to crack during cooling, with much less risk than was possible with the old loam sand cores and phosphoric

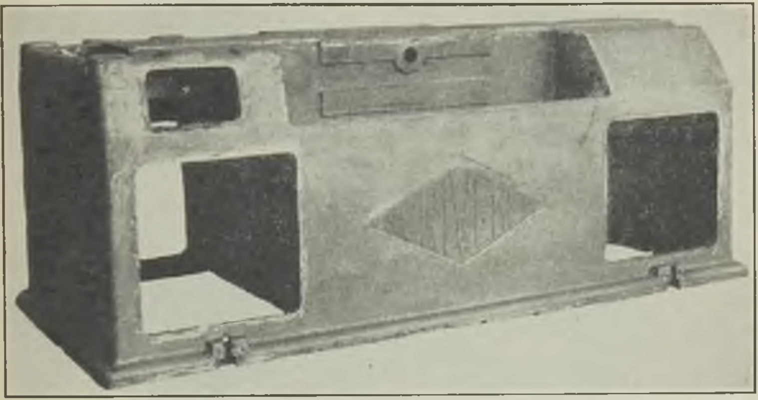


Fig. 5.—Machine Bed.

irons. The fact that moulders are now able to dispense with heavy reinforcements of the cores, and that oil-bonded sands after heating readily disintegrate and flow from the casting face, has also helped to reduce the number of cracked castings.

The production of the casting shown in Fig. 5, using loam sand cores, would have been attended by great risk of cracks occurring at these points. None of these cores were removed until the casting was cold. The weight of the casting is 33 cwts., the length 8 ft., the depth 4 ft. and the width 4 ft., whilst the general thickness of section is $\frac{3}{4}$ in. It was cast the reverse way up to the position shown, and in spite of the heavy slide on the top face no feeding was necessary.

FIG. 6.—GRAPHITE. × 60.

Composition of Metal

The composition of metal is, of course, a very important factor, but it is useless pouring good metal into a poor mould. It is personal experience that the production of castings in metal of suitable composition for modern engineering requirements demands much greater care and skill in making the mould than was required for the old phosphoric engineering irons. Phosphorus has been studied by many workers, and its influence on soundness is well known and understood by most foundrymen. Porosity and unsoundness due to segregation of iron phosphide eutectic will not be considered in this Paper. Total carbon is of vital importance and must be controlled as founding difficulties increase with reduced total carbon content. Many foundrymen use this type of metal because the influence of silicon and manganese on graphite size is less than when irons of high carbon content are used. The authors have found that other troubles encountered, such as high shrinkage, mould

Fig. 7.—Graphite. × 60.

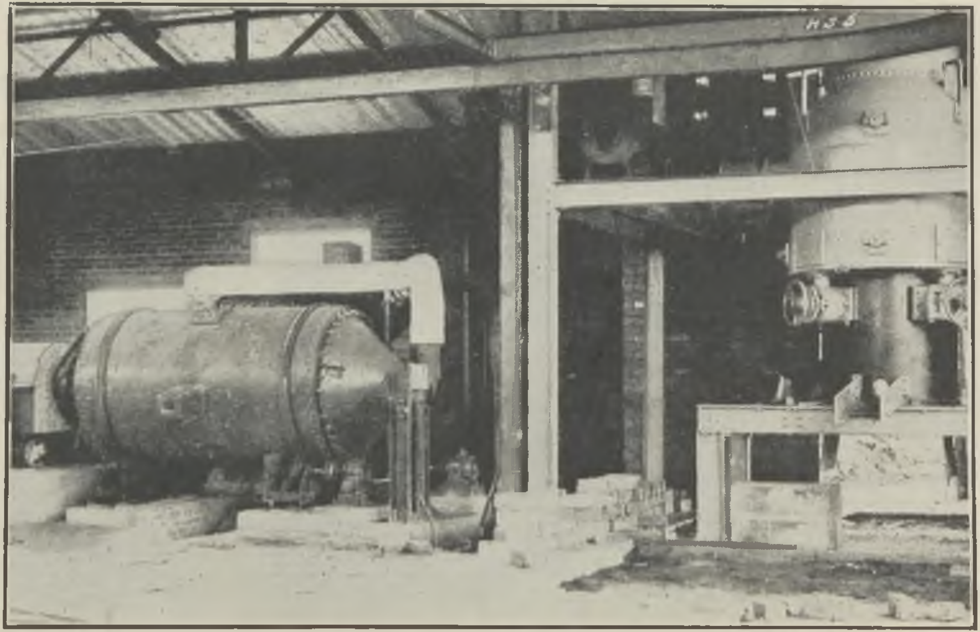


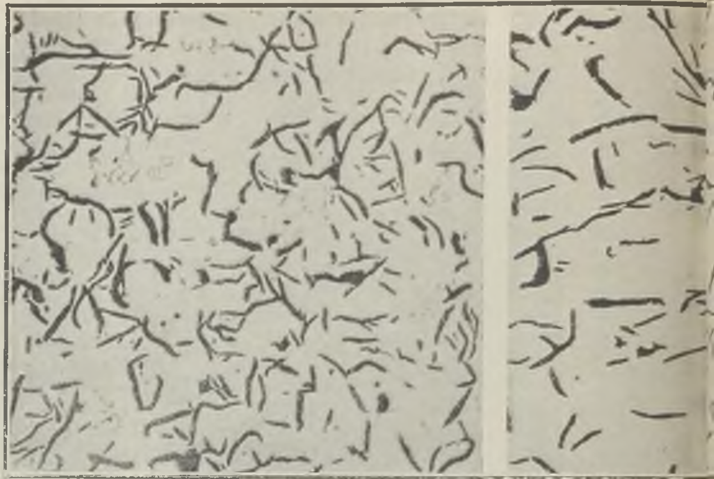
FIG. 8.—BALANCED-BLAST CUPOLA AND STEIN & ATKINSON OIL-FIRED ROTARY FURNACE.

erosion, occluded gases, etc., very considerably increase production costs and risk of unsoundness. They are mainly concerned with the production of sound castings, so that anything which tends to increase unsoundness is avoided. It is thought that ferrous alloys as near the eutectic composition as possible are the least difficult to handle for the authors' personal requirements. The difficulties of obtaining eutectic alloys at will can be easily appreciated, but the difficulty of reaching an ideal is no reason why it should not be attempted.

The extrusion in the cavity of the casting shown in Fig. 4 would be of almost eutectic composition, as that portion of the metal to solidify last would be squeezed into the cavity by the changing volume of the already-solid portion of the casting. The chemical analysis of the base metal was:—T.C, 3.45; Si, 1.25; Mn, 0.67; P, 0.043; S, 0.103, and Ni, 0.295 per cent., and of the extrusion: T.C, 3.85; Si, 1.18; Mn, 0.59; P, 0.060; S, 0.041, and Ni, 0.295 per cent. It is interesting to note the great difference in the sulphur and manganese content between the two metals.

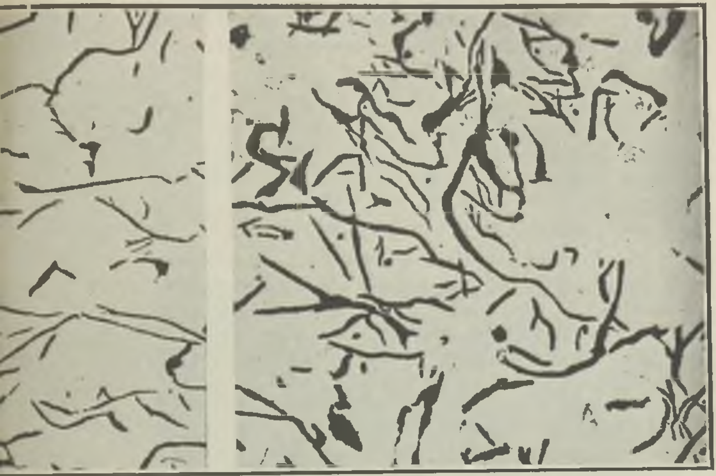
Fig. 6 shows a photomicrograph of the base metal, revealing fairly large graphite flakes, whilst Fig. 7 illustrates the extrusion. The remarkable difference in the size and type of graphite is apparent; that shown in Fig. 7 is the type generally associated with strong, sound cast iron.

Silicon is a very important element and has strong influence on size and quantity of graphite; its control is relatively easy and well understood in the foundry. The effects of manganese, however, seem to be rather obscure, in spite of the fact that a large number of workers have studied this phase. The authors undertook an experiment to prove the effect of manganese on graphite flake size, soundness, and surface finish. Four charges composed of 4 cwts. of unannealed malleable iron scrap, and 2 cwts. of Workington hematite, were melted in a 26-in.



Figs. 10, 11 and 12.—Graphitic

Figs. 13, 14 and 15.—Graphitic



UCTURE OF 4-IN. BARS. × 60.

RUCTURES OF 4-IN. BARS. × 60.

balanced-blast cupola, tapped in two 12-cwt. batches into a 15-cwt. ladle, and transferred to a Stein & Atkinson oil-fired rotary furnace.

Fig. 8 shows the two melting units. It was a simple matter to pour the metal, which was carried along the mono-rail shown at the top, into the rotary furnace by way of the spout. A brick was placed at the front of the spout to prevent metal flowing out, the spout being slightly higher than the position as shown.

The furnace was then rotated for half an hour. Five additions of Mn were made at five minute intervals. Manganese briquettes, being unobtainable, were made in the foundry, using sufficient 75 per cent. ferro-manganese to give 3 lbs. of Mn per briquette. The analysis of the ferro-manganese used was 6.88 per cent. T.C, 0.89 per cent. Si, and 75 per cent. Mn. The furnace was oscillated during the four minute intervals between each addition. After the four minute oscillation 2 cwts. of metal were tapped and cast into two moulds, one containing test bars of the following diameters:—0.75, 1.2, 2.2 and 4 in., and the other an ordinary Audco 4-in. valve body. The section of the latter varies from $\frac{3}{4}$ to 2 in. Each valve body was broken, and found to be grey, with the same tendency to increasing graphite size as was shown by the 2.2-in. test bars. After testing, the fractures of each set of bars were closely examined. The 0.75-in. diameter bars show little variation, and were mainly white iron. The fractures of the 1.2-in. bars, shown in Fig. 9, were very interesting, and were found to be increasingly grey with increasing Mn content.

All the bars except the 4-in. dia. ones were tested and gave the results shown in Table I. These are given mainly as a point of interest. Investigation of the influence of manganese on the strength of the irons was not intended. It will be noticed that strength has not increased with increasing manganese content; this may be due to the increased size of graphite.

It is difficult to show by means of a photograph the variation in structure, but from Fig. 9 it will be seen that there is a definite tendency to increasing greyness from bar No. 1 to bar No. 5. Bar No. 6 shows a slight reappearance of mottle, although the manganese content of bars No. 5 and 6 was practically the same, with a slight increase in silicon in bar No. 6.

Samples for chemical analysis were taken from the centre of each 4-in. dia. bar. The total carbon remained almost the same. There was, however, an appreciable decrease in the combined carbon from No. 1 to No. 4. Bar No. 5, which has the most open structure, showed the highest percentage of combined carbon. The 1.2-in. dia. bar in Series 6 showed reappearance of mottle, but silicon in that series had increased approximately 0.10 per cent.

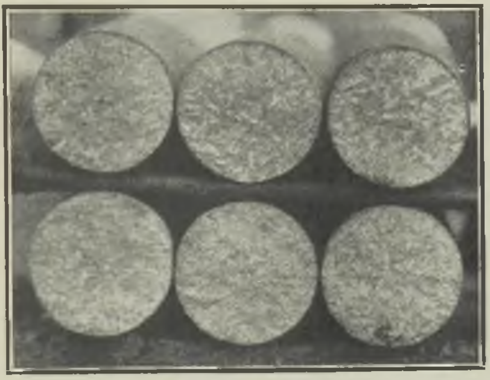


FIG. 9.—FRACTURES OF THE 1.2-IN. DIA. BARS.

The 2.2 in. dia. were all completely grey and showed increasing openness of grain with increase of manganese. A disc was sawn off each bar and turned in a lathe. The machinist did not find any difference in machineability of the metal.

The bar of series No. 1 had a much better finish than any of the others. The machined discs and fractures of these bars are available for inspection.

The 4-in. dia. bars were broken. Increasing graphite flake size was much more apparent than in the 2.2-in. dia. bars, and sections were taken from the centre of each bar for microscopic examination, and microphotographs of these unetched specimens at a magnification of 60 diameters are shown in Figs. 10 to 15.

TABLE I.—*Physical Tests on Bars.*

No.	Dia. Ins.	Centres. Ins.	Deflection. Ins.	Trans. rup. stress. Tons per sq. in.	Calculated tensile. Tons per sq. in.
1	0·748	18	0·133	24·87	13·80
2	0·759	18	0·130	24·9	13·80
3	0·755	18	0·135	28·9	16·05
4	0·773	18	0·135	24·3	13·50
5	0·775	18	0·135	28·5	15·80
6	0·760	18	0·112	20·46	11·40
1	1·209	18	0·159	35·2	19·45
2	1·219	18	0·135	32·45	18·00
3	1·205	18	0·099	26·37	14·60
4	1·221	18	0·169	33·4	18·55
5	1·214	18	0·142	26·0	14·45
6	1·209	18	0·142	28·6	15·80
1	2·249	18	0·135	32·1	17·90
2	2·269	18	0·133	27·9	15·50
3	2·264	18	0·124	26·1	14·50
3	2·276	18	0·136	30·7	17·05
5	2·278	18	0·146	28·25	15·70
6	2·259	18	0·124	28·3	15·70

Fig. 10 shows the size of the graphite flakes in the base metal used for this experiment. It has the typical appearance of a good quality high strength cast iron which would machine easily and give good surface finish and soundness.

Fig. 11 shows the effect of the first increase in manganese. There is a perceptible increase in length and thickness of the graphite flakes. A flake is shown which extends almost across the section.

In Fig. 12 can be seen the definite increase in the flakes as a result of further addition of manganese, although the number of flakes does not seem to have increased.

Again, in Fig. 13, with further increase in manganese, the graphite flakes are larger. An

Fig. 16.—Pearlitic Structure Etched Picric Acid. × 600.

iron of this type would take a very poor finish, and would be of little use in any corrosive service, as intergranular corrosion would be definitely accelerated.

Fig. 14 shows an increase in graphite size. The manganese increase in this case is about 0.35 per cent. Fig. 15 is very similar to Fig. 14, although ferro-silicon was purposely added to the melt before this bar was cast, in an attempt to prove

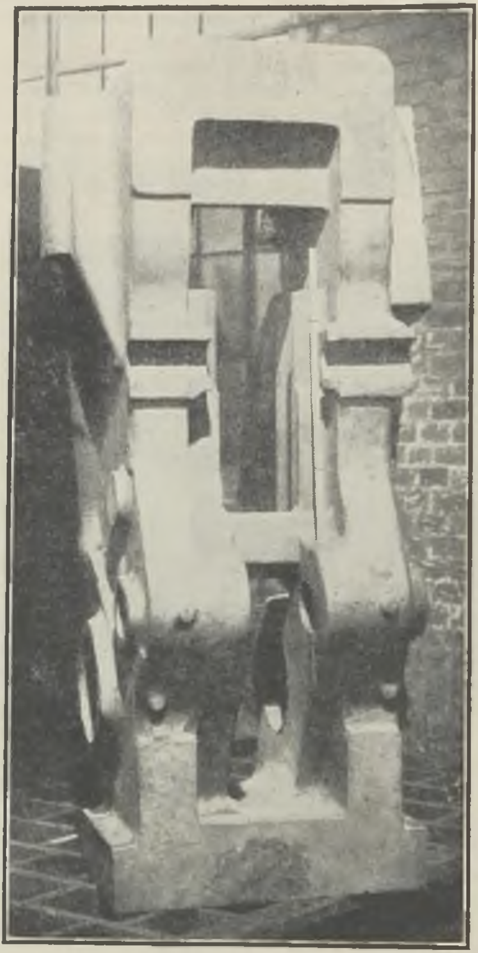


FIG. 17.—HEADER BODY CASTING WEIGHING 2¼ TONS.

that the effectiveness of silicon as a graphitiser was not affecting the results of this experiment. In order to prove that, although the size of the graphite flakes increased, the matrix remained entirely pearlitic, the two sections taken from the 4-in. bars Nos. 1 and 6 were etched with picric acid and magnified to 600 dias. The former, shown in Fig. 16, exhibits no free ferrite surrounding the graphite flakes, although pearlite is rather coarse, whilst the sample from No. 6 showed no free ferrite round the graphite, but some refining of the pearlite had taken place.

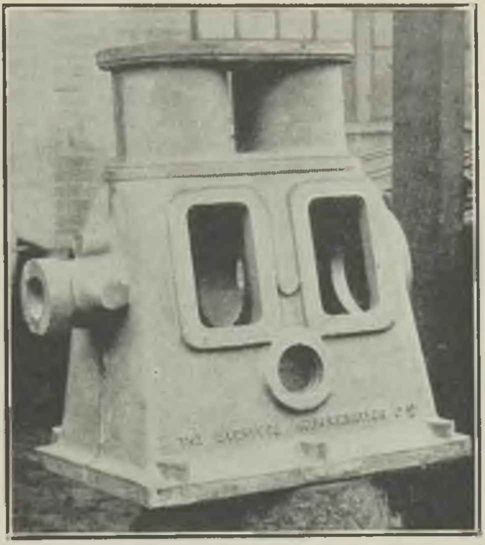


Fig. 18.—Compressor Casting.

The control of graphite size in the casting shown in Fig. 17 is essential. Large graphite would cause weakness at the corners and reduce the wearing properties of the two slides. The casting is a body for a heading machine which is subject to great variation in load; its approximate weight is $2\frac{1}{4}$ tons, and the thickness of section up to 7 in. The casting was fed at each end; all the cores were made in oil sand and stripped easily.

Fig. 18 shows an ammonia compressor body. The importance of pressure tightness and absence of large graphite in any casting which is to be placed in contact with ammonia need hardly be emphasised.

FIG. 19.—GRAPHITE. × 60.

Figs. 19 and 20 are photomicrographs of sections taken from castings similar to the large table illustrated in Fig. 2. Iron with the type of graphite, shown in Fig. 19, has all the properties desired and gives a steel-like appearance after machining. The casting was rejected because of slag inclusions on the top face.

Fig. 20 shows a section taken from a similar casting rejected for openness of grain and a poor appearance after machining. The manganese content of the first casting was 0.7 per cent. and in the second 1.10 per cent. The percentage of other elements was almost the same. It was experiences such as this which really led to this investigation. It is considered that there is still a great deal of work to be done on the effect of manganese on grey cast iron, and it is hoped at some later date to give results of further experiments using different base irons.

Fig. 20.—Graphite. × 60.

Acknowledgments

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Scottish Branch

Paper No. 621

MOULD AND CORE PROTECTIVE FACINGS AT ATMOSPHERIC AND ELEVATED TEMPERATURES

By R. F. HUDSON (Associate Member)

The subject of mould and core protective facings is one that has received surprisingly little attention in technical literature and it is doubtful if a previous Paper has been published. Primarily the application of a protective facing to the mould or core is generally a final effort to produce castings with a smooth skin, and secondly it is of some importance as an aid to the fettling operation. The effect of facings may be of considerable value in many other less obvious directions and it is hoped that subsequent remarks may contribute to new knowledge in this direction.

The materials employed in the foundry trade for facing purposes exist in a fairly wide variety and they can be divided into two main groups: (1) those such as plumbago, blacking and the like—classed as carbonaceous facings, and (2) materials such as silica flour, and known as mineral facings.

Carbonaceous Facings

The carbonaceous materials are widely used for the preparation of foundry facings and their action is twofold in producing a good finish:—

(1) They form a cushion of a reducing gas between the metal and the mould face; and

(2) being of a highly refractory nature and generally impermeable they prevent fusion of the sand and penetration of the mould by metal.

The carbonaceous facings generally used are plumbago or graphite, lamp black, charcoal, coal and coke dust, and others not so well known, such as pease-meal, as shown in Table I.

Table I.—*Typical Analysis of Carbonaceous Materials Used for Mould and Core Facings.*

Material.	Moisture. Per cent.	Volatile material. Per cent.	Fixed carbon. Per cent.	Ash. Per cent.	Sulphur. Per cent.	Ignition temperature. Deg. C.
Graphite	0.3	2.2	81.2	16.0	0.3	650–750
Coke dust	0.2	1.5	88.6	9.0	0.7	600–700
Anthracite coal dust	2.0	5.0	84.5	8.0	0.5	700
Carbon black—Lampblack	0.8	2.0	96.8	—	0.4	350–500
Gas carbon	1.5	6.7	91.8	—	—	
Wood charcoal (made at 350 deg. C.)	6.0	14.4	79.5	—	0.1	360
Bituminous coal dust	1.0	37.0	53.0	8.0	1.0	326
Pease meal (ground dried peas)	10.0	72.9	15.0	2.1	—	Very inflammable

Graphite is unquestionably the most important of the finishing materials for mould surfaces. It is a naturally greasy mineral of very high refractoriness, and when in its best form as Ceylon graphite it has a large flaky structure lending itself well to the covering of mould surfaces without adding thickness to any appreciable extent. Its very greasiness, however, prevents it adhering to the mould surface unless held by some other material. This difficulty is not so noticeable with the poorer and more amorphous forms of carbon, which when finely powdered will enter the pores of the sand and adhere firmly.

The best flaky graphite has often a fixed carbon content of 98 per cent. while the poorer forms of graphite may only have a fixed carbon content of 60 per cent. The foundryman will readily appreciate that paying carriage on sand or other impurities at graphite rates is uneconomical. Graphite, being of a flaky structure, has several advantages over the cheaper form of amorphous carbon. The flakes do not allow the same amount of metal penetration as do the granular pieces of the amorphous carbon, and it reduces the surface friction especially in thin sections.

Coke and coal dust are the forms of amorphous carbon which are in general use. Coke dust has a fixed carbon content of about 89 per cent. Coal dust is divided into two groups, the high-volatile bituminous type with a carbon content of 53 per cent. and the anthracite form with a carbon content around 85 per cent., and ignition temperatures of 326 and 700 deg. respectively.

As these different forms of carbon vary in fixed carbon content they likewise vary in refractoriness as is shown by the ignition temperatures in Table I. The Ceylon graphite is the most refractory and charcoal has much lower refractoriness.

Care must be taken to select the facing which is the cheapest and yet will give a satisfactory finish to the type of work it is required for.

In many cases one does not require the best grade of graphite to obtain satisfactory results, but in other cases where thick sections and high temperatures are common one requires the very best to get good results. Charcoal, lampblack, etc., are forms of amorphous carbon which are least refractory and should only be used, if at all, for light castings.

Pease-meal is one carbonaceous facing which is not in general use, yet it will, in some cases, give quite good results. It is much less refractory than the better forms of carbon and has a high moisture content. In non-ferrous practice it will give quite good results. A slight advantage it holds over the graphite facings is that it is slightly sticky and adheres more strongly to the mould face. Other carbonaceous facings rarely employed to-day are rubber solution and water-soluble binders such as dextrine, these being used for strengthening fins and thin sections and forming a hard skin on the mould face.

Mineral Facings

Mineral facings are, perhaps, not so widely used as the carbonaceous facings except in the case of silica flour, which is very extensively used in many branches of the foundry trade. Silica flour is usually sold in a very pure state, containing 90 to 96 per cent. silica, and when supplied to this specification is very refractory. Unfortunately, silica flour is obtained from various sources and each different source of supply cannot be guaranteed to behave similarly when suddenly subjected to a big increase in temperature. Silica flour may be derived from tripoli powder, kieselgühr, ground quartz or super-fine sand.

Other mineral facings met with in the foundry are zirconia, soapstone, talc, and cement, but none of these is used in general practice to any great extent in this country. Zirconia is a similar material to silica but is much more refractory and has future possibilities.

Soapstone, a white, grey or greeny-white powder is obtained from a mineral known to geologists as steatite, and receives its name from the soapy feeling it has. It has quite a high percentage of objectionable constituents such as lime and water. It has therefore a relatively low fusion point and imparts to the castings an objectionable white appearance; thus it can only be used for certain classes of work. A typical analysis is: Silica 39.06; alumina 12.84; iron oxide 12.80; magnesia 22.76; lime 5.98 and water 6.56 per cent.

Talc is a similar material to soapstone but neither of these two substances are greatly employed in this country and are principally used in America.

The only other mineral facing that will be mentioned in this Paper is cement. This is sometimes used in green-sand work especially for intricate work when sleeking may be difficult to perform; the moisture in the sand causes the cement to set, thus forming a very hard skin.

Before leaving this subject it seems desirable to mention materials such as carborundum and aluminium dust which although scarcely within the scope of this Paper might be of interest. Carborundum or silicon carbide when dusted on to the mould partially fuses on to the metal and promotes a hard, abrasive skin. It is thought that there is room for a great deal of research into types of facings with which the mould may be dusted to promote certain advantageous properties such as corrosion resistance on the surface of the casting.

The commercial blackings sold are often adulterated with coke, anthracite coal dust, soapstone and bituminous coal so as to cheapen the mixture; the good grades may be adulterated seriously and still be of a higher quality than the poor ones.

Commercial Carbonaceous Facing Materials

Dry facings used in Green-Sand Work.—It is now proposed to deal with facings used in green-sand work.

Considering primarily those used in cast-iron practice, the major percentage of facings used in this work are of the carbonaceous type, and are usually called blackings. These commercial blackings vary in composition, but all are principally composed of some form of graphite adulterated with coal, coke dust and soapstone in varying degrees. Sometimes a little of some binder may be used to give them additional adhesiveness. The better grades have a higher percentage of Ceylon graphite, while the inferior types may have crushed coke or lampblack to form their base. The usual means of application is to dust them on to the face of the mould through a fine bag.

For small and medium sized green-sand work the moulds are usually only dusted with the blacking; for heavier work after being dusted the moulds are often sleeked, and for extra heavy green-sand work, castings weighing about 10 cwts., a high grade of blacking, such as Ceylon graphite, is usually used. This is dusted on to the mould and afterwards sleeked. These blackings are only applied to produce a good clean skin on the castings, preventing the sand by their refractoriness and gas-forming properties from fusing on to the metal. In Table II are given some examples of commercial blackings used for the different purposes.

From this table one can arrive at conclusions concerning the composition of the various blackings. For instance, No. 1 blacking, used for furnace purposes, etc., has a high volatile content, and from Table I it is seen that only bituminous coal has a similar high-volatile content, so it is reasonable to infer that bituminous coal dust comprises a high percentage of this blacking. Similarly Nos. 2, 3 and 4 blackings, used for blackwashes, are low in volatile, and from Table I only graphite and coke dust come into this category. Since graphite is not present, as shown by sleeking, the inclusion must be coke dust. In Nos. 5, 6 and 7 blackings, which are used for dusting green-sand moulds, the two likely combinations used are graphite and bituminous coal dust, as both ash and volatile contents incline to be higher. In the author's foundry, for light and medium green-sand practice, No. 5 blacking is used, and although quite low in graphite, gives good results.

Facings used in Non-Ferrous Practice.—With the lower casting temperatures employed, the sand has not to withstand such a severe test as in the iron and steel foundries, and less refractory facings may be used. No. 5 blacking, shown in Table II, as used for light and medium cast iron work, will give quite good results. In the author's own practice pease-meal is used, applied only by dusting.

Green-sand Moulding for Steel Castings.—In many cases no coating is used whatsoever, but sometimes lampblack may be deposited from an oxy-acetylene flame. Occasionally the moulds may be skin dried, by wetting the face of the green-sand mould with molasses, wood extract or some proprietary wash and drying off with a lamp.

Mould and Core Protective Washes

Cast Iron and Non-Ferrous.—For dry-sand work the facing is applied wet in the form of a wash. Similar forms of washes are used in both cast-iron and non-ferrous practice for use with oil sand, dry sand and loam. A commercial blacking is used, composed of ingredients as previously mentioned but containing very little graphite and more coke dust and forms of anthracite coal dust. An analysis of a satisfactory blacking sold for the purpose is shown in Table II. In some cases in non-ferrous practice a graphite—clay-water wash is used which gives a better finish than the ordinary blackwash to the heavier dry-sand jobs.

Many solutions are used to bind the blacking to the sand. The most common is, perhaps, clay water with a little dextrine or some other gum to increase the strength of the mould surface after drying. Molasses-water or any vegetable substances having adhesive qualities are also

Table II.—*Typical Analysis of Commercial Carbonaceous Facing Materials.*

Blacking No.	Moisture. Per cent.	Volatile material. Per cent.	Ash. Per cent.	Fixed carbon. Per cent.	Sulphur. Per cent.	Remarks.
1	1.6	7.1	16.5	74.3	0.5	Cheap blacking for covering metal in ladles, etc.
2	0.4	1.9	10.0	87.0	0.7	Blacking for making blackwash for dry-sand moulds, etc.
	2.2	2.4	6.2	89.2	—	Do.
4	1.6	2.6	11.5	84.3	—	Do.
5	0.6	3.2	37.5	58.4	0.3	For dusting on green-sand moulds.
6	2.4	5.2	21.3	71.1	—	Do.
7	1.2	2.8	12.7	83.3	—	Do.

employed. The soluble rosins existing in the waste liquid of the pulp mills, which when neutralised and concentrated are specially good, are known under the name of wood extract in this country.

A straight molasses-water or wood extract wash is sometimes painted or sprayed over the ordinary blackwash to strengthen the mould face, but whenever an oil or molasses wash is used care must be taken when drying the mould. An oil wash cannot withstand the high temperatures as can a clay wash and if it be heated too strongly the oil will burn out, leaving the blacking loose on the mould face.

Steel.—It is obvious that the facings for steel will have to be much more refractory than those mentioned for use with cast iron; even the finest graphite is unequal to the task of producing a satisfactory finish on steel castings, as such a high temperature is employed.

In many cases no wash is used at all, as the foundryman depends on the qualities of his natural moulding sands to supply the necessary finish. Of the washes that are currently used those with silica as their basis are the most popular. Silica is obtained from one of the previously mentioned sources and ground to a consistency of a flour, hence its name, silica flour. The white paint sold for coating moulds consists essentially of silica flour with the additions of a little clay. The black paint sold commercially for this purpose is of the same materials as the white paint with the addition of about 6 per cent. graphite. Typical analyses of the white paint are:—

	No. 1. Per cent.	No. 2. Per cent.
Silica	88.82	96.2
Alumina	7.84	0.76
Ferric oxide	Trace	1.04
Lime	0.36	1.0
Loss on ignition	1.68	0.55

Mixed with bentonite and water, silica flour forms quite a satisfactory wash. Molasses and core oil are sometimes used as binders, but are not thought to be quite so satisfactory, as in a thick coating, where a large area of the mould is exposed to the rising metal, the molasses or oil binders burn out, allowing the silica to fall in flakes or dust to form dirty areas or holes on the casting. These are also detrimental on

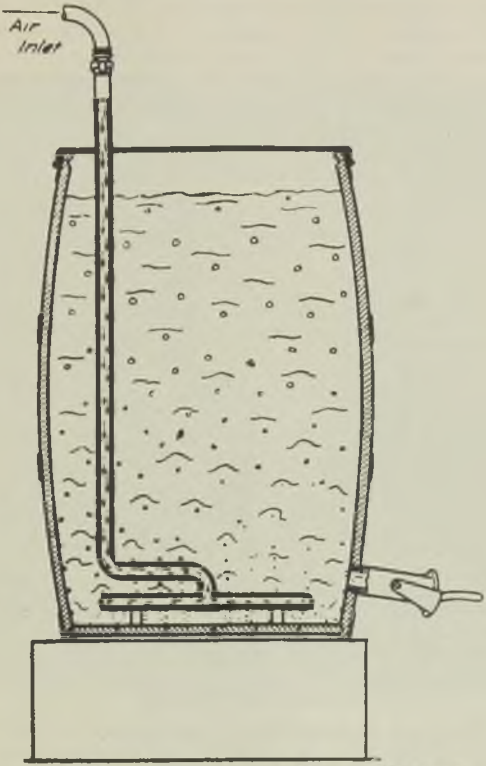

Fig. 1.—Apparatus for Mixing Washes by Compressed Air.

account of their being gas producing materials. As the fine silica flour forms such an impermeable facing and evolves no gas, it tends to prevent any metal penetration, or formation of iron oxide through the burning of the steel in air, and the further change of the iron oxide to iron silicate through contact with the extremely hot sand. The iron silicate being fluid penetrates the sand grains and causes them to fuse to the metal.

Sometimes a very fine natural silica sand suspended in water is used as the wash, and tar is also occasionally used for heavy work. Molasses or a vegetable oil such as linseed may be sprayed on the mould face before drying in order to increase its strength.

TABLE III.—*Recommended Specific Gravity Figures for Applying Wet Blackings.*

Method of Application.	Specific Gravity.	Degrees Baume. (Liquids Heavier than Water.)	Degrees Twaddell.
Blacking for spray or swab	1.21–1.24	25–28	41.7–47.9
Blacking for brush application ..	1.26–1.28	30–32	52.2–56.6
Blacking for dipping ..	1.35–1.38	38–40	71.0–76.2

Methods of Mixing

There are three generally used methods of mixing: (1) by hand in a bucket, (2) by compressed air in a barrel, and (3) by machine. If any wash be mixed by hand one cannot be sure of consistent results. Some moulders may use different quantities and the mixing may not be uniform, so that lumps may occur instead of a rich creamy solution.

Mixing by compressed air in a barrel, as shown in Fig. 1, is an improvement, but mixing by machine is the most efficient means of ensuring a wash consistent in quality and density as typified by Fig. 2. In this machine the water and blacking, etc., are placed into one of the conical tanks and kept circulating until a uniform mixture is obtained. About half-an-hour circulation gives very excellent mixing and the blacking will not settle out for some hours. It can, however, be stirred up at any time by restarting the pump. Two tanks are provided, so that when one is nearly empty, a fresh batch of blacking can be mixed in the other tank.

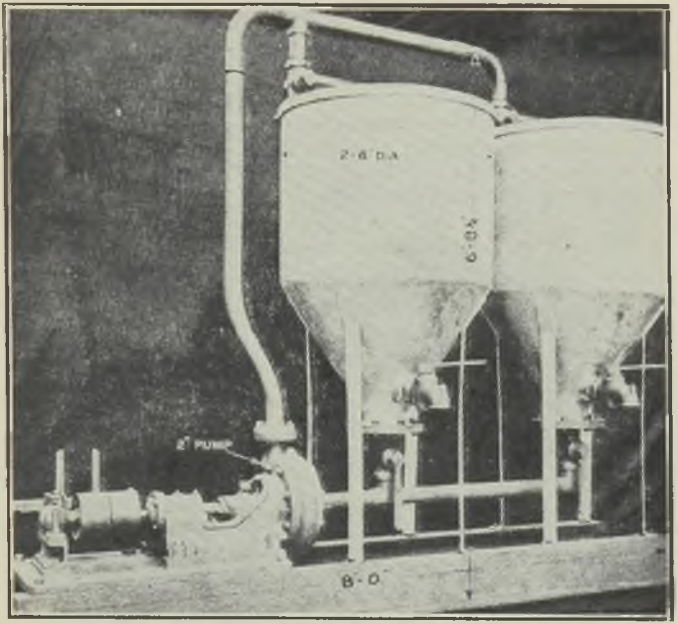

FIG. 2.—MIXING APPARATUS FOR CORE AND MOULD WASHES.

With the older system, where the moulder dipped his blacking pot into a large tank of blackwash, he had either to draw out thin liquid from the top or heavy blacking from the bottom. If this were to be avoided, he had to stand some time stirring up the mixture. With the machine, however, a uniform blackwash is always available for use. All carbonaceous materials used in blackings have specific gravities between 1.5 and 2.0 and so will settle out, some remaining in suspension longer than others. The liquid they are suspended in plays an important part in their settling time, those suspended in an oil wash settling quicker than those in clay water. The specific gravities of the various mixtures recommended are shown in Table III.

Methods of Application

There are three principal methods of applying the washes to the moulds and cores: (1) By use of a swab, (2) by a brush, and (3) by a spray. Of the three methods, application with the spray is undoubtedly the most efficient method. It ensures that the wash is firmly attached to the mould face by its penetration between the sand grains, and gives a fine even coating which is not liable to chip or flake off.

Application of a wash either by swab or brush has several disadvantages. Even coating cannot be guaranteed and a thick coating, which tends to chip more easily and to possess less permeability, generally results. Brushing, too, if the sand be weak or coarse, breaks the surface and disfigures the casting, even if nothing more serious results.

A single coating is recommended as best practice, but if more than one coat be applied, the previous coat should be thoroughly dried before applying the next. When applying with the swab the one coating may be varied in thickness according to the size of the job it is intended for. The thickness of the coating may vary from $\frac{1}{64}$ to $\frac{1}{16}$ in.

Sleeking Denounced

It is a disadvantage to sleek the coating after application, and if sleeking be imperative, sleek as little as possible. Sleeking in dry- or green-sand moulds lowers the permeability by closing up the mould surface and drying is detrimental. Impermeability caused by too much sleeking often results in spots of sand and blacking adhering to the top side of the casting. This is specially liable to occur in broad or flat surfaces.

The dry-sand facing sand should not be too wet or the pores of the sand will be filled with moisture, which will prevent the wash drying in. The wash is usually applied to dry-sand moulds when the sand is in the green state. Too much clay bond in the wash is also a possible cause of trouble, causing contraction cracks after drying.

The sand, too, plays an important part in the production of castings with good finish. A high moisture or clay content coupled with unequal or rapid drying will cause contraction cracks across the mould face. " Flowability " of the moulding sand is also important. Too much clay bond causes too high a green compression strength and will give a poor " flowability " which will cause unequal ramming, producing a broken sand surface so that extra sleeking becomes necessary.

Another coating which may be used, but which is not popular at present, is the deposition of a layer of lampblack from an oxy-acetylene flame. This is quite satisfactory when in combination with some other coatings but is not quite refractory enough itself for dry-sand work, although sometimes used to coat green-sand moulds into which steel has to be cast.

Mould and Core Washes at Atmospheric and Elevated Temperatures

Description of Apparatus Used.—Various washes, some of known composition, others proprietary washes of different types, were tested. A quantity of each was obtained and evaporated down to a loam-like consistency. The evaporation was done in water baths where the temperature never exceeded 100 deg. C. Care was taken that only water was driven off.

Once the wash was obtained like loam a sufficient quantity was placed in small split core boxes for complete drying. These boxes were 2¼ in deep and 2 in. dia., so that, when the test pieces were completely dried, they would be standard A.F.A. specimens. The extra ¼ in. in length was allowed for shrinkage while drying. At the bottom of the core box were several sheets of absorbent material, and below these was a perforated disc to allow free access of air, as shown in Fig. 3.

Drying was necessarily a prolonged procedure as the test pieces had to air-dry several days before stoving, and at first many cores were spoiled owing to too quick a drying. The aim was to manufacture blackwash test pieces and dry them under exactly the same conditions as were prevalent in the foundry.

Washes of all the usual combinations were tested as were proprietary ones for iron, steel and non-ferrous work. It was unfortunately found impossible thoroughly to test the steel washes in the manner desired owing to lack of facilities.

Washes Tested at Atmospheric Temperature

The five washes were thoroughly examined, and the A.F.A. dried compression strength, the A.F.A. permeability and loss on ignition tests were carried out. The first wash tested was an ordinary iron and non-ferrous wash consisting mainly of blacking and clay water. The second was an oil wash, actually a mixture of blacking and wood extract, for iron and non-ferrous work, and the third wash consisted of sodium silicate and blacking for iron and non-ferrous work.

The fourth was a proprietary wash for use with cast iron, and the fifth was a proprietary wash for use with cast iron and steel. Another proprietary wash for steel alone was tested, but owing to its high shrinkage, test pieces without

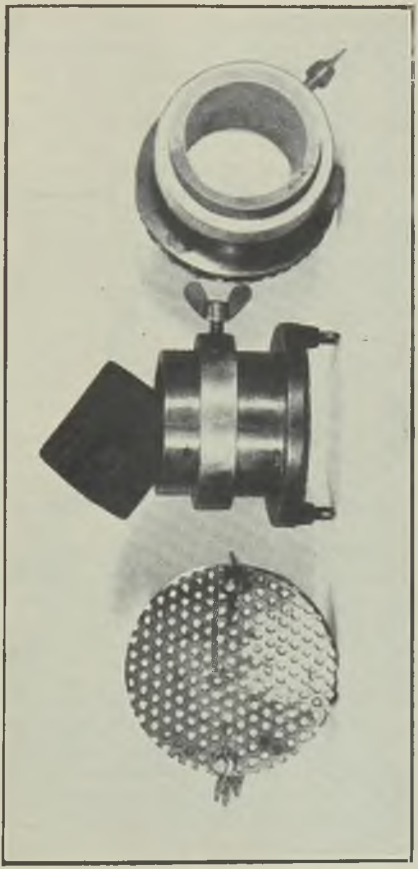

Fig. 3.—Apparatus for securing Standard Specimens.

cracks could not be obtained from it. Table IV shows the composition and physical properties of the washes used at room temperature.

Of these washes the oil wash had the greatest A.F.A. dried compression strength, the figure being 1,184.0 lbs. per sq. in. The next strongest was the No. 5 proprietary wash for cast iron and steel with a strength of 747.0 lbs. per sq. in. The other washes were all about the same strength of from 340 to 400 lbs. per sq. in.

The permeability of all the washes was similar to loam. The No. 4 proprietary wash had the highest permeability A.F.A. number of 0.81, and the No. 1 ordinary clay water wash was the most impermeable with an A.F.A. number of 0.037. The oil wash No. 2 had the highest loss on ignition, and only had an ash content of 12.11 per cent. Sodium silicate blackwash and ordinary clay water blackwash had respective ash contents of 14.12 and 22.87 per cent. The two proprietary washes both showed high ash contents, specially the cast iron and steel wash. The No. 5 wash had an ash content of 79.42 per cent. which suggested the presence of silica flour or some other non-carbonaceous material.

The required properties of a wash for cast iron and non-ferrous metals at atmospheric temperatures are:—(1) High permeability; (2) low surface friction; (3) ability to form a strong coating firmly attached to the sand, and (4) high loss on ignition.

A wash suitable for use with steel must:—(1) Form an impermeable skin to resist metal penetration; (2) have a low surface friction; (3) be refractory; (4) form a strong coating firmly attached to the sand, and (5) contain as little gas producing ingredients as possible.

Washes at Elevated Temperatures

The washes previously mentioned were all tested at elevated temperatures. The testing apparatus was the same as used by Mr. F.

TABLE IV.—*Compositions and Test Results of Washes Used.*

No.	Blackwash mixture.	Used for	Physical tests at room temperature		Loss on ignition. Per cent.	Ash. Per cent.
			Dried compression. Lbs. per sq. in.	Dried permeability. A.F.A. No.		
1	*Ordinary foundry blackwash :* 10 pails water .. .. 10 pails clay water .. 4 cwts. blacking .. .. 8 lbs. dextrine	Dry-sand moulds and cores, cast iron and non-ferrous metals	342.0	0.037	77.13	22.87
2	*Oil blackwash :* 5 parts water .. .. 1 part wood extract .. Blacking until a rich cream	Do.	1,184.0	0.45	87.99	12.11
3	*Sodium silicate blackwash :* 9 parts water .. .. 1 part sodium silicate .. Blacking until a rich cream	Cast iron	340.0	0.44	85.88	14.12
4	Proprietary wash	Do.	403.0	0.81	37.89	62.11
5	Proprietary wash	Cast iron or steel	747.0	0.24	20.58	79.42

Hudson in his work on the properties of moulding sands at elevated temperatures and described in his Paper* on that subject. The results obtained are shown in Figs. 4, 5 and 6.

Expansion

All the washes were tested for their expansion or contraction, and greatly varying results were obtained (Fig. 4). The proprietary wash No. 4 showed the greatest expansion, expanding 0.016 in. on 2 in. A steady expansion took place with a sudden increase between 500 to 650 deg. C., which suggested together with the high ash content this wash contained, that the sudden increase was due to silica flour. The other proprietary wash, No. 5, showed the same tendencies but the sudden alpha-beta change only occurred after a steady contraction. This was, perhaps, caused by a large percentage of clay, probably bentonite, as this wash was intended for use with both cast iron and steel.

The No. 1 ordinary foundry blackwash behaved as one would expect from its composition, a small steady expansion up to about 0.008 in. on 2 in. at 750 deg. C., and then a steady contraction. The sodium silicate blackwash showed a slight contraction followed by a small expansion but was never far from the zero line. The oil wash steadily contracted to a maximum of 0.007 in. on 2 in.

Dried Compression Strength at Elevated Temperatures

As shown by Fig. 5 all the washes excepting No. 1, ordinary foundry wash, lost strength on heating. This one, however, retained its strength up to 500 deg. C. and then decreased in strength only very slowly. The oil wash, the strongest wash at room temperatures, lost strength rapidly, falling from about 1,200 lbs. per sq. in. at room temperature to 230 lbs. per sq. in. at 500 deg. C. Once the wood extract began to coke above 500 deg. C. the strength rose

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* "Some Properties of Mould and Core Materials at Elevated Temperatures," Proceedings Inst. Brit. Foundrymen, Vol. XXIX, p. 475.

again to about 450 lbs. per sq. in at 600 deg. C., from which temperature it gradually decreased again.

Both the two proprietary washes showed the signs of a silica composition, decreasing in strength, rising again through the alpha-beta silica change point and decreasing again from 900 deg. C. These two washes were as strong at 900 deg. C. as at room temperature. The sodium silicate blackwash decreased steadily in strength, having no strength at 900 deg. C.

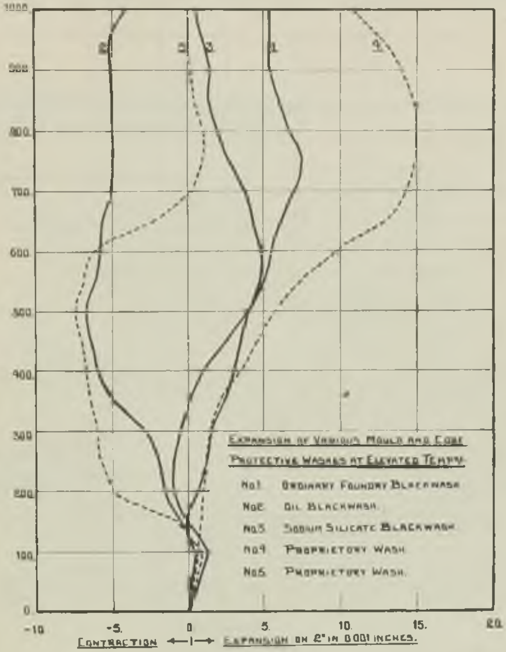

FIG. 4.

Dried Compression Strength after Cooling from Elevated Temperatures

From Fig. 6 it will be seen that the washes, after cooling, behaved in a similar fashion, following closely the graphs of the previous tests at elevated temperatures. The strengths, however, were slightly lower in almost every case. The silica change points were evident in both the proprietary washes as before. The oil wash showed a similar increase due to the wood extract coking. The No. 1 foundry blackwash showed a steady decrease in strength while the sodium silicate blackwash behaved similarly, only on this test it had slightly more strength at 900 deg C.

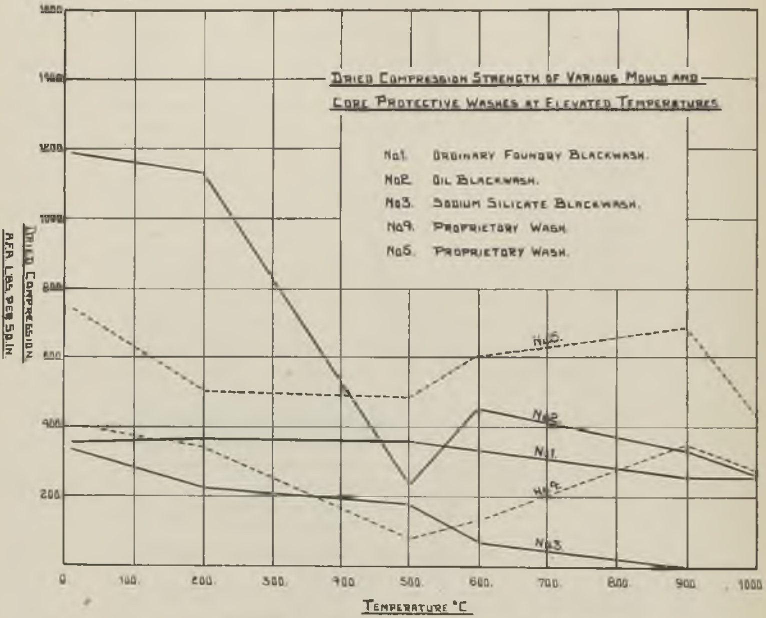

FIG. 5.

Finish Produced by the Washes Tested on Actual Castings and Experimental Test Bars

All the five washes were used in the foundry to blackwash actual moulds for the production of iron castings, and results attained were as tabulated on the next page.

Another proprietary wash for steel castings was tried but, as with No. 5, it was unsatisfactory. This wash was a white-paint silica wash.

Two test bars were cast, one in cast iron and one in gunmetal (Fig. 7). Each test bar was coated with six washes, the five washes previously mentioned and a sixth, which was a mixture consisting of 24 parts water, 12 parts plumbago, 2 parts dextrine and 2 parts bentonite, extra water being added when necessary. The bars were 3 ft. by 6 in. by 3 in. deep. The bottom face and sides were coated with the six washes, every 6-in. section being coated with a different

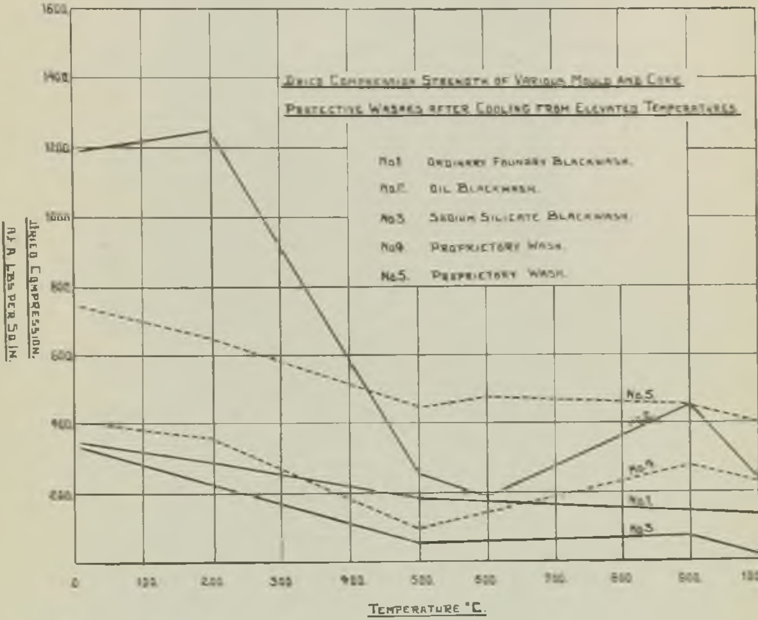

Fig. 6.

wash. There was one main gate with six runners supplying each different section of the bar. The cast-iron bar was cast at 1,260 deg. C. and the gunmetal one at 1,220 deg. C.

The bars were examined and the results agreed very closely with the actual test conducted in the foundry. In both cases the oil wash had the best finish of the five washes previously tested, but the plumbago-dextrine-bentonite wash was superior to any of the six on both bars. The appearance of the test bars straight from the mould is shown in Fig. 7.

1	Foundry blackwash	Satisfactory finish.
2	Oil blackwash . .	Satisfactory finish, best finish of all five washes tested.
3	Sodium silicate blackwash	Unsatisfactory finish, sand adhering to casting. On heating the sodium silicate rose to the surface of the test pieces, forming a white easily fusible surface.
4	Proprietary wash for cast iron	Passable, but not definitely satisfactory.
5	Proprietary wash for cast iron and steel	Highly unsatisfactory, sand fused firmly to the metal.

Conclusions

Iron and Non-ferrous Washes.—The above tests give definite information on how the various ingredients of a wash affect the final finish. For cast-iron and non-ferrous work, graphite in every case gives a better finish to the casting than any other material in common use. In green-sand moulding, however, a blacking containing a little graphite and adulterated with some of the previously mentioned ingredients will give a satisfactory finish. In dry-sand work where a wash is applied no graphite is required to give good results.

Silica flour is undesirable in iron or non-ferrous facings and if used will give an inferior finish when compared with carbonaceous material.

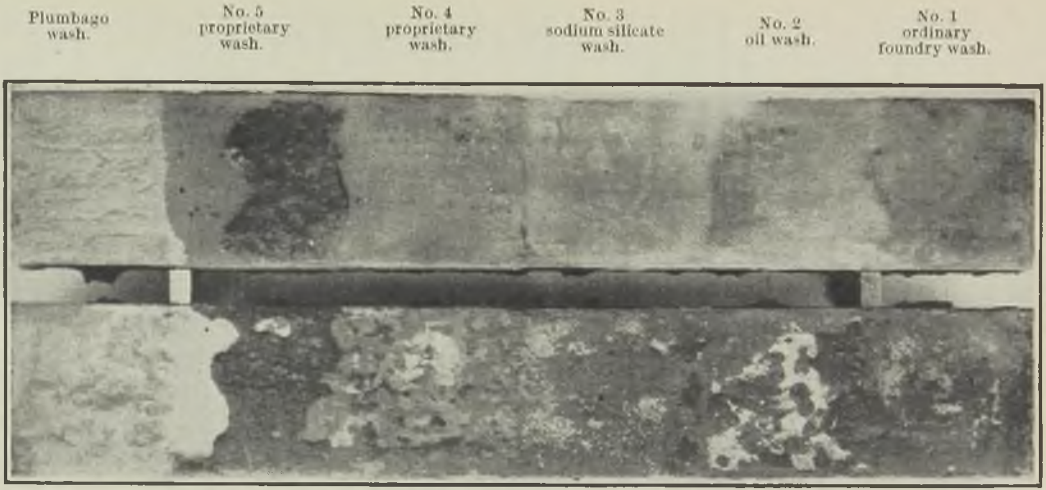

FIG. 7.—TEST BLOCK SHOWING THE EFFECT OF VARIOUS WASHES ON THE FINISH OF GUNMETAL (BOTTOM) AND CAST IRON (TOP).

No. 5 proprietary wash for cast iron and steel and the other wash for steel, both containing silica flour, gave exceedingly bad results, the sand and facing being strongly fused to the metal. This wash contracted on heating, whereas No. 4 proprietary wash, which also contained silica flour to a lesser degree, expanded almost to an equal extent as the dry-sand facing sand it was covering and the finish was reasonably good. A wash such as No. 5 wash flakes from the mould and will cause a bad finish and probably holes.

An ideal wash should have equal expansion as the moulding sand. This is not so important in iron and non-ferrous practice if the wash be composed of high volatile materials, for example, No. 2 oil blackwash. If a high ash content be present combined with unequal expansion, holes and dirty areas, etc., will occur.

High initial compression strength is desirable. The wash will then retain its strength until a skin is formed on the casting, but once the metal is set the strength could decrease in order to facilitate the fettling operations. The permeability of the wash should be as high as possible to enable free exit of the gases from the mould cavity.

Steel Washes.—Silica flour seems to be the best material for steel washes when used correctly. The wash for steel has to be refractory and no gas being evolved the expansion becomes very important. In order to get the best results the wash must have the same expansion as the sand, otherwise one is sure to experience flaking which results in unsightly castings. A partial remedy is to apply the wash only very thinly. High compression strength is recommended but is useless unless the expansion of the sand and wash is equal.

Molasses or core oils are unsatisfactory binders for large moulds unless in conjunction with bentonite or some form of clay, as the molasses burn out and allow the silica flour to fall off.

Excessive additions will also cause blisters which fall off when the metal strikes them.

In regard to synthetic sands for any type of work, tests seem to indicate that when blackwashing a synthetic sand containing just sufficient amount of clay bonding material, the blackwash washes away the covering bond and weakens the mould face. To counteract this an extra strong coating is suggested.

Finally, the author expresses his thanks to the directors of Glenfield & Kennedy, Limited, to Mr. H. Gardner, works manager, for permission to give this Paper, to Mr. F. Hudson for his advice and help in preparing this Paper and also to Mr. F. McCulloch for his assistance in preparing the slides.

London Branch (East Anglian Section)

Paper No. 622

SOME CONSIDERATIONS OF CUPOLA OPERATION

By H. H. SHEPHERD (Member)

Introduction

The initiation of the cupola furnace is usually attributed to that well-known eighteenth century English foundryman, John Wilkinson, but it would be more correct to state that this furnace was gradually evolved from the blast furnace and its modifications. It may be correct to state also that his patented " low erection, not exceeding 10 feet high " furnace was the forerunner of the cupola. As to the method of operation such as it is known to-day, the first recorded instance of alternate charging of pig-iron, scrap and coke is that contained in a patent granted to a John White in 1824.

The past 15 to 20 years have seen several other methods of melting iron for the foundry introduced and, in some cases, these new methods have become firmly established. One could give numerous instances where one or other of these newer melting mediums have displaced the cupola; nevertheless, the prophets of a few years ago who said that the introduction of a particular method of melting would result in the extinction of the cupola have been proved wrong. The application of these more modern methods, like the application of mechanisation to the foundry, can be overdone, and it can prove to be entirely wrong in some cases.

The author would hasten to add that he does not possess any views which may be termed old-fashioned or biased, but the facts are that there is still much in favour of cupola melting as an efficient and economical melting method under many conditions. High-quality castings of all sizes, shapes and weights can be produced from many widely differing types of mixtures ranging from ordinary white irons—including those requiring subsequent treatment to render the castings made from them into malleable cast iron—through countless varieties of ordinary grey cast irons to alloy cast irons.

Inherent Advantages

It is well worth while to note some of the advantages of cupola melting:—

(1) The cupola is the quickest method of melting;

(2) It is the cheapest method of melting when considered from the practice of melting, alone;

(3) With the exception of the electric furnace, the cupola has a higher thermal efficiency than any other furnace. This thermal efficiency ranges from 35 to 45 per cent.;

(4) Properly controlled cupola practice will give a continuous supply of hot and what is of perhaps greater importance—exceptionally fluid iron; and

(5) There is another advantage, which is that cupola melting is eminently suitable for foundries requiring a continuity of metal supply over long periods of time.

The quality of cupola metal can be very much enhanced if the management is prepared to give as much care to control as is given to other types of melting furnaces. Fundamentally, the cupola has not altered in its general design and method of operating over the past 100 years or more. There have been many patents relating to design and practice almost since its inception, but most of them are obsolescent, and one can set down the chief modifications as being again brought about more by evolution than by sudden changes. The height, for instance, has been gradually increased and the modern counterpart of John

Wilkinson's " low erection furnace not exceeding 10 feet high," is a structure which may vary in total height from 22 to 40 feet.

Construction

The most important dimension in respect of the furnace height is the distance between the top of the first row of tuyeres and the charging door sill. This is known as the effective height, since the shorter it is the less the efficiency due to heat losses and loss by incomplete combustion. The shorter this height the greater the tendency for flames or combustible gases to be present at the charging door, yet lack of flame at the charging door does not necessarily indicate efficient practice, it all depends upon the amount of CO gas escaping, each unit of which represents a loss of two-thirds of the available heat units. From this it follows that the only sure means of determining how efficiently a cupola is operating in respect of combustion is to analyse the top gases. For ordinary practice the CO content may range from 6 to 10 per cent. or more, with properly controlled practice it can be brought down to 3 or 4 per cent. and, in certain practice, may be less than 2 per cent.

It will be appreciated that as the effective height of the cupola increases so does the resistance to the blast increase, therefore, there is a limit to this effective height. In cupola design it is usual to calculate the effective height on the basis of ratios to the diameter of the furnace at the melting zone; these will range from 4.1 for small cupolas, to as much as 6.1 or more for larger sizes. The height from the base plate to the charge door of moderate-sized cupola should not be less than five times the melting zone diameter if one is to obtain efficient practice.

Diameter of Shell

It follows, as a matter of course, that the size of cupola one uses is almost entirely governed by the output required. In actual fact, the larger the diameter the better the results, other things being equal, and with the proviso that all the metal melted can be handled without recourse to the practice of putting the blast on and off, a procedure which is fatal to good cupola operation.

It is generally advisable to instal a cupola which will permit melting of more iron per hour than the amount actually required, immediate requirements being controlled by increasing the thickness of the lining. Double the initial melting requirements is a safe figure to work to in selecting a suitably sized furnace. It should not be more than two and a half times the immediate capacity required per hour, otherwise the lining will be so thick that a great deal of extra coke will be necessary in the bed and first few charges to heat this lining, resulting in abnormally high carbon and possibly high sulphur metal. Moreover, such practice is not economically sound, and may react very definitely against securing good castings.

Tuyeres

As to the position of the tuyeres, the height of the first—or maybe the only—row from the base plate will be largely governed by the amount of iron (if any) it is desired to store in the well. Two to two and a half feet from the base plate represents average practice when a fair storage is required, but in receiver or continuous melting practice this height is usually much less and may only be a few inches. Considering the effects of tuyere positions alone, low tuyeres increase the effective height of the cupola and, of course, save bed coke. Furthermore, when it is realised that the coke bed below the tuyeres has no effect upon the speed of melting, and one can say that this coke has no beneficial effect upon the temperature of the iron, it may have detrimental effects; then for best results the tuyeres should be as low as is consistent with the amount of metal it is required to hold in the well before tapping. The height of the tuyeres will determine the height of the bed.

Most of the statements just made refer to a single row tuyere condition, whereas modern practice employs two or more rows of tuyeres. There have been many modifications in the design, number and positions of tuyeres. Two rows, three rows and spirals of tuyeres, the last system being first used about 1850-60, have all been employed to a greater or lesser extent, but with the exception of one or two types of cupolas, these varieties have died out, and it is found that the ordinary two row tuyere design predominates.

Summing up this question of "one or two rows of tuyeres?" the author would express the opinion that two rows of properly designed and positioned tuyeres will result in more rapid melting and hotter iron than is usually the case if one row only is used.

The most suitable shape for tuyeres is a matter which involves many opinions, but perhaps the slightly flared tuyere of not too large dimensions would meet with general acceptance. By "not too large dimensions" is meant that it is far better to employ a number of tuyeres of such size to have the desired total area at the outlets than to use only two or three; this is especially the case with flared tuyeres.

It is well known that the total cross sectional area of the tuyeres should bear some definite relationship to the area of the furnace at the melting zone. Many years ago Cook recommended the following, based on the type of castings produced:—

For soft castings, tuyere area = $\frac{1}{8}$ of melting zone area.
For general castings, tuyere area = $\frac{1}{9}$ of melting zone area.
For cylinder castings, tuyere area = $\frac{1}{12}$ of melting zone area.

An American authority, Y. A. Dyer, also some years ago, published the following recommendations for the ratio of tuyere area to cupola area:—

For cupolas from 24 in. to 42 in. dia. = 1:5.
For cupolas from 44 in. to 62 in. dia. = 1:6.
For cupolas from 64 in. to 82 in. dia. = 1:7
For cupolas from 84 in. to 90 in. dia. = 1:8 to 1:8.3.

Undoubtedly, the most successful practice which has incorporated more than one or two rows of tuyeres is that of the Balanced Blast system. Space will not permit the consideration to any extent of this design and method of cupola operation, which was devised by Fletcher, and which is patented by the B.C.I.R.A. E. Wharton, W. Y. Buchanan and the author of this Paper have dealt pretty fully with the Balanced Blast cupola system, and those who are further interested are referred to these Papers. [1] [2] [3] [4]

The rapid and continued success of Fletcher's system is strikingly illustrated by the fact that within the course of about six years something like 140 Balanced Blast cupolas have been installed, and the total hourly capacity is over 1,000 tons. Further, their installation has been widespread, for besides many which are operating in this country, there are also many in use or in course of installation in Australia, India, America, Denmark, China, Czecho-Slovakia, Germany and France, etc. Surely, a remarkable achievement in a comparatively short space of time.

It can be stated without fear of contradiction that this success is due to the fact that Fletcher was the first to realise that to secure and maintain a properly balanced atmosphere, would necessitate a specially designed cupola, particularly relating to the tuyeres, and that all these would require to be adjustable in order to obtain the correct balance of air between the main lower tuyeres and the auxiliary upper tuyeres. Further, the attainment of a correctly balanced atmosphere was worked out by Fletcher on different lines from those previously adopted; in other words, the principle adopted by him, as a result of investigation and experience of many types of melting and smelting furnaces, was that the air supply to the lower part of the coke bed should be restricted so as to limit the amount of free air or oxygen in this zone to

FIG. 1.—METHOD OF HANDLING RAW MATERIALS AT THE AUTHOR'S FOUNDRY.

the lowest practical limit and, at the same time, maintain the maximum amount of carbon monoxide in these gases.

The carbon monoxide is later burnt to carbon dioxide by the auxiliary tuyeres. The practical result is that, rapidly melted, high temperature and fluid iron freer from oxidation, is obtained under economical conditions, and invariably the Balanced Blast system shows considerable savings in coke.

Charging

Mechanical handling is rapidly taking the place of manual labour and modern foundry stock-yards are usually equipped with overhead travelling cranes.

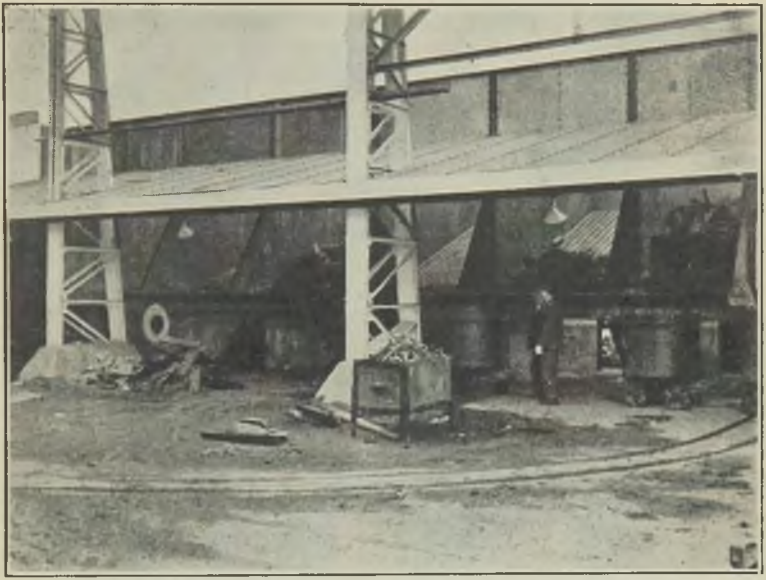

FIG. 2.—SHOWS THE SLOPING BINS AND SPECIAL CONTAINERS TO HANDLE RAW MATERIALS.

Figs. 1 and 2 illustrate the method of raw materials handling at the foundries with which the author is associated. The materials are loaded into sloping bins from which they can be raked into specially designed containers which pass over weighbridges in order that the appropriate amount of each of the constituents of the cupola charges can be weighed to within reasonable limits.

Mechanical charging of cupolas is becoming more and more popular and is, in fact, almost a necessity for cupolas operating large melts over long periods. There are, however, few mechanical chargers which do the job really efficiently, the most satisfactory type, so far as the author is concerned, is that employing the " drop bottom " bucket principle. The type of bucket and method of operation are illustrated by Fig. 3.

If the installing of a cupola plant and mechanical charger is contemplated, then a fair sized cupola platform is recommended as an investment well worth while. For mechanical charging the author does not advise mixing the coke with the metal charge in the buckets, but recommends that a supply of coke and limestone be kept on the cupola platform, and that these are weighed and charged into the furnace separately, preferably by the man handling the bucket hoist if this be the system employed.

So far as hand charging is concerned, too much stress cannot be laid on the fact that to charge a cupola correctly in order to obtain uniformity of melting does require some care and thought. To put any sort of labourer to " throw in " the charge is a great mistake. It is well worth while making sure that charging is carried out correctly, and even with mechanical means some considered attention must be given if the best results are to be obtained.

Blowing Units

The centrifugal fan has come to be accepted as an efficient means of supplying the air blast. It is cheaper and less costly to maintain than the positive blower of the Roots type, and since the electric current consumed is proportional to the volume of air used, the power costs are also less. The delivery of air is more automatically and simply controlled with the fan blower, for, since the quantity of air delivered varies with the resistance met, control of air volume can easily be obtained by operation of a blast gate fitted directly in the main blast pipe. For these reasons a variable speed motor is not necessary.

Fan blowers are much more sensitive to furnace variations, such as obstructions, slagging of tuyeres, etc., than are positive blowers.

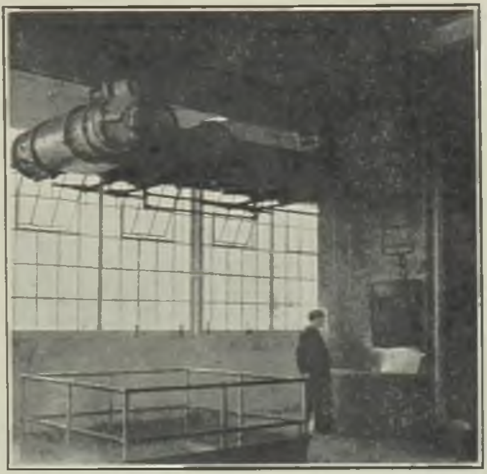

Fig. 3.—Showing Drop Bottom Type Bucket used for Mechanically Charging a Cupola.

Another point of interest with regard to the latter is that usually a more uniform volume of blast results than from a fan, especially when the equipment is new or kept in first-class condition.

In U.S.A. there are many cupolas receiving their air supply from Roots type blowing plants, This is probably because of the much larger size of cupola than is customary in this country, and. obviously, with such furnaces the resistance offered by the charges is very considerable. However, even in these cases the fan is replacing the positive blower.

Considering fans and blowers purely from a point of view of efficiency of cupola control, the author has no definite opinion or recommendation to offer. He is inclined towards favouring the positive blower, and some of the advantages of this method of supplying air, which have been referred to, namely, the greater tendency to a more uniform air volume and less susceptibility to furnace conditions, have influenced the author in this direction. During a recent visit to many German foundries the

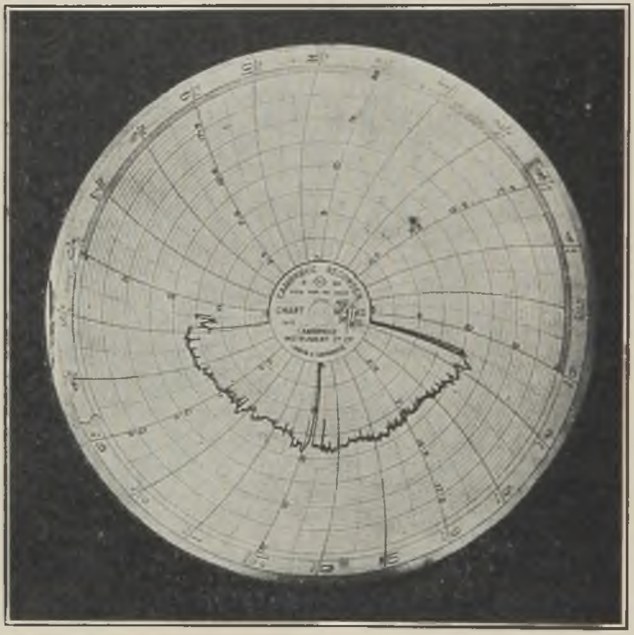

FIG. 4.—BLAST PRESSURE CHART; BALANCED BLAST CUPOLA.

author was very interested by the fact that the positive blower was being used exclusively.

Constant Volume Essential

In modern cupola practice it is recognised that pressure is only of secondary importance compared to the *volume* of air entering the furnace.

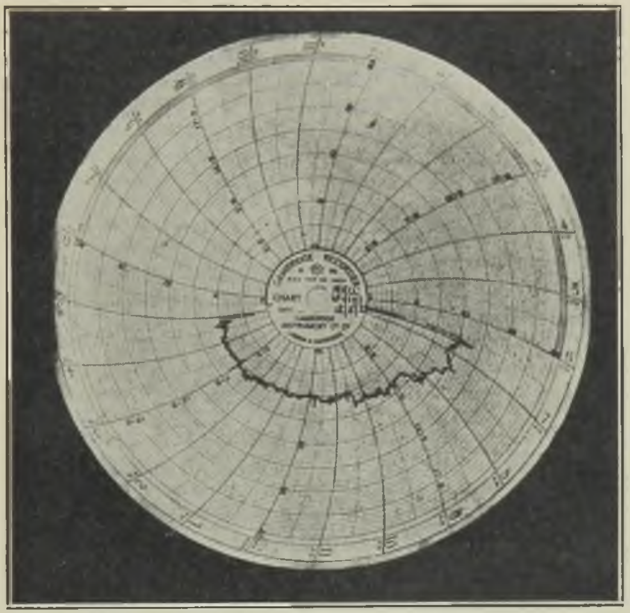

Fig. 5.—Blast Pressure Chart; Balanced Blast Cupola.

The blast should, therefore, be regulated to keep a constant volume; with a positive blower regulation this is controlled by varying the speed of the driving motor. It is advisable with fan blowers to regulate the volume by a blast gate in the main which is now the recognised practice. Fan blowers should be so equipped that they can be driven at such a speed that sufficient volume is available at the highest pressure likely to be encountered. Good practice should aim at controlling the volume of air for small and medium sized furnaces, within plus or minus 5 to 7½ per cent. of the air required per minute, and within 10 per cent. for large cupolas.

Whilst volume is of first importance, pressure conditions and control should also be taken into account. As is well known, the pressure of the blast required usually increases with increase in diameter. The tendency to blow at high pressures was associated with the time when positive blowers were more popular than they are now.

The positive blower, as its name implies, a positive pressure, but as previously stated, in the case of the fan the indicated pressure depends to some extent on the resistance offered by the charges in the furnace and any obstructions at the tuyeres. For this reason, knowledge of the volume of air delivered to the cupola per unit time becomes of increasing importance. Reliable instruments can now be purchased to measure and record blast volume and pressure.

If founders are seeking correct air control in conjunction with the proper measuring instruments the following warning is given. Make sure that the cupola is reasonably airtight at the tuyeres, connections, etc., and that welded and other types of joints in the delivery pipes and air belts have not cracked or warped, otherwise the figures as to air supply will be erroneous and consequently very misleading.

The author's practice is to blow with as low a pressure as is consistent with obtaining the required air volume and melting rate, other things being equal. For a 27-in. melting zone diameter cupola 7.5 ozs. was the average pressure used, whilst it was found that in the case of Balanced-Blast cupola practice the pressure could be as low as 5 to 6 ozs. and still become very hot and fluid iron. Figs. 4 and 5 show blast pressure charts of a Balanced Blast cupola which was operated under these conditions.

Actual Requirements of Air

To calculate the amount of air required a practical figure of 140 cub. ft. per pound of coke can be used when the coke contains 92 per cent. carbon. Using this figure and a metal to coke ratio of 10:1, it is found that 224 lbs. of coke and 31,350 cub. ft. of air will be required per ton of metal. Multiplying this figure by the hourly melting rate of the cupola gives the amount of air required per hour. H. V. Crawford has clearly shown that the quantity of air required may vary from approximately 30,000 to 20,000 cu. ft. per ton of iron depending upon variations in atmospheric conditions, and that for correct practice the air should be measured by weight and not by volume, in order that the amount of oxygen shall be constant. Space prevents detailed consideration of this interesting and important phase of cupola practice, and this section of the subject will be concluded by strongly recommending the use of a somewhat lower volume of air—about 5 per cent.—than the calculated requirement. It is, in any case, advisable to employ the minimum rather than the maximum quantity.

Lining the Cupola

The most modern procedure is to line the furnace with siliceous material which, after being suitably prepared, is rammed between the shell of the furnace and a template or former. The author has no criticism to make of this method provided that the lining material is correctly prepared and applied, and proper attention is given to the drying out. It is, however, correct to state that unless one treats a monolithic lining when it is first put in like a raw fireclay, by giving it a very careful drying and firing extending over several days before being put into practice, failure is sure to result.

Personally, the author prefers to use good firebricks—not too hard, and containing about 30 per cent. of alumina. One reason for this is that the operation of the Crane foundries does not permit the time for inserting monolithic linings. A $\frac{1}{2}$-in. layer of ganister is always placed on a new brick lining from base plate to well above the tuyeres; this gives good protection to the brickwork during the first melt after lining. Such a lining will last over 11 to 12 months, which it is felt is good considering the cupolas operate for 10 to 11 hours each day and have annual outputs of 8,000 to 10,000 tons of metal.

The daily patching practice consists of using first quality ganister, together with 1-in. firebricks; a few full-sized firebricks are required two or three times a week in the melting zone.

Standardised Patching

At this stage an important point in regard to the internal diameter of the cupola should be mentioned. It is a simple matter to calculate the melting rate of a particular diameter, since any correctly operated cupola will melt 10 to 11 lbs. of iron per hour per square inch of area at the melting zone; an alternative figure of 0.75 ton per hour per square foot of bore area at the tuyeres can be used. Obviously, then, if the diameter is allowed to vary much from the correct diameter, either by being made smaller or larger, it will seriously affect the output. Probably many cases of trouble could be traced to large variations in the diameter of the furnace after patching. To obviate such troubles the cupola should be patched *each* day to a standard diameter, and it is advisable to insist that the furnaceman uses a gauge stick cut to the dimensions of the diameter required. It is, of course, necessary to see that where patching finishes shelving or sudden tapers in the ganister are avoided, otherwise " hanging " or " scaffolding " will occur.

To force a given diameter furnace to give a much greater output than is the correct output for that size by blowing hard is bad practice, as it is likely to cause oxidised iron and a severely cut lining.

Sand Bottom and Tap Hole

Considerable care is necessary in making the sand bed or bottom; the tap hole and also the slag hole, if sound and trouble free practice is to be obtained. Good sand, yet not too strong, must be used for the bottom, and it must be well rammed, but not too hard. Failure to observe these precautions will result in either metal possibly leaking through the bottom doors or considerable difficulty in getting the sand bottom to drop away when the doors are released at the end of a melt.

There are a number of well-established ways of forming the tap hole, but where it is required to stop the flow of metal after the required amount is drawn off, the author prefers to use a tap hole brick. This consists of a tapered brick carrying a tapered $2\frac{1}{2}$ in. to 3 in. diameter hole through the centre; the tap hole proper—usually $\frac{1}{2}$ in. to $\frac{5}{8}$ in. in diameter and about 3 in. in length—is formed round a wood peg pattern.

If foundry conditions are such that a continuous supply of metal can be taken care of throughout the melt without resorting to stopping the tap hole, then a tap hole brick is a necessity. It should be about 3 or 4 in. thick and have two tap holes situated in it, one being about 2 to $2\frac{1}{2}$ in. above the other; then, if for any reason the lower hole seizes up, the top one can be opened.

As to the diameter of tap holes for continuous operation, a $\frac{1}{2}$-in. hole will deliver about 5 tons of metal per hour, whilst $\frac{5}{8}$ in. and $\frac{3}{4}$ in. will give 10 and 15 tons per hour respectively. Consideration of the above will indicate that careful attention must be paid to the size of the tap hole when the metal is running continuously from the cupola; further, it is not advisable to adopt such practice unless the foundry can take care of at least 5 to 6 tons of metal per hour.

Slag Separating Devices

Slag separating devices are associated with the tapping equipment, particularly in continuous tapping practice. A simple form of slag separating spout is illustrated in Fig. 6. As the spout is filled with metal, the slag is held back by the bridge (made of firebrick) and passes off at right angles to the flow of the metal. At the end of the heat the metal left in lowest regions of the spout is tapped off through a side hole.

An anonymous writer in a recent issue of the American journal "The Foundry," gave some very interesting observations and recommendations appertaining to front slagging spouts. These followed on this writer's attempt to design a slagging and tapping spout which would not "blow" at the front. The following, extracted from the article in question, summarises the matter very well:

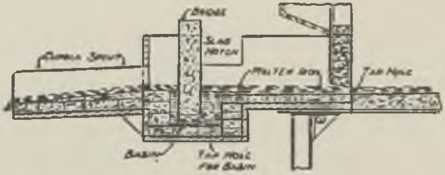

Fig. 6.—A Simple Form of Slag Separating Spout.

"Successful application of a front slagging spout depends entirely on the courage displayed by the foundryman in making the spout so that the iron will run uphill. In many instances the front slagging spout has been a failure because the foundryman will not make the difference in elevation sufficient to seal the tap hole. To prevent air and slag from blowing through the tap hole the static head of metal in the spout must be greater than the pressure in the cupola."

Obviously, then, dimensions which apply to the head of metal in the spout cannot be fixed for any given spout; it will vary with the pressure in the cupola. Fig. 7, taken from the article referred to, shows the varying dimensions necessary for the spout, and, also diagrammatically, illustrates a slagging and tapping spout based on this principle.

The most obstinate " hard " tap hole can be opened without the risk of badly damaging it by heavy hammer or chisel blows and resultant accompanying dangers and troubles for the remainder of the melt. The equipment needed comprises a welder's burner, oxygen and acetylene gas and a piece of ⅜-in. or ½-in. gas pipe. To open the hole heat it with the burner till the set metal commences to run, then quickly remove the burner and, having previously connected the gas pipe to a cylinder of oxygen, turn on the gas and force the pipe—which will commence to burn—into the hole until it is freed, an operation which will only take a few minutes in all.

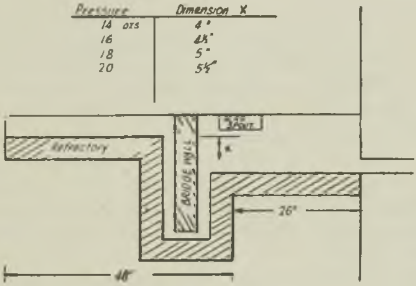

Fig. 7.—Shows the varying Dimensions for the Spout, and a Slagging and Tapping Spout.

The Coke Bed

Correct height and a properly prepared and conditioned coke bed is essential. Make a point of starting off with a proper coke bed and the foundation for a successful melt is established. It is well known that the amount of coke for the bed is decided by the height required and *not* by weight; it is weighed only for recording how much coke is used, for the purpose of costing and stock records. Once a fire is started the coke should not be forked on just anyhow, but added in comparatively small lots at a time and in the places where previous additions have burnt through. The aim should be to build up a *level* and *solid* bed. To make sure that the coke does not "hang" in any part of the bed it is recommended that the lower tuyeres be poked at several intervals during the making up of the bed.

The author's practice is to build up the bed to within 3 or 4 in. of the required height and to burn this through till all the coke is a bright red, then 50 to 75 lbs. of limestone are added and the remainder of the bed coke added, after which charging commences, and "blowing" starts immediately afterwards. The tap hole is left open till the metal is seen to pass the tuyeres, which usually occurs in 5 to 6 min., then it is stopped with floor sand. For regular "botting" or stopping the tap hole, a mixture of strong clay mixed with a little coal dust is used.

A very useful way of checking the bed condition and the work of the furnaceman in this connection, is to analyse the first few ladles tapped. If the total carbon and sulphur are higher than the results obtained when the bed conditions are standardised, it is safe to conclude that the bed was either too high or not burnt through uniformly or sufficiently. On the other hand, lower carbon, silicon, and maybe sulphur, indicates the reverse conditions.

Charges

All materials—pig, scrap, coke and limestone—comprising the charge should be weighed and scales demanding the use of loose weights should be avoided, as invariably some of the weights get lost and cause many inaccuracies to arise.

The weight of the charges have considerable influence on the working of the furnace. Reasonably heavy metal charges rapidly absorb heat from the furnace gases and so tend to increase the thermal efficiency by reducing the lost heat units, and also minimise the escape of CO. Fletcher has shown that light metal charges sandwiched between shallow coke charges give rise to oxidised metal and require more coke per charge to maintain the required temperature. On the other hand, if the weight of the charge be too great, then dull metal is possible, because the bed may be burnt too low before it is replenished by the coke charge. To avoid these troubles it is recommended that the weight of the metal charge be equal to about one-eighth of the hourly melting rate of the cupola.

Subject to the above factors being taken into primary consideration, the weight of the charges should also bear some definite relation to the well or capacity of the furnace. A useful figure to bear in mind in regard to this is that one cubic foot of well space will hold approximately two cwts. of iron.

Again, with intermittent tapping practice, it is a good plan—subject to previously stated conditions—to arrange the weight of metal tapped to bear some relation to the weight of the charges. The author's practice in one foundry is that the amount of metal per tap is approximately equal to the weight of one metal charge. It was found that by doing this a very uniform run of chemical composition can be obtained over the whole melt, which is essential for the successful production of cupola blackheart malleable. An endeavour is made to standardise and synchronise as far as possible all the steps in charging and tapping. The well carries molten metal at least equal to two charges, so that the metal is always covered with a layer of slag, and when slag has been flowing freely from the slag hole for a minute or so, the furnace is tapped. Occasionally the metal is raised in the well so that a little passes out of the slag hole; this ensures that the slag is not building up to too great an amount and so reducing the metal carrying capacity of the well.

Handling Tapped Metal

The metal carrying capacity of the well of any cupola can, of course, be varied to suit particular requirements. Storage in the well has the advantage that the metal temperature is maintained for a much longer period than is the case with external storage in the form of receivers. On the other hand, the use of a receiver permits a shallower well and a lower coke bed.

Where a foundry is producing large or medium castings, receiver practice can be very suitable, but where high pouring temperatures are required, the use of the ordinary type of receiver may result in the temperature being too low. To counteract this, many modern receivers are independently heated by gas or oil. There are not so many of this type of receiver in this country, but they are fairly common in Germany.

In a mechanised foundry, especially of the repetition production type, where the metal must and can be handled quickly, a very convenient way of handling the metal is to tap into a large tea-pot ladle, such as shown in Fig. 8. The ladle illustrated holds about 1,000 lbs. of metal, sufficient to supply five pouring and distributing ladles, also shown.

Limestone Additions, Sulphur and Carbon Pick-up

Although sulphur is not now regarded as injurious as it was at one time, and that for certain purposes a somewhat higher amount than usual may even be beneficial, in general, the properties of the metal are enhanced if inclusions of any kind—such as manganese sulphide—are kept to a reasonable minimum amount.

A good basic slag is a sure means of keeping sulphur absorption by the metal as low as possible; to obtain such a slag, adequate limestone additions must be used. An amount equal to 30 lbs. per 100 lbs. of coke charged is not excessive, and will give a good desulphurising and fluid slag. If the scrap and steel scrap used be rather dirty or rusty, then more limestone should be used. A moderate amount of fluorspar in addition to the limestone is very often advantageous; about one-fifth of the limestone quantity is ample.

Fig. 8.—A Large Tea-pot Ladle of Special Value to Mechanised Foundries.

The main factors which affect the carbon pick-up are:—

(1) Type and composition of mixture.
(2) Reactivity of coke.
(3) Height of coke bed.
(4) Variations in coke bed height.

(5) Temperature of melting zone.

(6) Air volume and pressure.

A number of authorities have investigated the problem of carbon control and pick-up; among recent investigations and published information may be mentioned those of Bamford[5], Parkes[5], Johnson[6], Mackenzie[6]. All these investigators agree that the greatest amount of carbon pick-up occurs in the melting zone and that there is no material increase in carbon content of metal left in the well of the cupola, which is contrary to the commonly held view. The higher the temperature, the greater the carbon absorption, and hence, other factors being equal, the higher the melting zone temperature the higher the carbon pick-up.

The reactivity of coke is shown to have an effect in that dense cokes, having low reactivity, give lower carbon absorption than the light open cokes of high reactivity.

Whilst it has been shown that raising the height of the tuyeres has little, if any, effect upon carbon pick up, raising or lowering the effective coke bed height (*i.e.*, the height from the tuyeres upwards), materially affects the carbon content of the metal, as is well known. The explanation is, that the higher the bed the greater the amount of incandescent coke through which the iron has to pass and, in general, the greater the absorption of carbon and, of course, *vice versa.*

Summarising the above in the light of practical requirements, it can be stated that to produce metal of a required carbon content and to keep this element as constant as possible, one must—assuming that a suitable mixture be used and that the coke is in line with the requirements given above—carefully control the height and conditions of the coke bed, so that it varies as little as possible throughout the melt. Linked with the control of coke bed will be that of air supply, which implies that which has already been mentioned, namely, correct and constant volume at the correct pressure.

In concluding this Paper, attention is drawn to a procedure initiated only a few years ago, of maintaining fine control, as it were, of the metal composition by the addition of the metal charges of ferro-silicon briquettes, and also briquettes containing manganese. It is a practice which the author has used almost since the briquettes were first put on the market, and he would say without hesitation, that the procedure is the most economical, safe and efficient way of making silicon and manganese adjusments. Anyone who may be further interested is referred to an excellent Paper by J. H. Williams,[7] which deals with these additions, apart from other matters of vital interest to the metallurgist and foundryman. Additional fine adjustment of composition can be carried out if necessary by small additions of ferro-silicon and/or ferro-manganese to the ladle.

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Scottish Branch

Paper No. 623

GATES AND RISERS FOR LARGE NON-FERROUS CASTINGS

By A. DUNLOP (Associate Member)

The primary concern of every foundryman is the production of sound castings. The soundness of castings is determined by several factors, such as metal composition, melting conditions, casting temperature, quality of moulding material, method of moulding, gating, etc., all of which require attention if good results are to be obtained.

Gating is a very important factor, involving the determination of the location, size, shape and number of runners and risers required to produce a good casting. Much consideration should be given to the runners and risers since their size, shape, position and number may each be deciding factors in the successful production of castings. The method of gating to be applied to any casting is mainly governed by two things, the design of the casting and the characteristics of the alloy to be used. When considering non-ferrous alloys, one is immediately confronted with the many different and complex alloys in use, and it is only proposed to deal in this Paper with two types of alloy, namely, bronze and high-tensile brass, and to discuss under these headings, principles and methods of gating as applied to some large castings.

Bronze Alloys

As the properties of the alloy used must be kept in mind, it is proposed to survey some of the peculiarities of the bronze alloys. The copper-tin system forms the basis of this class of alloy. The alloys which find use in engineering practice contain up to 16 per cent. of tin with varying amounts of zinc, lead or phosphorus. Some castings are made in the simple binary alloy if this includes the copper-tin alloys which contain a small amount of phosphorus. By far the larger number of bronze castings, however, are made from alloys containing zinc and sometimes lead. Many specifications for this type of alloy are in use, in many cases differing from one another in minor respects. In a recent Report of the Non-Ferrous Sub-Committee of the Institute of British Foundrymen it is stated that 37 specifications in current use are covered by the following range of composition: Cu, 82 to 93; Sn, 4 to 9; Zn, 1 to 8; and Pb, 0 to 7 per cent. Perhaps the most widely used bronze is the 88 per cent. copper, 10 per cent. tin, 2 per cent. zinc Admiralty mixture.

In considering the principles underlying methods of gating large castings in this type of alloy, some of the defects associated with faulty methods will be discussed, together with gating methods which help to minimise these faults. Such defects may be conveniently discussed under three headings:—(1) Shrinkage and contraction defects; (2) dirty castings; and (3) misrun castings. The above defects, however, are not always due to incorrect gating practice.

Shrinkage and Contraction Defects

There are three varieties of shrinkage in the cooling of molten bronze—liquid, solidification and solid. The most critical period is the solidification stage, that is, the transition from liquid to solid. A prevalent defect in bronze is lack of density—not blow holes and large shrinkage cavities, etc.—but general lack of density giving poor castings and bad physical properties. Some light can be thrown on this type of defect by a study of the constitutional diagram for copper-tin alloys, part of which is shown on Fig. 1. Although this is the diagram for the simple binary alloys, it is quite applicable to those bronzes containing zinc. Zinc has a somewhat similar effect to tin in the constitution of the copper-tin alloys, in that beyond the limit of the alpha solution, it increases the amount of delta present. For practical purposes zinc is equivalent to half its amount of tin in the production of the delta constituent. On referring gunmetals to the copper-tin constitutional diagram, it is necessary to convert the zinc and tin contents to the apparent tin content.

The constitutional diagram is of the solid solution type. The upper line A B, known as the *liquidus*, indicates the temperature at which solidification commences, while the line A C D, known as the *solidus*, indicates the temperature at which solidification is complete. This shows that the copper-tin alloys freeze through a temperature range which, in the case of an alloy having a tin equivalent of 10 per cent., is approximately 200 deg. C. The effect of phosphorus, in amounts such as are usually met with in ordinary phosphor-bronze, is to lower both the temperature of the beginning and of the end of freezing. For example, 0.1 per cent. of phosphorus added to a bronze containing 10 per cent. of tin lowers the commencement of freezing by about 25 deg. C. and lowers the temperature of final solidification by about 150 deg. C. A phosphor-bronze with 10 per cent. tin and 0.1 per cent. phosphorus has a freezing range of approximately 325 deg. C., and is therefore cast at a lower temperature than straight bronze.

Metallic solid solutions do not usually—and the bronzes are no exception—crystallise from a single centre outward uniformly, but grow faster in certain directions than in others, resulting in a dendritic formation. Since, during the freezing process, bronze contracts considerably, each dendrite occupies less volume than the liquid from which it is formed, and consequently tends to leave a space around it. Because the alloy has such a long freezing range, the amount of metal in a partly frozen condition is large, and being traversed by a mass of dendrites, the feeding liquid has difficulty in filling up the cavities and so producing sound casting.

The main factor is the period of solidification; the longer this period, the more likely is the density to be low. The period of solidification is controlled to a certain extent by the composition and temperature of the metal and by the thickness of section. The higher the casting temperature and the greater the mass, the lower the density is likely to be. The earlier solidification of a thin section of a casting may prevent the feeding of an adjoining thick portion, which, owing to its mass, must solidify later, and unless fed with liquid metal will be unsound.

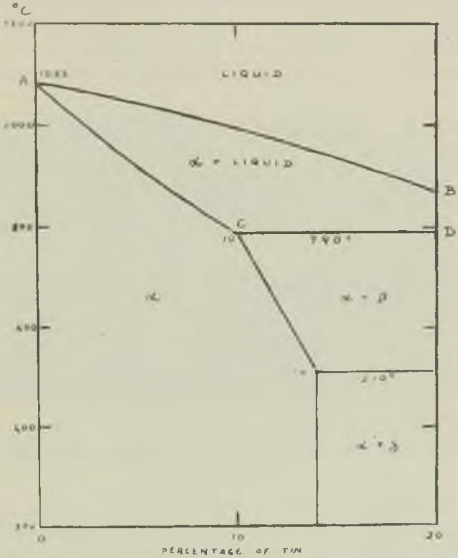


Fig. 1.—Constitutional Diagram of Copper-Tin Alloys.

Various methods may be adopted to overcome this difficulty. By admitting the metal at a thin section, the continued flowing of fresh metal superheats this part of the mould with a consequent delay in the rate of cooling, at the same time comparatively cold metal is supplied to the thick section with a subsequent speeding up in the rate of cooling. In this way a more even cooling down of the metal in the various sections of a casting is promoted. Alternatively, a large runner may be employed, leading into the heavy section, the runner keeping liquid long enough to provide feeding metal; this method has a limited application for large castings.

Another method of promoting an even cooling

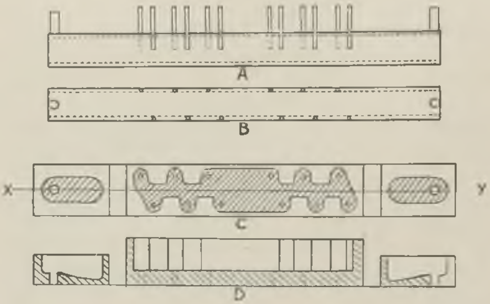


Fig. 2.—Method of Gating and Pouring 22-ft. long Liners, cast Horizontally.

in sections of differing thickness is to increase the thermal conductivity of the mould at the thick section, by using a metal chill, or, in a milder form, by sprigging the mould face at that point. It would be advantageous if means could be devised to control the thermal conductivity of the moulding sand, when sand of comparatively high thermal conductivity could be used to ram the parts of the mould of thick section while sand of lower thermal conductivity is used for the thin sections. Should none of the above methods be suitable, the heavy section should be connected to a feeding riser.

It will be seen that the ideal process of solidification should commence at the furthermost part of the casting and continue progressively toward the feeding points where the final liquid shrinkage can be compensated by liquid metal from the risers. Such risers must therefore be large enough to remain liquid until the parts to which they are attached have solidified, unless some artificial means is employed to prevent this prior solidification. Solidification of the metal in the riser may be retarded by rod feeding, in which method a preheated wrought-iron or mild-steel rod is moved up and down through the gate into the casting. The solidification of the metal in the gate being retarded, the metal in the riser is allowed to feed down into the casting. Skill is required in the manipulation of the feeding-rod for careless movements of the rod when the metal is becoming pasty will cause a porous area in the casting below the riser.

Fig. 3.—A 30-ft. long Liner Weighing over 6 tons.

A prevalent cause of cracks and hot tears, other than those caused by unyielding cores, etc., is the contraction stresses set up by varying rates of cooling in different parts of the solid casting. Much can be done in the way of equalising the rate of cooling by applying the runner gates to the lighter portions, and thus superheating these lighter sections. It is also essential that the mould be evenly filled with molten metal, otherwise cooling will commence at different times at various parts of the cast-

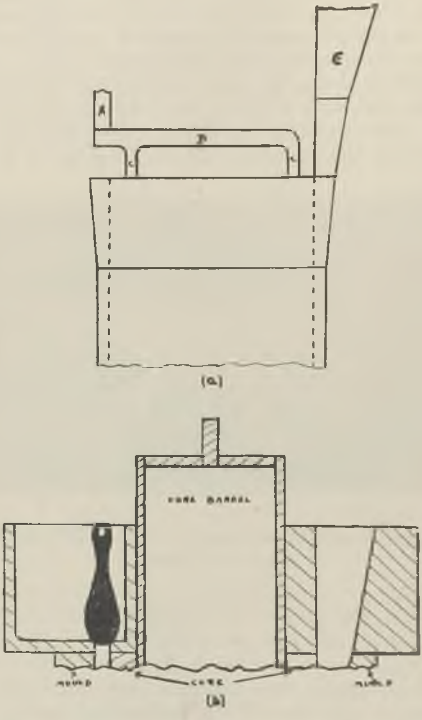


Fig. 4.—Method of Gating Liners, cast Vertically.

ing, with the result that contraction stresses are set up. The aim in all methods of gating should be to fill the mould cavity with molten metal in such a manner that solidification takes place from remote parts of the casting towards the feeding points and that the subsequent cooling of the solid casting is as uniform as possible.

Dirty Castings

By dirt in castings is meant foreign inclusion, such as sand, slag, oxide, etc. All sand holes in castings are not due to faulty moulding sand; the defect may arise when using the best moulding sand by the use of faulty methods of gating and careless preparation of gates and pouring basins. A large gate playing on one part of the mould or core may result in a scab, while, if the metal had been admitted at two or more points, the trouble would have been avoided. The runner gates should be so arranged

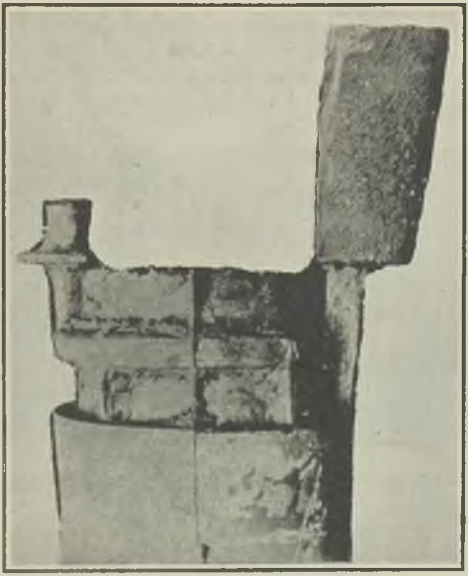


Fig. 5.—Vertically-cast Liner with Gates and Risers Attached.

that the metal has an unrestricted flow into the mould cavity, and should not impinge on any projection of the mould or core, but should flow as gently as possible with the minimum of turbulence and splashing. When deep work is being run from the top, the first metal should serve as a cushion for the remainder, otherwise erosion of the mould may occur and result in a dirty casting.

Whenever sand holes are found in a casting, these are usually associated with a scab, but often no scab can be found. A likely cause of the trouble is sand washed in from the pouring basin. The sand of which the pouring basin is composed should receive as much care and treatment as the facing sand which lies against the pattern, but quite often this is not so, and any kind of sand is thought good enough for a pouring basin.

Fig. 6.—Condenser Door Casting Weighing 30 cwt.

In some cases the dirty areas are due to slag poured in with the metal. Many types of skimmer and strainer gates have been devised to minimise the amount of dirt entering the mould; these gates are designed to take advantage of the difference in specific gravity between the molten metal and the inclusions, or the cohesion which holds foreign material in contact with the sand of the mould. One of the best methods of ensuring the delivery of clean metal to the mould is to provide a good pouring basin. By pouring rapidly, a reservoir of metal is formed in the basin; the dirt being lighter than the metal, remains on top, while clean metal is fed into the gate or gates from the bottom. Actual sizes and shapes of pouring basins will be discussed when the methods of gating actual castings are considered.

One of the functions of a riser is to lead dirty or drossy metal from the casting. A riser placed at the highest point of a mould, such as on the edge of a flange or boss, facilitates the escape of dross from the mould. Dummy or blind risers are often used for this purpose on the top edges of castings, preventing the formation of gas pockets and ensuring clean edges by leading from the casting any dross which might collect at these points. Another method of eliminating dross and sluggish metal is to fix the outer orifice of the riser at a slightly lower level than the level of the metal in the pouring basin, and when the mould is full, pouring is continued until one or two cwts. of metal has been run off at the riser.

FIG. 7.—THE CASTING SHOWN IN FIG. 6. THE SECTION THICKNESS IS $\frac{9}{16}$ IN.

Misrun Castings

It is essential that the pouring gate or gates should be so arranged as to deliver metal to all parts of the mould at the same time. With work of thin section this is especially important. Its neglect may lead to a misrun casting or to the less obvious but equally fatal defect known as a "cold shut." It can be easily appreciated that a thin stream of metal having to traverse a large mould area will quickly become chilled. When two such streams meet there is always a possibility of complete fusion not taking place. It is therefore desirable to restrict the area of mould served by one gate, the area depending, of course, upon the thickness of metal. The volume

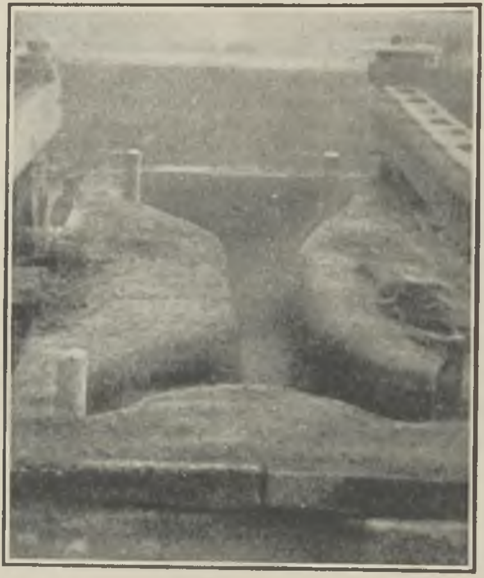


Fig. 8.—Pouring Basin for the Casting shown in Figs. 6 and 7.

of metal which a gate supplies to a casting depends upon its cross-sectional area and shape. A round gate will pass more metal than a rectangular one of similar area. The in-gate area is governed by such factors as the composition of the metal, the area of the mould surface and weight and section of the casting, but the gate area must be large enough to prevent misruns or cold shuts, but not so large that difficulty is encountered in keeping the head up in the pouring basin during the teeming of the mould.

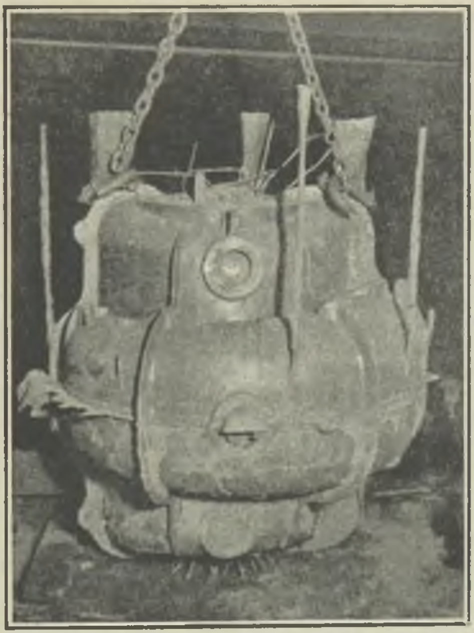


FIG. 9.—A 25-CWT. CENTRIFUGAL PUMP COVER.

When it is found necessary to increase the volume of metal entering the mould, this is best done by increasing the number of gates rather than increasing the area of the existing ones. This method reduces the danger of the greater flow of metal eroding the mould face.

While the foregoing are some general principles governing the satisfactory application of gates and risers, their actual design is also determined to a great extent by the design of the casting. A few typical examples of methods of gating actual castings will now be discussed.

Many tons of gunmetal are made into liners which vary in length from a few feet to over 30 feet, a large proportion of the liners made being used on propeller shafting, etc. These castings are machined all over, and have usually to pass a hydraulic test to ensure freedom from porosity. Liners are cast either in a horizontal or vertical position, the larger ones being made horizontally, the others vertically. The firm with which the author is associated cast liners up to 22 feet long in a vertical position, and Fig. 2 indicates the method of gating and pouring liners cast horizontally. Diagrams A and B are elevation and plan respectively of a liner with the gates attached. In this casting twelve runners were used with a riser at either end, the outer orifices of the risers were so placed that when the mould was filled, a few cwts. of metal could be run off. Diagram C is a plan view of the pouring basin and riser heads, while D is a section through X Y. By pouring the metal rapidly into the wide central section of the pouring basin a reservoir was quickly formed from which the twelve gates were supplied with clean metal. The heads made as shown at either end of the casting collected the metal which was run through. Fig. 3 shows a 30-foot long liner weighing over 6 tons, and twelve 1-inch diameter gates were used to run the job.

Fig. 4 illustrates the method of gating liners cast in a vertical position. Sketch (*a*) shows the top end of the liner in the casting position. A three-quarter circular connecting gate, B, joins the main down-gate, A, to four in-gates, C, while E is the feeding head. As a further safeguard towards obtaining a sound top end to the liner, an extra 3 or 4 in. was added, which tapered outwards to increase the mass and prolong the period of solidification towards the top; at the same time it collected any dross which formed on the surface of the metal as it rose in the mould. Sketch (*b*) is a section through the head box, illustrating the pouring basin and feeding riser. A cast-iron plug was used temporarily to close the down-gate until the basin was filled, after which the plug was withdrawn and the pouring regulated to keep the basin full; this ensured the delivery of clean metal to the mould. Rod feeding was applied to the riser to prolong the solidification of the connecting gate until the top of the casting had become solid. Fig. 5 illustrates the end of a vertically cast liner with the gates and feeding head attached.

Fig. 10.—A 10-ft. dia. Tube Plate Casting.

Two views of a condenser-door casting are shown in Figs. 6 and 7. This casting weighs 30 cwts., and the average thickness of section is $\frac{9}{16}$ in. Four $1\frac{1}{4}$-in. diameter down-gates run the casting from the bottom flange. Three risers were taken off the main branch flange and one riser from the smaller flange. Two dummy risers were fixed on the body of the casting at the junctions of the strengthening ribs. The pouring basin for the casting is shown in Fig. 8, the photograph having been taken before the gate pins had been withdrawn. As in the case of liners cast in horizontal position, the metal is poured rapidly into the basin to form a reservoir which supplies clean metal to the four down-gates.

A 25-cwt. centrifugal pump cover is shown in Fig. 9. Five $\frac{7}{8}$-in. dia. down-gates ran the casting at the joint of the mould. Two of these gates were broken off in stripping the casting, but their position on the casting can be seen. A similar type of pouring basin to that used for the condenser door casting was employed to supply the metal to the five down-gates. Three risers were fixed on the top edge of the flange and were rod fed.

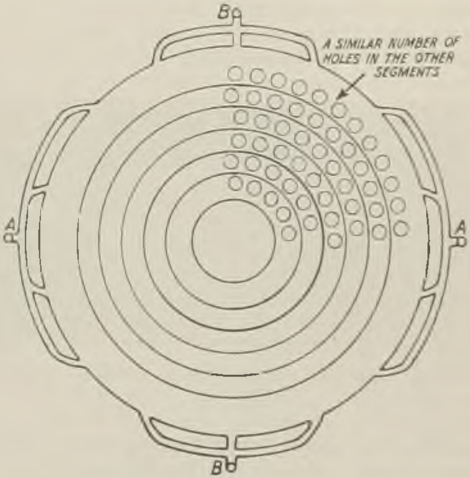


Fig. 11.—Method of Gating the Casting shown in Fig. 10.

A 10-ft. diameter tube plate with the gates attached is shown in Fig. 10. The method of gating, however, is better illustrated in Fig. 11.

Two down-gates A A, 2 in. diameter, were connected by a curved runner, 2 in. broad by $\frac{5}{8}$ in. thick, to four in-gates, whilst the two down-gates were supplied with metal from a common pouring basin 7 in. wide and 9 in. deep. B B are risers or flows connected to the casting by gates as shown. The outer orifices of these risers were 1 in. higher than the bottom of the pouring basin, and were connected to a trench in the floor. When the mould was filled, 2 or 3 cwts. of metal was flowed through, and run off at B B.

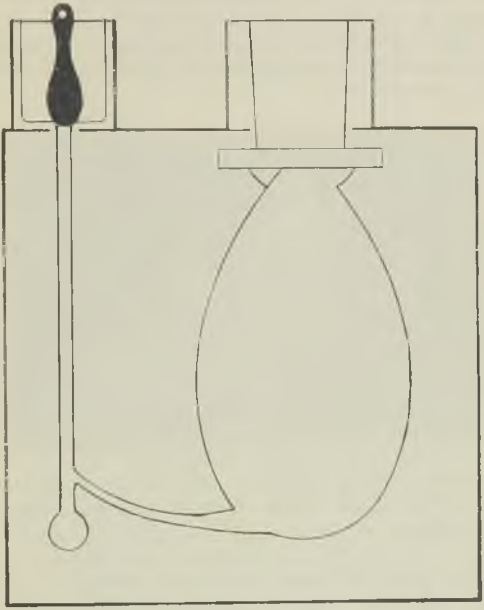


Fig. 12.—Method of Casting a Propeller Blade.

High-Tensile Brass

The high-tensile brass alloys, or, as they are more commonly called, the manganese bronzes, is a class of alloy extensively used in engineering. Castings varying in weight from a few ounces up to many tons are made in this type of alloy. The alloys are essentially high zinc brasses to which small additions of various other elements have been made. The chief metals used for these additions are manganese, aluminium, iron, tin and nickel. The composition of high-tensile brass is usually within the following limits:—Cu, 50 to 60; Sn, 0 to 1.5; Fe, trace to 2.0; Al, trace to 3.0; Mn, trace to 4.0; Ni, 0 to 3.0, and Zn, remainder.

Fig. 13.—A 15-ft. dia. Four-bladed Propeller after Removal from the Pit.

The successful manufacture of castings in this series of alloys requires great care and considerable experience. Although these alloys have a lower melting point than the bronzes already discussed, they are considerably more difficult to cast, the main obstacles to the production of sound castings being the great tendency of the molten metal to oxidise and form dross, coupled with a much greater shrinkage. Both of these characteristics necessitate close attention being paid to gating practice.

Great care has to be exercised in fixing the runner gates to overcome the tendency of the metal to oxidise and form dross. Splashing of the metal into the mould must be avoided and any gate which allows the metal to fall vertically to the bottom of the mould is useless. Bottom pouring, therefore, is essential, and the gate should lead the metal to the bottom of the mould, whence it can enter the mould cavity gently. The use of small gates which widen towards the casting facilitates the quiet entry of the metal, while the gradual widening of the gate as it nears the casting reducing the velocity of the metal. Whenever possible, the runner gates should be so located that the metal has a good flow before being interrupted by cores or protruding sections of the mould, the stream of metal being continuous and unbroken. Agitation of the metal in passing through the mould must be avoided, since this creates scum or dross that may lead to defects in the casting. When pouring, the down runner should be kept full of metal to exclude air.

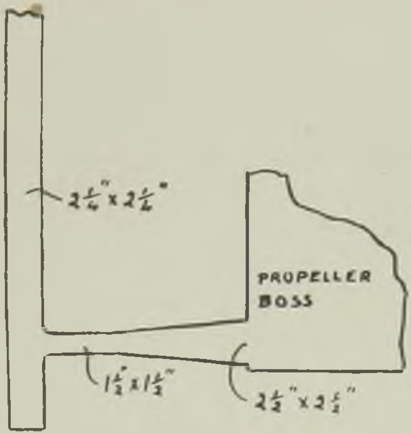


Fig. 14.—Details of one of the Down Gates and In-gates for a Propeller.

A dirt trap or sump made at the bottom of the down runner is advisable; this takes the first rush of the metal and traps the dross formed by the drop of the initial entry, at the same time helping to prevent splashing of the molten metal as the alloy enters the actual mould. It is advisable when pouring large castings to use a pouring basin of such a capacity as to hold at least one-quarter of the metal required for the casting. The basin should be used in conjunction with ball-plugs to close the runner or runners temporarily until the basin is filled. The advantages of this arrangement are, firstly, only clean metal enters the mould and, secondly, the down runners are kept full, giving uniform pouring with the minimum of turbulence.

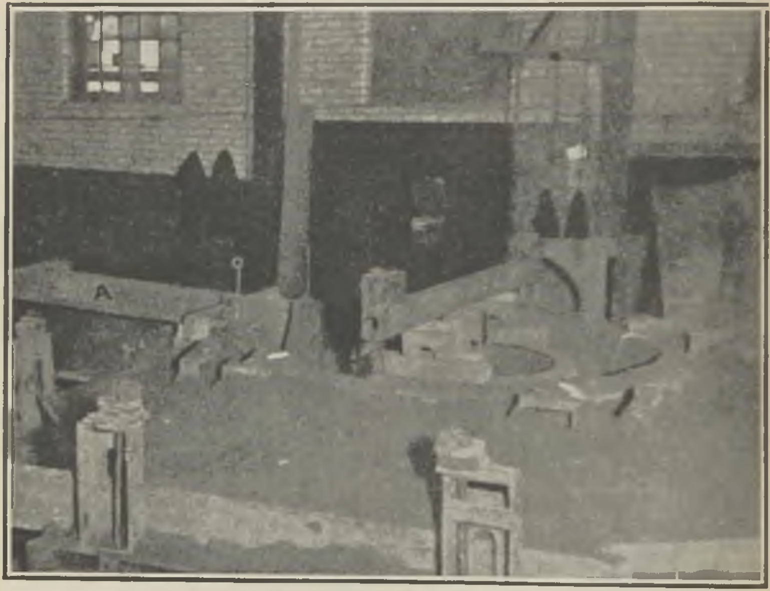


FIG. 15.—POURING BASIN FOR THE PROPELLER SHOWN IN FIG. 13.

To compensate for the large liquid shrinkage, proper feeding is important to avoid unsoundness. Large feeding heads or chills should be used over changing and thick sections. The use of chills, however, must be made with caution, since their application may only remove the shrinkage defect to some unexpected place. It is not advisable to use chills when it is possible for feeders to be effectively employed. It is false economy to reduce the number or size of feeding risers when working with this class of alloy. Whenever possible, moulding should be done in such a way that the heavy sections are placed in the upper part of the mould, these heavy sections being connected to a good feeding riser. The risers should be appreciably thicker

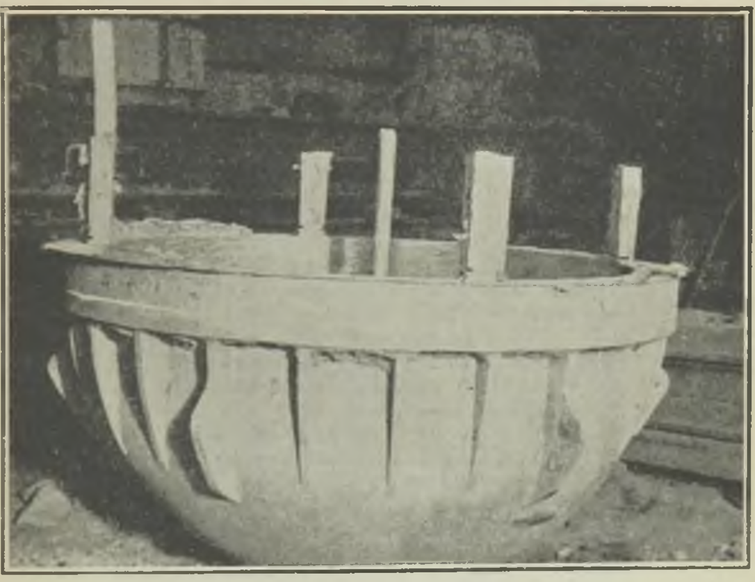


FIG. 16.—A HALF-SPHERE CASTING 5 FT. DIA. AND WEIGHING NEARLY 2 TONS.

at the top than the thickest section of the casting, to prevent the possibility of their premature setting before the casting is completely fed. In some large castings rod-feeding has to be resorted to, while periodically hot metal is added to the riser. For example, in large castings such as propellers of from 8 to 12 tons weight, the feeding heads should remain liquid for two hours or more after pouring.

The method of casting a propeller blade illustrates most of the points discussed, the procedure being shown in Fig. 12. The blade was cast upright and was run from the tip. A pouring basin of ample capacity was used and the down runner closed with a plug. When the basin was filled, the plug was withdrawn and the pouring regulated to keep the basin full. When the metal reached the level of the top of the runner, pouring was stopped. Sand was thrown on top of the end of the runner in the pouring basin, and a weight was then placed on top. The feeding head was then filled with hot metal from the ladle and rod feeding applied to keep the head open. The following are some figures relative to a blade which weighed 35 cwts. when dressed. The weight of the feeding head was 12 cwts., the diameter of the down-gate was 2 in., and for 8 in. the in-gate diameter was $1\frac{1}{4}$ in., then gradually opening out to the mould, where the dimensions were 4 in. by $1\frac{1}{4}$ in. This gating arrangement ensured the quiet entry of the molten metal into the mould.

Fig. 13 shows a 15-ft. diameter four-bladed propeller, immediately after lifting from the casting pit. The total weight of the casting, as cast, is over 10 tons, the feeding head alone weighing about 2 tons. The feeding head and three of the four runners can easily be seen. Fig. 14 gives details of one of the down-gates and in-gates. The pouring basin of this propeller is shown in Fig. 15. The arm, A, carried the molten metal to the four runners in the circular basin around the feeding head, and the runners were closed with plugs until the basin was filled.

Sufficient metal was poured into the casting to about three-quarter fill the feeding head. In the actual propeller illustrated the feeding head thus formed was rod-fed for nearly an hour, when 10 cwts. of hot feeding metal was added and the rod feeding continued for another hour.

A half-sphere casting with gate and risers attached is shown in Fig. 16. This casting is about 5 ft. in diameter, weighs nearly 2 tons, and, when bolted to another half-sphere of the same type to form a complete sphere, has to withstand an internal hydraulic pressure of 600 lbs. per sq. in. The casting was run from the bottom by a 2-in. diameter down-gate, which passed through the centre of the core, and was fed by increasing the thickness of the flange. Four risers are shown fixed to the feeding head proper; these were not intended for feeding purposes, but were used as a means of centring the core. Three of these risers were blocked up,

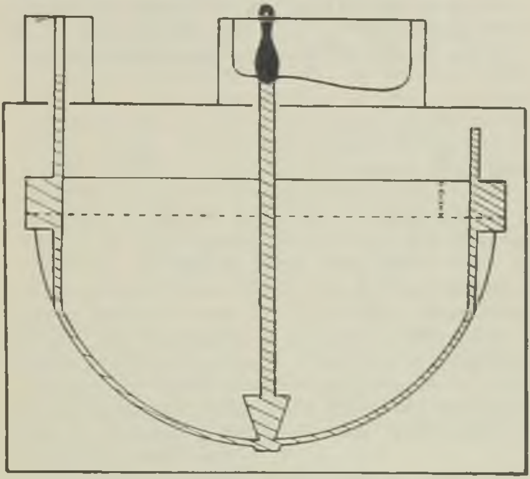


Fig. 17.—Section through the Mould of the Casting shown in Fig. 16.

while the fourth merely acted as a vent and indicated when the mould was filled. Fig. 17 is a section through the mould, illustrating the pouring basin employed; a plug was again used to close the down-gate until the basin was filled. It will be noted that the runner opens out into a cone prior to entering the actual mould, and this arrangement prevented a draw forming in the casting at its junction with the runner.

In conclusion, the author desires to express his thanks to the management of Steven & Struthers for permission to read this Paper, and to Mr. James Steven for his help and encouragement.

Scottish Branch

RUNNERS AND RISERS FOR GREY IRON CASTINGS

Paper No. 624

By J. LONGDEN (Member)

The runner arrangements for grey iron castings must be related to certain elementary and important principles. The runner basin, down-gate and any in-gates provided are part of a single system, which must be viewed as a whole. For work of importance, the runner basin should have a capacity of at least 400 cub. in. for each sq. in. of cross-sectional area of the down-gate, but even where this proviso is met, its effect can be negated by the faulty shape of the runner basin. Long, narrow and shallow basins, as depicted in Fig. 1, should be avoided, for dross gathers over the down-gate and is easily sucked into the casting. The type of basin shown in Fig. 2 is much more satisfactory, for the currents set up tend to bear dross away from the down-gate, besides which the greater depth of basin tends to ensure that only clean metal enters the down-gate. An undesirable form of basin is shown in Fig. 3, where the sloping front reduces the basin capacity and results in metal being flung out of the basin whilst the man pouring is struggling more or less ineffectively to keep the basin full.

For heavier work, where two or more down-gates enter one basin, the rectangular basin is to be preferred, with, if possible, a length of about one and a-half to twice the breadth, and a depth of at least one-third the length of the down-gate. The currents set up in such a basin are depicted in Fig. 4, and the dross is drawn away from the down-gates. For some classes of work, the shape of the basin must perforce be irregular, but the same general principles apply. Important work of more than a few hundredweights should have all down-gates ball-plugged. For smaller work, covering the gate with a perforated tin disc is satisfactory.

For small work, the tun-dish basin shown in Fig. 5 is often used, but is only suitable for hand-ladle castings, small down-gates making it possible to keep dirt out of the mould. With any but a small gate it is almost impossible to keep dirt out. The tun-dish types shown in Figs. 6 and 7 are better, but have little to commend them. This type of basin is particularly objectionable in crane-ladle work, where, owing to the size and shape of the basin, the stream of metal may be directed straight into the down-gate, as shown in Fig. 8, resulting in a severe cutting and straining action in the region of the in-gate. The down-gate in any basin should be kept to one side, so as to avoid this possibility. In a green-sand mould, the sand grains are bonded with moist clay, the mechanical strength of which is incapable of withstanding the direct impact of a stream of metal falling from any considerable height. This is less true of dry sand and loam, but is still significant.

Fundamental Factors

Factors influencing the speed and completeness with which molten grey iron fills a mould are:—(1) Its pouring temperature; (2) the velocity attained in descending the down-gate; (3) the degree of frictional resistance set up by the walls of the mould; and (4) the degree of freedom from change in the direction of travel. These factors must all be considered in relation to size and position of gates. A primary question is: How far will molten grey iron run? Briefly the answer is that it will continue to run from a higher to a lower level, to any distance from the point of entry, as long as it remains liquid. Having regard to attainable temperatures for cupola melted metal, and to radiation and conduction losses suffered by the metal as it travels in a mould, there is a limit in practice.

Grey cast iron, dependent upon its composition, ceases to be wholly liquid at temperatures ranging from 1,230 to 1,240 deg. C. At temperatures below this, particles begin to solidify, and the metal becomes rapidly more and more inert. The moulder recognises readily three ranges of temperature; dull, hot and "damned hot." The last condition is recognisable by the will-o'-the-wisp blaze on the clear surface of the metal, undoubtedly due to a flame burning the carbon to its oxide. A higher temperature still is indicated when a black smoke or fume rises from the metal. To the trained eye, the surface of cupola melted iron bears a useful indication of its temperature. From diffident estimations made by the writer with an optical pyrometer, it is suggested that when the "blaze" becomes intermittent, slowly giving place to the characteristic surface "break," the temperature has fallen to about 1,350 deg. C. This temperature, affording over 100 deg. C. superheat, gives a useful datum line for visual judgment of the suitability of iron temperatures for given jobs, and is probably the best temperature at which to pour castings having to withstand pressure tests.

Lower temperatures, except where general section thicknesses are heavy, lead to trouble. Very light castings, such as the guard casting shown in Fig. 9, are best cast with the "blaze" still on.

Running a Guard Casting

The guard casting affords an illustration of the necessity of placing gates to obtain quick distribution of the metal throughout the mould and in such a manner as to avoid distortion of the casting. Its area is considerable, having regard to its general thickness, which is ¼ in. In filling the mould, the streams of liquid metal are subject to frictional hindrance above and below. Therefore, the gates must be well distributed, so that the stream of metal from any one gate has not far to go before it joins with the others. This casting can be cast quite well with a spray runner along the straight edge of the casting, supplemented by two groups of drop-gates at the rear, as seen in the sketch. Unfortunately, the spray runner bends the straight edge, since this is made the hottest part

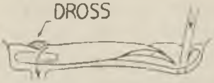


FIG 1

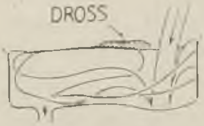


FIG. 2

FIG. 3

FIG. 8

FIG. 5

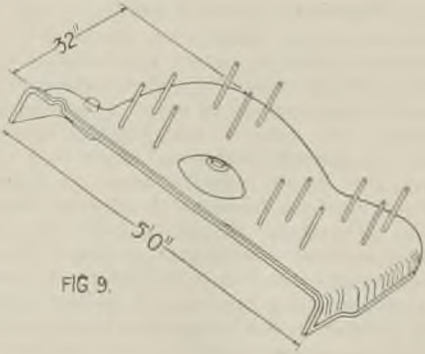


FIG 9.

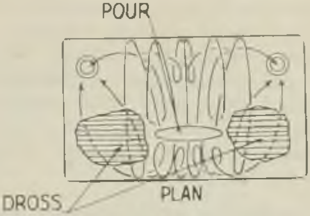


FIG. 4

FIG. 6.

FIG. 7.

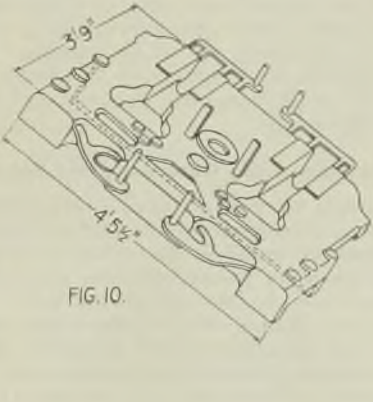


FIG. 10.

of the casting. In any casting, the heavier parts, or, alternatively, the hotter parts, cool last. This means that they contract last. If the last part to contract is tied to a body of metal which cannot contract with it, it must bend or break the casting. This is demonstrated in the phenomenon of camber, the breaking of pulley arms, etc. The casting shown in Fig. 9 comes out quite straight if poured through four groups of three ½ in. dia. drop gates, as shown in the sketch.

In making light castings, much use is made of the drop gate, which is often wedge-shaped, narrow and long where it joins the casting. The joint spray is also much used for heavier as well as light castings, and often affords the best means of ensuring satisfactory distribution and avoiding local " hot spots." It must, however, be used with care. Usually, a down-gate from the runner basin is placed over a long or short channel cut in the joint, from which the sprays are cut, of convenient size and spacing. If the channel is long and deep, as is necessary in the case of larger castings, with fairly strong sprays or in-gates, there is sometimes danger of breaking the casting. If the actual casting in the region of the runner cools last, no harm will be done, but if the runner channel cools last, it may tear a piece or pieces out of the casting. This can be obviated by breaking up the spray into one or more disconnected sections, fed from separate down-gates.

Combination Drop Gate and Joint Spray

An example of the use of a combination of drop gate and joint spray is shown in Fig. 10. The general thickness of this casting is ⅜ in. The down-gates are grouped into one long runner basin across the middle of the top part. The common pipe, cast on the flat, offers some variation in the arrangement of runners. Short lengths of small diameter may be cast quite well with runners as shown at A or B, Fig. 11.

Pipe and Cylinder Castings

Runners at one end of a 4-ft. pipe, as at A, Fig. 12, are usually sufficient. For longer ones up to 8 ft., similar runners at each end are satisfactory. For still longer lengths, these runners are supplemented by drop runners on the body, as at B, Fig. 12, or by suitable sprays on the joint, as at A, Fig. 13. Large-diameter pipes offer more difficulty. The types of runner detailed above are sometimes used for large pipes, but have little to commend them. The best runner for a large-diameter pipe is as shown at B, Fig. 13. Here the metal has a free, uninterrupted sweep up the body of the pipe, making for reasonable freedom from faults.

Whilst such a runner is quite satisfactory on a pipe or similar casting, it would be quite unsuitable on the bore, say, of a piston or slide valve cylinder cast on the flat. There must be few castings, whether made in green sand, dry sand or loam, in which small or large portions of the mould surface are not detached owing to the scouring action of inrushing metal. These pieces, sometimes only particles, aggregate usually at places not far from the in-gate, and gas bubbles, caused by turbulence, accumulate there. Such patches on the bore of a cylinder would make it defective. For castings of this type, in-gates must be at convenient places where either any small defects are not so damaging, or dross can be conducted into a convenient head. Fig. 14, showing a simple slide-valve cylinder, illustrates this point. The in-gate A, running into the flange of the steam chest at the joint line, has the advantage of being well away from the bore, but is not good. A runner of this type makes for excessive turbulence in the region of the in-gate, which induces scabbing of the mould and a frothy condition of the metal. The in-gate at B is much better, giving a free run for the metal to the end of the flange, with less turbulence. The small dross-head C, directly above the point of entry, will take care of any dross which may gather, and is easily cut away. The fountain gate at D is better still, as the metal, welling up from below, is less scouring. Cylinders of this type, up to a bore of 18 in., have been made successfully in large numbers in green-sand moulds, the larger ones being skin dried.

Heavy Cylinder Practice

Large numbers of heavy cylinders, made in dry sand, have been cast successfully horizontally. Fig. 15 shows one end flange of a piston valve cylinder, with down-gate and in-gate, together with a form of trap runner. The metal falls down the gate D into chamber A, from there passing into down-gate B. Where B leaves A, however, it is restricted by the introduction of a slot core at C, which reduces the cross-sectional area of the down-gate B at this point to some 75 per cent. of that of down-gate D. The metal therefore rides a little in chamber A, where dross tends to be held.

Large cylinders are usually cast on end, with, if possible, a suitable head above the bore. The best runner system is a combination of drop and bottom running, and this is shown in Fig. 16. The in-gate on the bottom joint is placed so that the metal enters the mould tangentially, or it may be sprayed under the steam chest. Only one down-gate, with in-gate, is shown in the sketch, but very large cylinders may need two or more, together with gates providing entry into the flange of the steam chest, or other convenient point of entry, about half-way up the mould. Further, where possible, the down-gates to the bottom should be stepped, to reduce the velocity attained by the metal on its entry into the mould.

Fig. 16 shows, at the top, a plan of the runner basin. The down-gate A is deflected at the top, thereafter passing down to the bottom joint. This runner is ball-plugged at the basin entrance and at B is a shutter which can be lifted at will. The basin is continued behind the shutter and contains the drop runners, which are also plugged. In pouring, the basin is filled and the down-gate A plug is drawn. When the bottom of the mould is estimated to contain some six to nine inches of metal, shutter B is lifted out and, when the whole basin is again full, the plugs on the drop gates are lifted out. Pouring is then completed. The drop runners are spaced some eight or nine inches apart, all round the bore, except in the region of the ports, no runner being nearer a port than nine inches. The shutter is advantageous, for without it there is a danger that a trickle of metal will find its way under the plugs of the drop gates, and will not drop straight down, but creep down the walls of the gate and mould, becoming a streak of solid metal on the core or mould wall, which may or may not be remelted. In any case it is oxidised and a source of danger.

Liners which have a nest or nests of ports are usually cast similarly. The first metal passes down from the basin through a runner along the joint to an in-gate at the bottom of the mould. When the metal reaches the neighbourhood of the ports, drop runners from the top are opened and pouring is completed. Liners without ports are best run with drop runners from the top.

Any truly cylindrical grey iron casting, having to be machined and pressure-tested, is most likely to be sound if cast on end, with suitable provision of dross or feeder head. This gives the simplest form of runner, *i.e.*, the straight drop from the top. Runners of this type, the cross-section of which is rectangular, should be located, and so arranged that the streams of metal fall clear of mould or core surface. This is difficult in practice unless the metal section be thick, and it is necessary that the mould be set up for pouring with the aid of a plumb-line to ensure that it is quite vertical. Obviously, the longer the mould is, then the less likely is it that the falling metal will not hit core or mould surface somewhere before reaching the bottom.

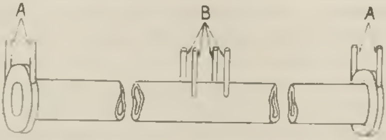


FIG. 12.

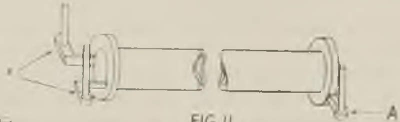


FIG. 11.

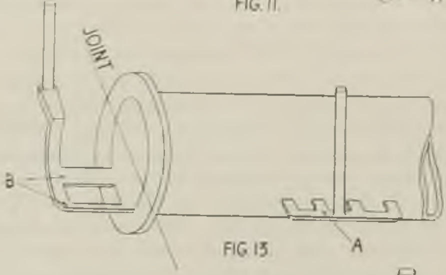


FIG 13.

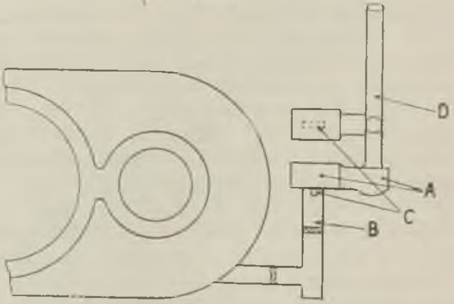
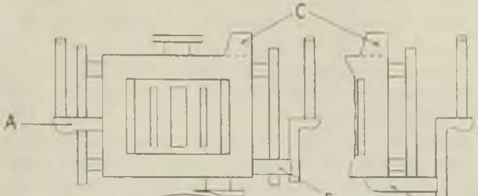


FIG. 15.

FIG. 14.


C
A
B
D

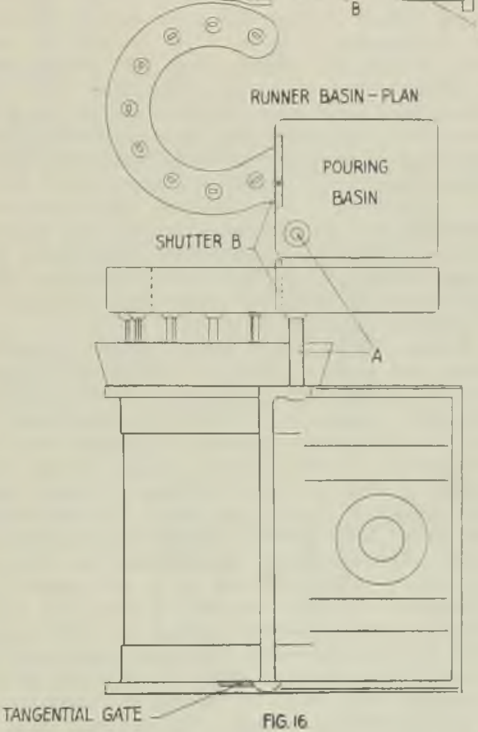

RUNNER BASIN – PLAN
POURING
BASIN
SHUTTER B
A
TANGENTIAL GATE

FIG. 16

Roller Castings

Fig. 17 shows the arrangement of runners and basin for a 36-in. dia. roller, 10 ft. long. The drop runners are sixteen in number, each $1\frac{1}{8}$ in. by $\frac{5}{16}$ in. in cross-section. It is not intended here to over-emphasise the relative value of the rectangular drop runner as compared with the round one in such a case. If a runner basin be made up having two gates, one rectangular and one round, of the same cross-sectional area, and if the basin be set up in such a way that the metal falling through the gates can be observed for a distance of 3 or 4 ft., it will be seen that, whilst the metal from the round gate keeps its cylindrical shape, the metal from the rectangular gate keeps the form set by the gate for only a few inches and then gradually draws together, so that, some 15 in. below the gate, both columns of metal are apparently alike, *i.e.*, cylindrical Nevertheless, the temporary flattening of the downward stream will usually enable the metal stream to drop safely below top flange fillets and the like before broadening out. The narrow, rectangular runner may also be said to exercise a modified strainer effect.

Rollers, liners, rams, pans, straight hydraulic pipes and similar types of castings are usually cast on end with drop runners. In this method the heavy impact with which the first metal to fall is detrimental strikes the bottom face of the mould. In the case of a roller, of the type shown in Fig. 17, with a flanged bottom face, the impact is severe, but, after the first blow, the metal itself forms a cushion to take the impact. The conditions are different in the case of, say, a hydraulic ram or a pan where, as illustrated in Figs. 18 and 19, the first metal drops on the spherical surface at the bottom and continues to batter the same spots until the base of the mould is full. In the case of the hydraulic ram (Fig. 18) plenty of runners with a correspondingly small cross-sectional area so as to reduce the severity of the impact at any one spot must be provided, and the bottom must be made in special materials to resist the attack.

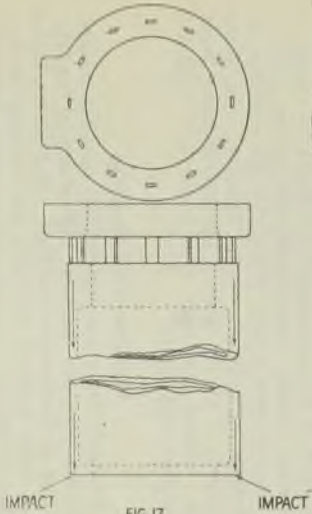


FIG. 17.

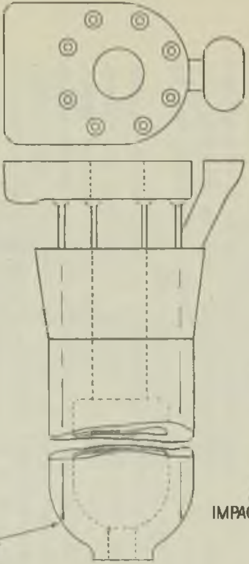


FIG. 18.

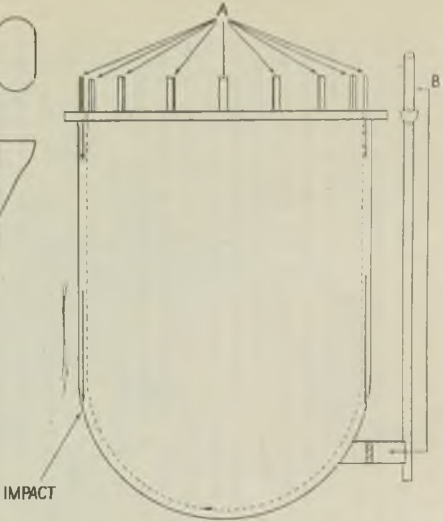


FIG. 19.

Running Pan Castings

In the case of pans, up to 5 cwts. of the type shown in Fig. 19, where the mould material is suitable, they can be cast quite well through a single runner going down through the centre of the core into the bottom of the mould. Larger pans, up to 25 cwts., can be cast with three, four or five drop gates. Larger pans are better with similar runners spaced all round, as shown at A. Where such pans are very heavy and deep, the danger of fracturing the mould surface by drop runners is serious, and an alternative is sometimes used in the form of the bottom gate shown at B, supplemented by drop runners from the top. A scabbed mould makes the bottom of the pan unsatisfactory for its work, but this bottom runner is not without its danger, for the stream of metal impinges directly on the rounded bottom surface of the core. In the case of very heavy pans, the mould is sometimes cast the reverse way up. Bottom runners are then sprayed into the flange, supplemented by sprays at a joint nearer the top.

A further consideration is that, when molten iron falls from a height, it splashes on impact with the bottom, forming oxide-covered spots. Consequently it would be foolish to run the steam cylinder shown in Fig. 16 with drop gates only. Some oxidised particles, reacting with carbon in the molten stream around it, would be swept or splashed round underneath the ports, and a defective bore would result. With castings of straight cylindrical form, however, the drop runners, if evenly spaced, effectively bring from the bottom up into the head any oxidised particles and dross.

Machine Tool Castings

Probably the plain, cylindrical casting, poured on end, presents the least difficulties in running of any of the heavier castings. Bed plates, lathe and other machine tool beds and castings having large horizontal surfaces offer more difficulty. Bottom running is always resorted to, supple-

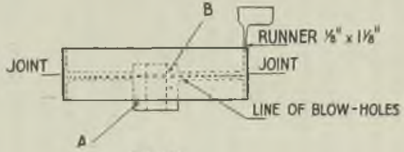

B
RUNNER ⅛" x 1⅛"
JOINT
JOINT
LINE OF BLOW-HOLES
A

FIG. 20

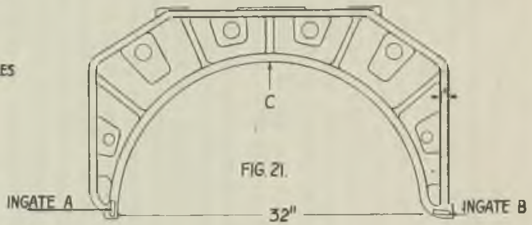

C
INGATE A
INGATE B
32"

FIG. 21.

mented by in-gates at higher levels where the depth of the mould is considerable. The question again arises: How far should molten grey iron be expected to run from any one set of gates? In practice one sets a limit; for any given degree of casting temperature and composition a thicker stream of metal will travel farther than one of thin section, owing to the reduced frictional hindrance. No difficulty is found in running from one end castings 14 ft. long, of a construction similar to that shown in Fig. 21, having a metal thickness of $\frac{3}{4}$ in. with iron low in Si and P. These are, however, inclined from the runner for pouring, and one would hesitate to cast them from one end on the flat.

Recently the author was privileged to see some very fine machine tool beds at Craven Bros. (Manchester), Limited, including one 35 ft. long, weighing about 27 tons. This was cast through two sets of in-gates, one set at each end comprising four in-gates, each 5 in. by $1\frac{1}{8}$ in., placed at the shear faces. The streams of metal from each end must travel 17 ft. 6 in. before meeting. If perfect coalescence is to be obtained the two streams on meeting must be wholly liquid. This coalescence takes place on the shear faces, which are heavy. When these are full, however, the metal must climb through relatively thin sections and must have sufficient superheat to enable it to do so. A bed 41 ft. long was cast by the same firm, but the end runners were supplemented by additional gates at about half-way along its length. These were opened when the mould was half full, to liven up the metal at that spot. In this case, therefore, the metal from each end bottom runner had to travel $20\frac{1}{2}$ ft. before meeting the opposite stream. This distance probably represents the limit of distance a stream of molten grey iron should be expected to travel in a mould.

Where large quantities of metal pass through a gate, the region of the mould in its vicinity becomes very hot. Consequently, in such areas, difficulties may arise in respect of open grain or burning on of chills, if used. Further, when molten iron runs any considerable distance, the advancing spear-head of the metal must become oxidised a little, collecting, as it runs, small particles from the surface of the mould. That spear-head, therefore, may form a spongy spot at the far end, or where two streams meet, such spot being disclosed later under hydraulic or steam test. In the case of the casting 14 ft. long run from one end, referred to above, provision is made for the first 14 lbs. or so of metal to be run off through a channel into a chamber head.

A Pulley Casting

Attention is now directed to the 16-in. dia. pulley shown in Fig. 20. Many thousands of these have been made by machine, jointed and gated as shown, with abnormally small scrap losses. A number of castings were returned from the machine shop, however, after the rims had been turned, showing a remarkable series of blow-holes just below the joint, as shown in the illustration. This was puzzling, but investigation showed that the moulder, for the first time, had cast them with the deeper boss, A, down. The order was reversed and trouble ceased. It is worth while to consider this example. The pulley is normally cast with the shallow boss, B, down. In pouring, the mould fills slowly till the level of the arms is reached, when metal runs along them into the boss. The steady rise in the rim comes to a halt whilst the bottom boss fills and thereafter the rise is slower whilst the arms and boss continue to fill. The halt in the rise of the level of metal is longer with the deep boss down than with the shallow. The metal slightly oxidises around the outer edge of the rim, and when the metal again begins to rise, it fails to lift a minute rim of oxide, which, when the molten metal rises above it, reacts with carbon, leaving entrapped bubbles of carbon monoxide.

A similar instance is the 3¼-ton casting, a cross-section of which is shown in Fig. 21. It is a 10 ft. long steam chest, the semi-circular undersurface of which is machined and polished. The core is much intersected by strong longitudinal and lateral webs. The mould is inclined, for pouring, from the runners, which are at one end in the positions A and B shown in the sketch. A large number of these castings have been made without any trouble, but one, after polishing, showed a fine hair line, about 4 in. long, on the surface at point C, at the end opposite the runners. There was no leak under water or steam test, but examination with a high-powered glass showed the line more clearly. It was not a crack, but apparently a line of oxide, and the presence was disclosed, at intervals, of a number of minute blow-holes, invisible to the naked eye.

This case was diagnosed as being in line with that of the pulley discussed above. When pouring begins, the lower parts of the mould fill rapidly, but, when the heavier parts of the casting are reached, the general rise is slower, and may momentarily be stationary. The two streams rise and meet at C. If that moment should coincide with a rapid drain of metal to fill up brackets at that level, what might be called the lips of the converging streams may hesitate in that position. Hesitating and oxidising, they fail to coalesce properly at the lips for a depth of, say, $\frac{1}{4}$ in.. but the oncoming metal rides over the top. This occurrence is explained by the gas-producing reaction which takes place. These castings are usually poured in 70 secs. through two in-gates, each $2\frac{1}{2}$ in. by $\frac{3}{4}$ in. The casting under discussion took 78 secs., owing to the fact that the in-gates had been unwarrantably constricted in moulding.

This indicates that there are natural limits to the slowness in pouring methods. Attempts have been made to rationalise this question by the production of formulæ relating time taken to pour to the weight of metal being poured. Such formulæ, however, can have no general utility, as they can only be applied in particular circumstances. As a rule, large horizontal surfaces should be covered as quickly as possible, though the design of castings frequently makes it difficult to determine suitable points of entry. With vertically cast moulds and small or lumpy castings greater freedom is possible.

Slow Pouring Conditions

Very slow pouring, in a few cases, is advantageous. The small gear blank shown in Fig. 23 is repeatedly cast cleanly and solidly through the pencil gate shown. This casting weighs 42 lbs. and takes 37 secs. to pour. A comparison of this with the pouring time of the casting shown in Fig. 17 shows the difficulty of stating any rule. One casting is 173 times heavier than the other, but only takes twice as long to pour. The blank illustrated in Fig. 24 is equally good if cast through a disc-edge runner, though the pencil runner fails. Slow pouring, with a view to avoiding draw or porosity, is usually only successful if the metal is poured at a temperature which barely enables the mould to be filled.

In some cases it is advantageous to make runners comparable with those used in non-ferrous practice. In Fig. 28 is shown the runner arrangement for a small air valve, while a section of the casting is shown in Fig. 29. An awkward conjunction of body and bosses near the flange makes it ordinarily very difficult to get solidity for the valve seatings and tapped holes, but gating as shown in the sketch gives invariable freedom from rejections.

In-gates

In-gates should be truly in line with the casting sections entered, whether vertical or flat, so that the liquid metal does not impinge directly on the mould or core surface at the point of entry. Where the in-gate enters at a circular flange, its entry should be tangential. Observance of these rules will eliminate many scabs and reduce turbulence, which makes for unsoundness. Fig. 22 shows the runner arrange-

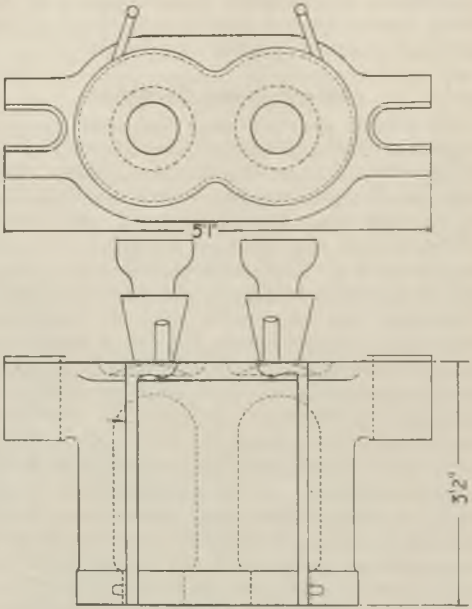


FIG 22.

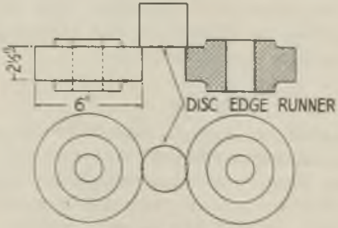


FIG 24.

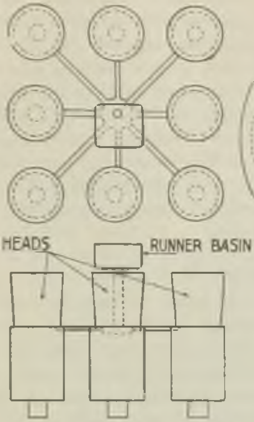


FIG.25.

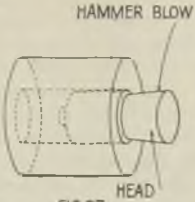


FIG.27.

FIG.26.

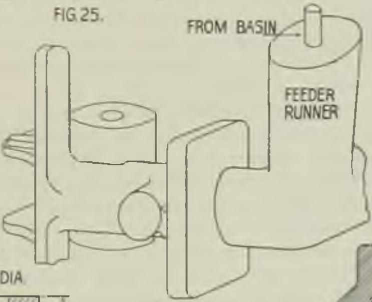


FIG.28.

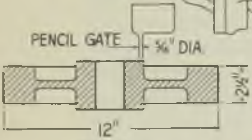


FIG. 23

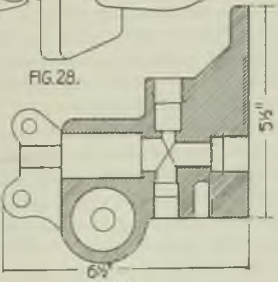


FIG.29.

ment for a double hydraulic cylinder weighing about 2¾ tons. It may be noted that the chief advantage of a tangential runner does not lie in its tendency to give the metal a revolving motion, for that is lost a few inches above the runner where it is running round a core, but in the fact that this type of runner has less tendency to cut the core surface and makes for better distribution. Where there is no centre core, the tangential runner will bring the dross to the centre, in position for entering the head should one be provided.

Functions of a Riser

Every casting must have a runner, but not every grey iron casting needs a riser, and the great majority of small grey iron castings made have no risers. Castings with pencil gates have no risers. The guard casting shown in Fig. 9 has none. Many castings are definitely better without a riser; but, nevertheless, the riser has important functions in grey iron.

It is, however, a convenience to know definitely when a large mould is filled, and in a mould of any considerable size which is cored, one or more risers should be provided in order to give an outlet for gas bubbles which may accumulate. Such risers should be in the regions at which bubbling may be suspected, and on the highest parts of the mould. When the top of a core or upstanding part of a mould is covered by molten metal, gas pressure inside the core or mould part may rise very quickly, and until the head of metal above the core is sufficient to counterbalance the gas pressure inside the core, gas will bubble through the rising metal. If the gas pressure inside a core rises too sharply (as is the case with an insufficiently dried or badly vented core) the metal may be blown out of the mould, gently or explosively. If a core continues to "blow" when a head of 12 in. metal is above it, it is clear that the gas pressure inside the core is more than 3 lbs. per sq. in. Whilst a mould is filling, therefore, some part or parts of it may be bubbling, and the metal stream, passing on and upward, may carry such bubbles safely away through the riser or risers. Many difficult cored jobs have been saved by the simple expedient of raising the height of the runner and riser heads a few inches, thus providing the necessary head pressure to force the gases in cores through the vents.

The bubbles referred to above are not in quite the same position as the air which is in the mould when pouring begins. The incoming metal readily displaces the contained air owing to its higher gravity. This air escapes easily through the pores of a green-sand mould, though perhaps not so readily through the blacking skin of a dry-sand or loam mould. The last two types are, however, all more or less cracked owing to varying expansions, when drying, of mould and mould materials, and subsequent cooling during assembly of the moulds does not close the cracks. These, together with the natural porosity of the sand, usually provide ample exit channels for the air with which the mould is filled before pouring.

Whistlers

The "whistler" is sometimes used to facilitate the escape of contained air from a mould during pouring, so as to reduce the resistance offered to the advancing metal in thin, upstanding or isolated sections in the top part. Its value is doubtful, for a small accumulation of gas is often found at its base and it has some of the disadvantages of the open riser. When a mould is filling, the contained air rises in temperature and, if it cannot by sufficiently quick exit find room for expansion, its pressure rises. At the same time, gas pressure and volume inside cores and upstanding parts of the mould is rising. If the gas pressure in the mould cavity is greater than that in the cores the gas of the latter will pass out through the vents. If it is less, some of the gas generated in the mould or cores will pass into the mould cavity, and find exit through a riser or whistler. This phenomenon has destroyed the usefulness of many otherwise good moulds. In green-sand moulds particularly, a rush of gas through open risers breaks away the mould surface in their vicinity, whilst the loss of pressure in the mould cavity may induce a pulling down of parts of the top, where large surfaces are concerned. In practice, therefore, risers are kept closed on all but the lighter castings. The lift of the ball, core or brick on the riser indicates that the mould is full.

It is sometimes urged that a riser helps to rid a casting of dirt as well as bubbles, but this is an illusion. Dirt usually remains firmly fixed to the first upper surface with which it makes contact, and no amount of "running through" will dislodge it. The writer has not yet found a single instance in which a riser, as distinct from a head, has removed dirt from a mould.

It often happens that the top part of a mould has a number of protuberances in the shape of bosses, lugs, brackets or flanges, and it becomes impracticable to put risers on all of them, and it is often useless and inadvisable to do so for they are better without. In such cases the dummy riser is sometimes resorted to, but its usefulness is very doubtful. It is not uncommon to find a bubble of gas at the base of such a riser and in the actual casting. The writer has not yet seen a dummy which contained dirt or a bubble, except at its base, where it has failed. A riser also reduces the pressure on the mould; this may or may not be advantageous. Certainly the riser can only reduce the pressure in the mould if its level is lower than that of the head of the runner basin.

An important use of the riser is for the purpose of feeding. In many cases an approximation to non-ferrous and steel practice obtains, *i.e.*, a heavy feeder head is provided which feeds naturally. Examples are shown in Figs. 16, 17, 18, 19 and 22, and every foundryman is acquainted with similar examples. In the case of the double hydraulic cylinder shown in Fig. 22, a feeder head is provided over each cylinder, and the risers are also rod fed. The practice of natural feeding can sometimes be extended with advantage to small castings. Consider the small air-cylinder piston shown in Fig. 26, which, as cast, has the form shown in Fig. 25. These have been made in thousands without a single rejection on the following lines. They are made eight in a box, and the centre runner feeds a single spray to each casting, each having a riser or head as shown. Pouring is continued until the heads are full. When cold, each in turn is slipped into a heavy cast-iron sleeve, leaving the head projecting, as shown in Fig. 27. The heads are broken off with a forehammer, and the castings are then thrown into the rumbler, after which they are turned, bored, tapped and screwed without disclosing any defect.

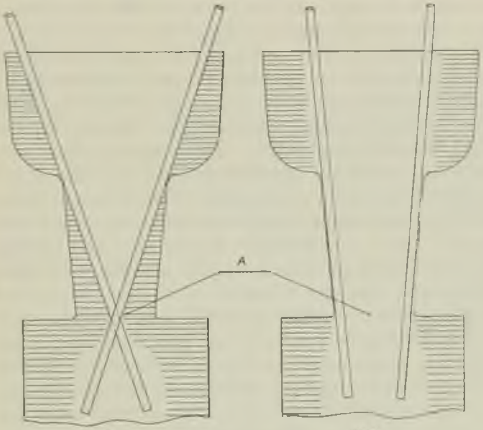


FIG. 30 FIG. 5

Rod-Feeding

Risers for rod feeding often give disappointing results, because they are made too small. A 7-in. cube cannot be fed through a 1-in. dia. riser. Such a case would require a 2½-in. dia. riser at least, but, given a riser of the right proportions, the feeding can be nugatory. It is sometimes suggested that rod feeding simply consists in keeping open the riser so that liquid metal may drain into the cavities forming below. This is quite true of the earlier stages of the feeding, but the really crucial stage in feeding is when the metal in the riser and adjacent casting has entered the pasty range between liquidus and solidus. Feeding is at all times hard and exhausting work, particularly on heavy jobs, and calls for a high degree of conscientiousness on the part of the man feeding. When the pasty range is reached, he is strongly tempted to "feed it up," but this usually results in a premature withdrawal of the rod by an inch or more at a time. Very soon he finds himself feeding the riser only, the metal below being solid. The casting, however, which the rod has not fed is still liquid, and a hole is left underneath the riser. The feeder, at the commencement, should dip his rod, usually, not more than three or four inches into the casting and keep it pumping at that depth, not coming higher until he has solid metal below his rod; then he may withdraw it as the solid grows below. If this practice is not followed, gaps may be formed when the metal is in the pasty range, which are bridged over.

Another difficulty arises from the way the rod is used. The man feeding may realise that the hole must be kept as big as possible, and consequently works his rod round as shown in Fig. 30. The head remains quite open at the top for a time, but soon, at the point A where the riser joins the casting, he is trying to feed through a hole little bigger than his rod. In a case like this, fresh supplies of hot metal are of little avail. The right method is shown in Fig. 31, the rod being carefully worked down the sides of the hole all round. Only thus can the job be fed solid.

Newcastle Branch

FURTHER DEVELOPMENTS WITH COAL-DUST IN MOULDING SANDS

Paper No. 625

By B. HIRD (Member)

Introduction

Since the first investigations into the action of coal-dust in mouldings sands, eight years ago, the author has from time to time made further experiments and practical tests with this material. Other investigators, notably Hudson and Winterton, have also made valuable contributions to the subject. The full value of coal-dust additions to moulding sand has not yet been thoroughly realised, and there is scope for further investigation and practical application of this material in the foundry.

The first Paper† by the author dealt with the action of coal-dust on the skin of grey iron castings, and gave a few tentative remarks on the appearance of the sand after the casting was removed from the mould. The further developments to be outlined deal mainly with its effect on the properties of the moulding sand.

Dealing first with the action of coal-dust in preventing the formation of scabs on the face of castings the three most common are the "solid scab," the "blind" or "sand buckle scab," and the "scour or runner scab."

The Solid Scab

The solid scab is formed when a portion of the sand from the mould face lifts, or buckles, either as soon as the molten metal covers it, or immediately before the metal reaches it, due to the radiation of heat from the metal. In this case the sand floats on the rising metal, and is deposited on the sides or top of the mould and forms shallow holes in the casting. The cause may be one of many: a patch of weak sand; a wet spot; a hard spot; ramming too near the pattern; faulty patching; neglected or poor venting or badly mixed or unsuitable sand.

Blind or Sand Buckle Scab

The blind or sand buckle scab is very closely related to the solid scab, but occurs at a slightly later period, during the filling of the mould, instead of being washed away by the flow of the metal, it is now held in its place. Imagine the temperature of the sand forming the face of the mould suddenly raised to a temperature of 800 or 900 deg. C. for a depth of about $\frac{1}{32}$ of an in. This high temperature causes the grains of sand to expand, and when certain conditions prevail, patches of sand buckle up into the molten metal. A very thin skin, which will then have formed on the metal, prevents this sand from floating away, but is not strong enough to resist the force of the pressure, causing the buckle, which presses inwards in the form of an angle, the apex of which cracks. and allows metal to bleed into the cavity formed through the crack as shown diagrammatically in Fig. 1.

Scour or Runner Scab

Scour or runner scabs usually form at or near the place where the metal from the runner. entering the mould, strikes the mould face, or core. It is of the solid type and is due to the breaking down of the bond of the sand grains, by the cutting action of the falling metal. Once the surface grains give way they crumble rapidly until sufficient depth of metal has formed to protect them.

For many years foundrymen have known that the addition of coal-dust to facing sand helps to prevent the formation of these scabs, but the reason is not well known. Investigations have led to the following conclusions:—The intense heat from the molten metal as it fills the mould first gasifies the particles of coal that are mixed in the sand forming the mould face, but the coal-dust immediately behind the mould face, being out of direct contact with the molten metal, partially metamorphoses into a tar containing gases. As these gases escape, due to rapidly increasing heat, they swell the small particles of tar, and push them into the pore spaces, and around the sand grains. This bonds the grains together much in the same way that flints covered with tar bond together in asphalt or tarmac roads. This action forms what is best termed a "hot bond" for the grains of sand, effectively preventing them from slipping or buckling. As the temperature increases, this tar cokes, and the sand grains are now held with a very strong bond.

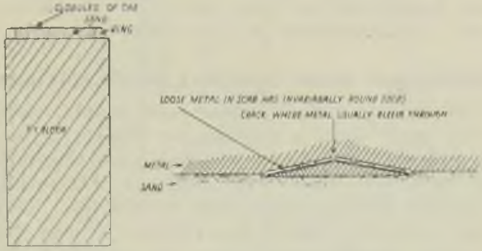


FIG. 1 (RIGHT).—SECTION OF BLIND SCAB SHOWING ANGLE WHICH PROVES EXPANSION OF SAND, AND FIG. 2 (LEFT), SECTION OF CAST-IRON BLOCK AND RING CONTAINING SAND.

Improved Green Bond Strength

The author has made a considerable number of experiments definitely proving that coal-dust additions to moulding sand creates green bond strength, and a practical application over a long period has confirmed the experiments. These latter were carried out on two continuous casting tracks, making railway chairs. Incorporated in the tracks was a continuous sand mixing plant which operated as follows:—After the castings were removed from the moulding boxes the hot sand was knocked out over a grating, and fell on to a belt conveyor. It was then elevated into a " Ketting " mill. While the sand was in the outer mixing ring 2½ per cent. of fine coal-dust was added, and 6 per cent. of water, and when mixed it was passed into the centre, and milled for three minutes. From the mill it passed through a disintegrator and was then conveyed by overhead belts to the moulding machines. For over two years no new sand was added, only the 2½ per cent. of coal-dust. Periodically, when the sand got too strong, burnt old sand was added to bring down the strength to the standard which was kept at 14 to 16 lbs. total load on a 2-in. by 2-in. A.F.A. sample, or 4½ to 5 lbs. per sq. in.

Summary of Some Coal-Dust Bond Experiments

For the purpose of these experiments, moulds were made from a rectangular block, 12 in. by 8 in. by 2⅛ in. thick. Enough sand was mixed to make one mould, with sufficient over to allow for loss during subsequent re-mixings. After each cast, the mould was allowed to cool down to room temperature, before the casting was removed. Tests with both " hand mixed " and " milled " sands were made. The hand mixed sands were turned with a shovel, and then put through a ⅛-in. sieve twice, to ensure thorough mixing. In the milled series, each re-mix was milled for 3 min. in a small double-roller pan mill. To concentrate on the bond, only strength test results are given. These were taken on A.F.A. standard test piece 2 in. dia. by 2 in. long, tested on a spring-balance compression testing machine, and the total breaking load is given in all tests.

The analysis of the coal-dust used was:—Volatile, 30.6; ash, 10.4; carbon (by difference), 59 per cent.; fineness, all through a 90-mesh sieve. The moisture of all mixtures was between 4 and 6 per cent.

The results of Experiment 1 are normal, for the strength of the sand decreases after each

Experiment No. 1.—*Stourbridge Red Sand.*—Ten per cent. of coal-dust was added, but no further additions were made.

HAND MIXED

Original mix before making first casting. Breaking strength 13 lbs.	Condition of castings.
Re-mixed after first casting 8 lbs.	Good blue skin.
,, ,, second ,, 8 ,, ...	,, ,, ,,
,, ,, third ,, 7¾ ,, ...	Good. Rather grey skin.
,, ,, fourth ,, 7½ ,, ...	,, Rough grey skin.
,, ,, fifth ,, 6 ,, ...	,, ,, ,, ,,
,, ,, sixth ,, 5 ,, ...	Poor. Top face drawn down slightly. Very rough grey skin.

Experiment No. 2.—*Stourbridge Red Sand.*—Ten per cent. of coal-dust was added, but no further additions were made.

MILLED

Original mix milled before making first casting. Breaking strength 23 lbs.	Condition of castings.
Re-milled after first casting 20 lbs.	Good blue skin.
,, ,, second ,, 20 ,, ...	Dull ,, ,,
,, ,, third ,, 21 ,, . ..	Grey ,, ,,
,, ,, fourth ,, 21½ ,, . ..	,, ,, ,,
,, ,, fifth ,, 23	,, ,, ,,
,, ,, sixth ,, 22½ ,, ...	,, ,, ,,

cast. In striking contrast, the milled series No. 2 show an increase of strength after the first two castings. Obviously, the sand is gaining bond from some source other than the clay bond or alumina in the red sand grains. Microscopic examination of the sand after the fourth cast showed all the grains were covered with a black carbon deposit, which must obviously destroy the clay bond. This suggested a bond created by coal-dust, so further experiments on the same lines were made with sharp sand to prove this.

The result of this experiment proved beyond doubt that the tar from the coal-dust liberated by the heat of the metal when the mould was poured was creating an excellent bond, especially after milling. Another experiment with sharp sand plus coal-dust, but this time hand mixed, proved that milling increases the bond.

Although the condition of the sand was better than the test results show, this experiment definitely proved the benefit of milling, to produce this bond from the coal-dust.

Experiment 5 was made this year with King's Lynn sharp sand, and a fine coal-dust made by a well-known firm of suppliers.

Castings made with this sand were good, even the first one cast in sharp sand and raw coal-dust was free from cuts, scabs and pulling down of the top. This was unusual, for previously castings in sharp sand had shown some, or all, of these defects. After leaving coal-dust bond sand for a considerable time, and air drying it to powder, its original bond strength may be obtained without remilling by remixing with 5 to 6 per cent. of moisture.

Conclusions

It should be clearly understood that raw coal-dust does not create this bond. It is the deposits from the coal when they are transformed by the heat from the metal as it penetrates into the sand of the mould during and after pouring.

Experiment No. 3.—*Sharp Sand (Briton Ferry) Dune Sand.*—Ten per cent. of coal-dust added to original mix, and 2½ per cent. added after each cast.

MILLED

Original mix before making first casting. Breaking strength 2½ lbs.		Condition of castings.
Re-milled after first casting	6 lbs.	Rough grey skin. Top pulled down.
,, ,, second ,,	8½ ,,	Better. Grey-blue skin.
,, ,, third ,,	10½ ,,	Good. Better blue skin.
,, ,, fourth ,,	13½ ,,	,, ,, ,, ,,
,, ,, fifth ,,	15 ,,	,, ,, ,, ,,
,, ,, sixth ,,	16½ ,,	,, ,, ,, ,,

Experiment No. 4.—*Sharp Sand (Briton Ferry).*—Fifteen per cent. of coal-dust added, then decreasing amounts of 5, 4, 3, 2, and 1 per cent. added after each cast.

HAND MIXED

Original mix before making first casting. Breaking strength 3½ lbs.		Condition of casting.
Re-mixed after first casting	6½ lbs.	Rough casting. Fair blue skin. Top pulled down.
,, ,, second ,,	6½ ,,	,, ,, ,, ,, ,,
,, ,, third ,,	7½ ,,	,, ,, ,, ,, ,,
,, ,, fourth ,,	5½ ,,	Better casting. Rough grey skin.
,, ,, fifth ,,	6½ ,,	,, ,, ,, ,, ,,
,, ,, sixth ,,	5½ ,,	,, ,, ,, ,, ,,

These deposits coat some of the sand grains with a black sooty carbon and a certain amount of tar, and it is this last product which creates the bond which is partly frictional, *i.e.*, gripping the rough carbon surfaces, and partly glutinous, *i.e.*, tarry residue.

Microscopic examination of the coated grains and a simple experiment confirm this theory. For the experiment a small ring about 2 in. dia. is made with a piece of $\frac{3}{16}$-in. or ¼-in. wire. The centre of the ring is firmly filled with a mixture of sharp sand plus 10 per cent. of coal-dust, plus 4 per cent. of moisture. A small block 2 in. sq. by 4 in. long is then cast, and as soon as the casting sets it is removed from the mould and the ring filled with sand is placed on the 2 in. sq. end. With careful observation small globules of tar will be seen pushing up between the grains of sand (Fig. 2). Other interesting points also confirming the presence of "hot-bond" will be observed.

Experiment No. 5.—King's Lynn Sharp Sand.—Ten per cent. of coal-dust was added to the first mix, and 3 per cent. after each cast.

Cast.	Coal-dust. Per cent.	Strength. Lbs.	Perm.	Moisture. Per cent.
Milled—				
First mix ..	10	3¼	134	4½
After 1st cast	3	5¾	93	5
,, 2nd ,,	3	8¾	70	5
,, 3rd ,,	3	12½	52	5
,, 4th ,,	3	17	40	6
,, 5th ,,	3	18¾	32	6
,, 6th ,,	Nil	19½	30	6¼

A study of the heat penetration diagram, Fig. 3, built up from results taken by F. Mask and E. Piwowarsky, and applied approximately to the test block, 12 in. by 8 in. by 2⅛ in. will be found interesting. Assuming the mould is made of well mixed sand plus fine coal-dust, one can follow in imagination the changes that take place

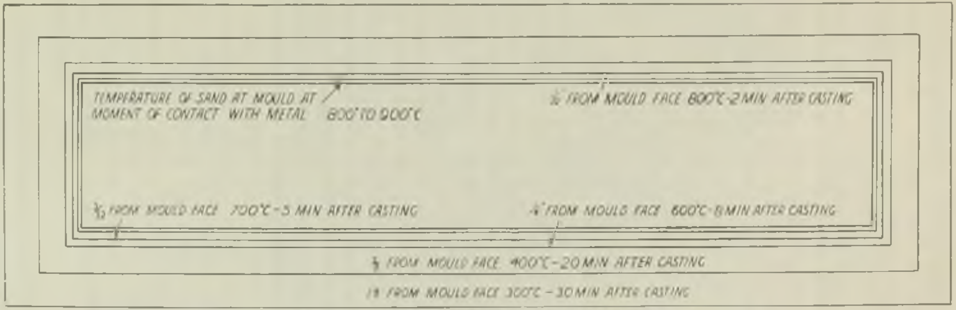


FIG. 3.—HEAT PENETRATION CHART.

in the sand from the time the metal enters the mould until the casting is cold.

As soon as the metal enters the mould the particles of coal on the bottom face give off their volatiles in the form of smoke immediately in front of the flowing metal, this smoke is trapped between the flowing metal and the mould face, the action takes place very rapidly on the bottom face, and then on the sides as the metal rises. The coal-dust on the top face gets the full effect of the radiated heat from the rising metal and the particles of coal on this face have already liquefied to tar before the metal reaches them, and created a very effective hot bond which prevents the sand from drawing down. The mould is filled in a few seconds, and the heat from the metal has started to penetrate the sand; this takes place slowly as shown by Fig. 3. At the mould face the temperature is approximately 900 deg. C.; as soon as the metal covers the face there is practically no air present to burn the coal-dust, so it melts into the form of a tar, at the same time gases form in the tar and exert a pressure trying to escape, this pressure forces the tar into every available space between the sand grains, and the liberated gases are forced back through the still unaffected and cool parts of the mould, where any tars they contain are condensed on to the grains of sand. This evolution of tar and gas continues into the mould as far as the heat required to cause it penetrates.

Sheffield Branch

HEAT-TREATMENT OF STEEL CASTINGS

Paper No. 626

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Some form of thermal treatment is given to almost all steel castings prior to delivery. The actual treatment given, of course, depends on the composition of the steel and the purpose for which the castings are required. It is intended in this Paper to explain why this heat-treatment is necessary and to describe the various treatments given to typical compositions. Some years ago the attitude towards the heat-treatment of steel castings was rather mixed. On the one hand, it was treated with a great deal of secrecy and on the other, it was assumed that, as long as the castings were heated to an undefined high temperature, then the heat-treatment requirements were fulfilled. In recent times, however, neither of these attitudes is tolerated, and the heat-treatment of steel castings should be just as carefully and scientifically controlled as any other heat-treatment process.

The importance of the heat-treatment operation requires no emphasis or justification in a Paper presented to this Institute, and suffice it to say, therefore, that in a sound casting the heat-treatment is largely responsible for the mechanical properties developed by it. The trend of modern times has been the insistence by engineers on high mechanical properties which can only be obtained with consistency by controlled heat-treatment, and it is one of the purposes of this Paper to describe how this may be accomplished.

Reasons for Heat-Treatment

It is not proposed to catalogue all the various steels and their appropriate heat-treatments, but to confine attention to qualities which are principally used for structural or general engineering purposes. The reasons for the heat-treatment of such steels may be briefly summarised as follow:—

(1) Release of internal stresses.

(2) To refine the coarse "as cast" structure.

(3) Further heat-treatment to the above may be given for following reasons:—

- (*a*) In low alloy steels, to give best combination of strength and toughness.
- (*b*) In stainless steels, to develop best mechanical properties and maximum resistance to corrosion.
- (*c*) In high manganese steels, to combine wear resistance with toughness.

The heat-treatment given to a casting may result, of course, in the fulfilment of several of the above purposes. For convenience it is proposed to consider each of the above subjects separately.

Release of Internal Stresses

The magnitude of the residual stresses in a steel casting is largely dependent on the geometry of the casting and on the restraining influence to its contraction offered by the mould and the cores. The existence of such stresses is, of course, only too well known in the steel foundry, where hot tears and distortion supply irrefutable evidence. Both these factors will tend to decrease the state of internal stress, but their influence is difficult to evaluate because the hot tears occur before the development of any appreciable elasticity, and while the distortion may lessen the stresses in the main members of the casting, this will, no doubt, tend to throw further stresses on subsidiary ones.

On the other hand, such visible signs of stresses may not be present, and yet the casting may possibly possess a high degree of internal stress. The allotropic transformation in the steel which occurs on cooling down may give rise to further residual stresses,[1] particularly when the transformation does not occur at the same instance throughout the casting.

The effect of temperature on the release of internal stresses has been studied in detail from many points of view, but the investigations in direct relation to steel castings appear to be very meagre, particularly from a quantitative standpoint. For the present purpose, however, the matter can be considered indirectly, and the deductions drawn therefrom may be applied to steel castings with sufficient accuracy for practical purposes.

Benson and Allison[2] have recently published data on the influence of temperature on the stress relief of strips of mild steel which were given an initial skin stress of 5 and 10 tons per sq. in. respectively. Fig. 1 summarises their results in this connection, and shows that a temperature of at least 600 deg. C. is necessary in order to render the material practically stress free. Naturally, the soaking time at the temperature has an influence on the release of the stresses, and Fig. 2 shows this effect on a series of strips similar to the above.

Stresses are induced in steel on quenching and Bühler, Buchholtz and Schulz[3] have made a very useful contribution to the knowledge on this subject by their investigation on cylinders of Armco iron and 0.30 per cent. carbon steel. These were quenched in water from 850 deg. C. and tempered at an ascending series of temperatures. Fig. 3 summarises graphically their results, from which it will be observed that a temperature of 600 to 700 deg. C. is required in order to render the material virtually stress free.

When the stresses are induced either by cold bending or by heat-treatment, they may be, for all practical purposes, eliminated by tempering at 600 to 700 deg. C. It would appear, therefore, reasonable to conclude that heating a steel casting to within the same range of temperature would result in the removal of any residual stresses. This temperature is lower than that required for grain refinement, which will be considered later, so that in most instances the removal of the stresses does not involve any special heat-treatment. While this treatment suffices in most instances, there may be special cases where greater freedom from stress is desired. When this is so, it is recommended that after the refining anneal, the castings be reheated to 600 to 700 deg. C. for a suitable period and slowly cooled in the furnace therefrom.

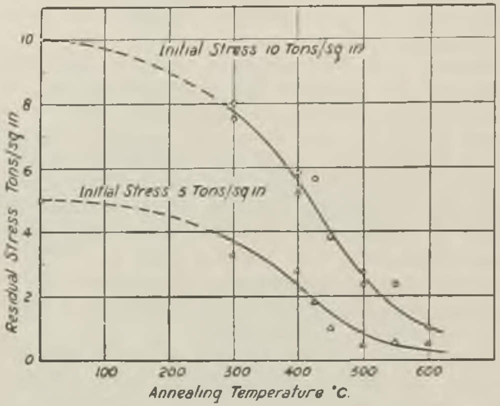

Fig. 1.—Effect of Annealing Temperature on Stress Relief.

Refinement of Cast Structure

The cast structure of metals and alloys is apt to be coarse relative to that of the wrought material of the same composition where the crystals have been elongated and broken up by hot or cold deformation. It is not possible to refine the cast structure of many metals and alloys by any form of heat-treatment, and in such cases the control of the grain size is largely effected by the rate of cooling from the casting temperature.

It is generally desirable to have the material as fine-grained as possible, because in this condition the maximum degree of toughness is developed, and this is usually required by engineers. In the case of steel, fortunately, it is possible by heat-treatment to refine the grain. The explanation of this, expressed in as non-technical language as possible, is as follows:—Iron can exist in the range of temperature which is now being considered in two forms. At ordinary temperatures it exists as ferrite which, for all practical purposes, does not dissolve carbon. At elevated temperatures iron changes to a form which does dissolve carbon, and the solution so formed is called "austenite." The carbon in steel exists as iron carbide (Fe_3C), which is called cementite. When the temperature of the austenite is reduced, the cementite is naturally precipitated, since it is insoluble in the ferrite. The constitution of the iron carbon system is such, however, that in the case of mild steel castings not cementite alone, but an intimate mixture of cementite and ferrite in a lamellar

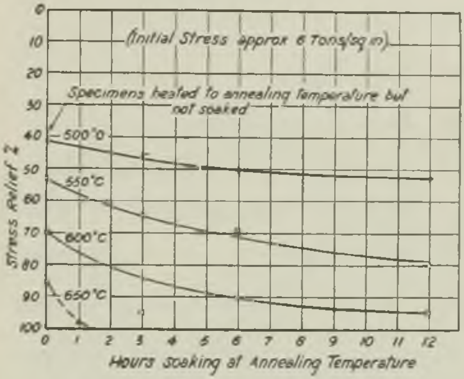

FIG. 2.—EFFECT OF SOAKING PERIOD ON STRESS RELIEF.

form is actually precipitated. This composite constituent is called pearlite.

The temperature to which the steel must be raised to accomplish the formation of austenite depends on the carbon content. The iron-carbon equilibrium diagram is of great assistance in helping to determine the most suitable temperature for various compositions. Fig. 4 gives one of the latest conceptions[4] of this diagram at the corner in which one is particularly interested when dealing with mild steel castings. To use this diagram intelligently, it is necessary to bear in mind the relationship between the extremely pure iron-carbon alloys used in its construction and the commercial steels, the heat-treatment for which is being dealt with. In addition it should be remembered that the diagram refers to equilibrium conditions, a state

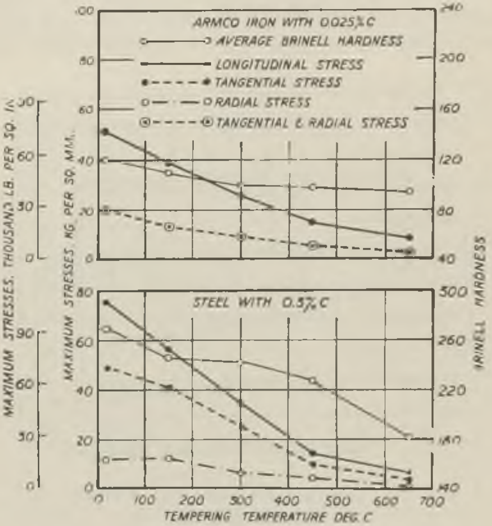

FIG. 3.—EFFECT OF QUENCHING ON INTERNAL STRESSES.

of affairs seldom attained perfectly in commercial heat-treatment practice. Above line GSE austenite exists, and the carbon is in solution. In area GPS, iron and a solution of carbon in iron occur. Below line PSK ferrite and pearlite exist.

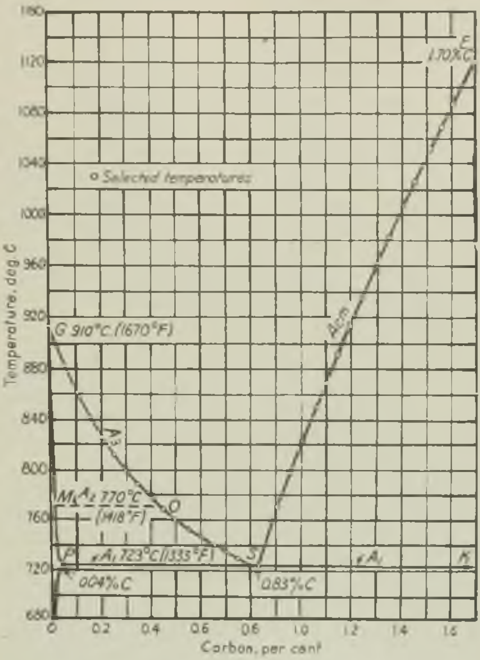

Fig. 4.—Iron-Carbon Equilibrium Diagram.

At present the area in which steel founders are particularly interested is that above line GSE, as they have to heat the steel until the intersection of the co-ordinates representing carbon content and temperature lies above this line. Naturally, the lowest possible temperature should be chosen, but, as indicated above, the diagram professes to represent equilibrium conditions, and, consequently, an allowance must be made to compensate for the inherent sluggishness of the steel in changing from one form to another. Commercial steel also contains other elements, such as silicon, phosphorus and manganese, which cause a departure from the ideal state envisaged by Fig. 4. The net result is, however, that a temperature about 50 deg. C. over the theoretical one is generally suitable.

Fig. 5 shows the typical coarse angular casting structure present before annealing. The white constituent is ferrite and the dark pearlite. One of the most distinctive characteristics of the structure is the geometrical regularity of the orientation of the above constituents. This is due to the precipitation of the ferrite on certain cleavage planes of the parent austenite. The formation is called the Widmanstätten structure, named after Widmanstätten who observed it first in meteorites.

By annealing as indicated above, re-crystallisation takes place, and refinement of the grain occurs as shown in Fig. 6. The relatively small crystals and the uniform dispersion of the pearlite will be observed.

Having decided on the temperature, the casting is slowly and uniformly heated to it, and after soaking for a sufficient time, is cooled in the furnace. For mild steel castings of normal dimensions and thickness of section, a temperature of 900 to 950 deg. C. is satisfactory, with a soaking time of 3 hrs. at this temperature range. For heavy castings the soaking time must be increased proportionately, and the temperature preferably kept towards the top limit of the range indicated.

It is outside the scope of this Paper to discuss the various types of heat-treatment furnaces suitable for steel castings, but the principal requirement is that they must be capable of giving a uniform temperature over the whole hearth area. To ensure that the correct temperature is uniformly maintained, it should be

FIG. 5.—COARSE ANGULAR CASTING STRUCTURE IN WIDMANSTATTEN FORMATION. × 40.

possible to measure the temperature at representative points in the furnace. Suitably protected permanent couples may be installed at these points or provision made for the insertion where desired of a poker type thermo-couple.

A discussion of the various types of pyrometers cannot be undertaken here, but a few remarks on the use of thermo-couples from a practical aspect may not be out of place.

Temperature Determination

In measuring temperatures by thermo-couples, the limitations of the method should be appreciated if the results are to be intelligently interpreted.

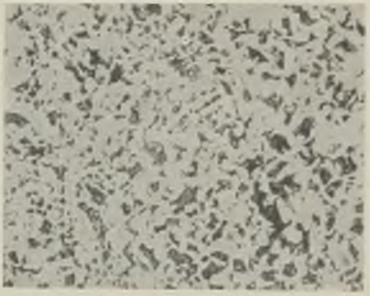

Fig. 6.—Refined Widmanstätten Structure after Annealing. × 100.

A pyrometer measures the temperature of the hot junction of the couple, but this may or may not be the same as that of the furnace. Precautions should be taken, therefore, to ensure that the hot junction is representative of the furnace. The relatively large mass of the castings in the furnace generally results in the temperature as recorded by a permanent couple, the point of which is not at the centre of the mass, being higher than that of the actual castings. The soaking time must, of course, be

Fig. 7.—Fracture of Mild Steel "As Cast."

Fig. 8.—Fracture of Mild Steel after Annealing.

reckoned to commence when the whole of the furnace contents has reached the desired temperature. The same remarks apply to the portable poker type couple, although perhaps to a less extent, as with this type it is often possible to rest the hot junction of the couple at the point where, to the eye, the furnace is coolest. Sufficient has, however, been said to emphasise the fact that, while the pyrometer is undoubtedly an extremely reliable instrument for measuring temperatures at the range with which this Paper deals, due care must be taken to ensure that the temperature recorded is truly representative of the furnace conditions. To check the correctness of the annealing of each heat of mild steel castings, quite a practical test may be carried out as follows:—

Representative pieces of runners from the same cast as is being annealed are placed before-hand at selected points in the furnace and subjected, therefore, to the same heat-treatment as the castings. After the completion of the annealing process, nicked fracture tests are prepared by sawing the runner half way through, then breaking the sample with a forge hammer. The grain size observed confirms the effectiveness or otherwise of the heat-treatment. A fine grain should, of course, be obtained from all samples. Additional confirmation may be obtained by the preparation of micro-sections, but as a routine test the fracture should be sufficient indication. Fig. 7 is a photograph of the fracture of mild steel "as cast," and Fig. 8 shows the appearance after annealing.

In order to enhance further the mechanical properties of mild steel castings which have been subjected to the grain refinement treatment, they are frequently normalised. This consists of heating the casting to a temperature above GSE line in Fig. 4, but barely as high as that necessary to break up the cast structure, and cooling in air therefrom. For ordinary mild steel castings a temperature of 880 to 900 deg. C. is suitable. Of the mechanical properties, those which are most improved are the yield ratio and the Izod impact value.

Heat-Treatment of Low Alloy Steel Castings

In addition to the refinement of the grain by annealing or normalising, the mechanical properties of steel castings can in many cases be enhanced by further heat-treatment. Mild steel castings, owing to their relatively low carbon content, do not readily respond, and are, consequently, seldom delivered in the hardened and tempered condition. In the annealed or normalised state also they generally possess sufficient ductility and toughness for most purposes.

On the other hand, when a higher tensile strength than is obtainable from this class of casting is desired, a sacrifice in ductility and toughness is inevitable if a plain carbon steel is still employed. For many applications this may not matter, as, for example, where resistance to wear is the primary function. However, in many instances, both high tensile and resistance to shock are required, and this can only be obtained by further heat-treatment of the castings.

One of the most outstanding developments in recent times has been the advancement made in the production of alloy steel castings. To obtain the maximum benefit from the alloying elements, it is generally necessary to subject the castings to a full heat-treatment, and it is the purpose of this section to indicate how this may be carried out.

The advantages accruing to the use of such alloy steels are principally, firstly, that, compared with carbon steels heat-treated to the same tensile strength, the ductility and toughness values are greatly increased, and, secondly, that the composition can be so adjusted that heavy sections can be made to respond uniformly throughout the thickness to the heat-treatment operation.

The heat-treatment of bars and forgings has been common practice for many years, and now presents few difficulties. On the other hand, the heat-treatment of steel castings still presents many problems, particularly when the castings are intricate. This is not a difficulty which is likely to be entirely overcome in time, because, as foundry technique is improved, the founder is called upon to produce even more intricate types of castings. There is no reason, however, to suppose that the technique concerning heat-treatment will not also advance or that compositions requiring simpler heat-treatment processes will not be developed.

As in foundry practice generally, heat-treatment is facilitated by symmetrically shaped castings possessing as uniform a metal thickness as possible. By this means the quenching operation is of equal intensity throughout the casting, and consequently the distortion is reduced to a minimum.

It is proposed to consider first the principles underlying the heat-treatment of steel, and then apply these findings to typical alloy steel castings. For this purpose, one has again to refer to the corner of the iron-carbon equilibrium diagram in Fig. 4. To obtain a homogeneous austenite solution, the temperature of the steel must be raised above line GSE. An allowance in temperature must again be made for the sluggishness of the steel, but, generally speaking, this need not be as great as that desirable for the grain-refinement operation described in the previous section. To ensure the uniform distribution of the carbide, the steel is then cooled quickly by quenching in oil or water, although with some compositions cooling in air may be sufficiently rapid.

In the quenched condition the steel is generally too hard and brittle for most purposes, and has, consequently, to be tempered or drawn to requirements. This is accomplished by re-heating the casting to a temperature below line PSK. Sufficient time must, of course, be allowed at each heat-treatment temperature to ensure the requisite soaking of heavy sections. It is difficult to enunciate definite rules regarding this, but, generally speaking, one hour per inch of thickness should be sufficient. For heavy sections this would have to be increased to two or more hours per inch.

Owing to their shape and varying thickness of sections, many castings tend to retain very high residual stresses on quenching. It is, consequently, advisable to transfer such castings, while still warm, from the quenching medium to the tempering furnace. Cooling in oil is in most cases preferred to quenching in water, but, if the composition be such that the latter method is essential, the severity of the quench can be greatly reduced by having the water at as high a temperature as is compatible with the degree of quenching desired. On the other hand, the nature of the casting may preclude even quenching in oil, and in such a case the composition must be adjusted to give satisfactory hardening by cooling in still air or by an air blast.

It will be realised from the foregoing that the heat-treatment of castings is not a straightforward process in which a single composition and a standard heat-treatment would be suitable for all castings requiring the same physical properties.

The composition selected depends largely on the size, shape and physical tests desired from the casting. The size influences the composition, because large castings will normally have a slower rate of cooling than small ones, and consequently require a higher percentage of alloying elements. On the other hand, the shape influences the choice of quenching medium. Water, as a rule, cannot be used except for the simplest forms, and, therefore, more expensive compositions suitable for oil quenching or air cooling may be required. The physical properties desired have naturally a large influence on the choice of steel, and, broadly speaking, the higher the tensile strength and the greater the toughness desired, the more expensive the steel will be because of the increased proportions of alloying elements which are then necessary.

It is not possible in this Paper to consider all the various compositions of alloy steel castings and their respective heat-treatments. Consequently, no attempt is made to catalogue such information, but particulars are given of representative compositions which have gained a certain degree of popularity.

In the foregoing, the author has considered for convenience the heat-treatment of steel castings on the assumption of Fig. 4 holding true. The various alloying elements influence to some extent the relative positions of the various lines on the diagram, but it is quite outside the scope of this Paper to discuss the effect of the different elements, either singly or in combination, on this aspect. Suffice it to say, therefore, that the temperatures given hereafter are in conformity with the principles enunciated, and have been found in practice to give satisfactory results.

NICKEL STEELS

Low Carbon 2 per cent. Nickel Cast Steel

Low carbon 2 per cent. nickel is a very popular composition for cast steel in America. It is recommended for locomotive frames, castings for mining, excavating and steel mill machinery and other parts subject to shock and fatigue stresses. The retention of impact resistance and ductility at sub-zero temperatures makes this composition particularly suitable for machinery operating in cold climates.

Analysis.—C, 0.20 per cent. max.; Si, 0.15 per cent. max.; Mn, 0.60 to 0.90 per cent.; S, 0.05 per cent. max.; P, 0.05 per cent. max., and Ni, 2.0 per cent. min.

Recommended Heat-treatment.—940 deg. C., 2 hrs. per in. thickness, air cool; 815 to 845 deg. C., 1½ hrs. per in. thickness, air cool; 595 to 680 deg. C., temper, cool in air or furnace.

Table I[5] shows typical test results obtained in the ordinary course of production with this composition.

TABLE I.—*Typical Test Results on Low Carbon 2 per cent. Nickel Cast Steel.*

Composition. Per cent.						Y.P. Tons per sq. in.	M.S. Tons per sq. in.	E. on 2 in. Per cent.	R. of A. Per cent.
C	Si	Mn	S	P	Ni				
0.20	0.33	0.81	0.024	0.011	2.11	21.7	36.4	32.0	60.7
0.18	0.37	0.76	0.023	0.015	2.16	21.5	33.8	29.5	61.8
0.20	0.30	0.67	0.023	0.011	2.04	23.4	36.4	32.5	59.9
0.19	0.30	0.89	0.024	0.012	2.07	24.5	36.4	27.5	52.2
0.17	0.30	0.84	0.022	0.012	2.09	22.7	35.4	32.6	62.3
0.19	0.30	0.91	0.023	0.012	2.14	22.9	38.0	29.0	52.0

TABLE II.—*Typical Test Results on Medium Carbon 2 per cent. Nickel Cast Steel.*

Composition. Per cent.					Y.P. Tons per sq. in.	M.S. Tons per sq. in.	E. on 2 in. Per cent.	R. of A. Per cent.
C	Mn	S	P	Ni				
0.28	0.97	0.040	0.034	1.99	27.8	42.2	26.5	48.4
0.28	1.00	0.045	0.035	2.16	27.1	43.4	26.5	53.6
0.27	0.91	0.047	0.033	1.98	25.5	42.2	25.5	47.5
0.30	1.05	0.071	0.030	1.95	28.3	46.5	25.0	54.8

Medium Carbon 2 per cent. Nickel Cast Steel

A medium carbon 2 per cent. nickel cast steel is used for castings demanding higher strength and elastic properties than those given by the low carbon 2 per cent. nickel steel described above.

Analysis.—C, 0.20 to 0.30 per cent.; Si, 0.25 to 0.40 per cent.; Mn, 0.70 to 0.90 per cent.; S, 0.05 per cent. max.; P, 0.05 per cent. max., and Ni, 2.0 per cent. min.

Recommended Heat-treatment.—900 deg C., cool in air; 650 deg. C., temper. Typical test results obtained from this composition are given in Table II.[6]

CHROMIUM STEEL CASTINGS

In chromium steel only those castings of a low alloy content generally containing 1.0 to 1.5 per cent. chromium will be considered for the moment. These castings may be heat-treated by quenching in water, oil or air, depending on the intricacy, carbon content and the duties required of the material. A composition found suitable as an inexpensive medium tensile steel is as follows:—C, 0.30 to 0.40 per cent.; Si, 0.50 per cent. max.; Mn, 1.0 per cent.; S, 0.04 per cent. max.; P, 0.04 per cent. max.; Cr, 1.0 to 1.5 per cent. This quality is found to be quite suitable for small and medium size castings and is generally given the following heat-treatment:—900 to 950 deg. C., cool in furnace; 860 deg. C., cool in air, oil or water; 660 deg. C., temper. After the above heat-treatment the following mechanical values are obtainable:—Maximum stress, 40 to 50 tons per sq. in., associated with 20 to 25 per cent. elongation.

Of the high carbon varieties a good hard wearing composition is one containing 0.80 to 1.0 per cent. carbon. This quality, of course, is not particularly tough, and consequently should not be used for parts subjected to shock. Fig. 9 shows a volute of a large sand pump about 10 ft. in dia. made of this type of steel. The heat-treatment given to this casting after refinement

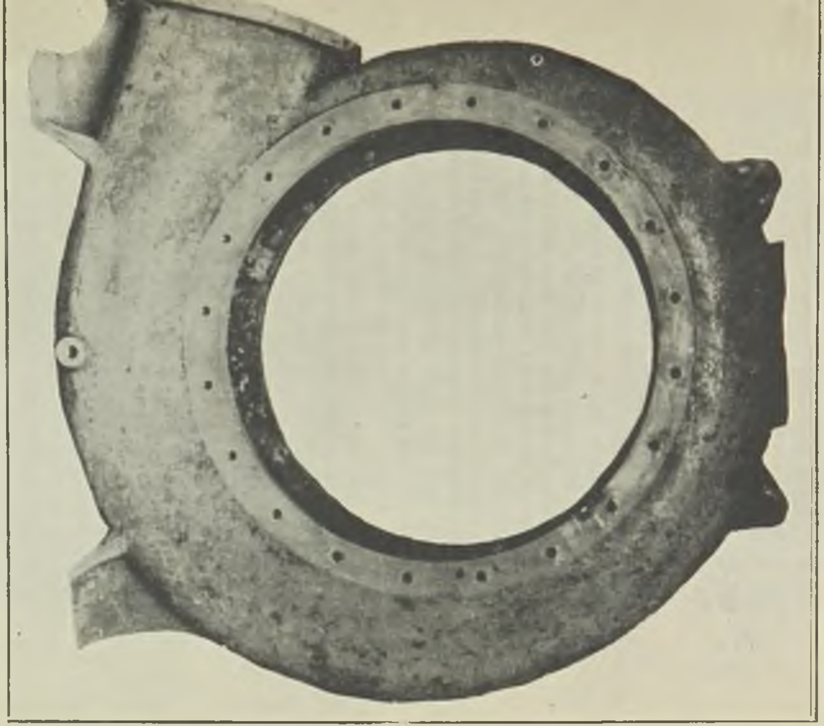

Fig. 9.—A Volute of a 10-ft. dia. Sand Pump in High-Carbon Chromium Steel.

of the grain as above, consisted of cooling in air from 860 deg. C. An air blast was also directed on the inside of the casing as this area was wanted as hard as possible in order to resist abrasion. The Brinell hardness of the casting after this heat-treatment was 280 to 300 and a test-bar heat-treated along with the casting gave the following results:—Maximum stress, 62 tons per sq. in.; elongation, 11.0 per cent.

NICKEL-CHROME CASTINGS

A wide range of compositions of nickel-chrome castings is available. The chromium may vary from small amounts up to 2 per cent. and the nickel up to 5 per cent. Likewise the carbon content may be up to 0.60 per cent., although the range 0.20 to 0.40 per cent. covers most requirements. A typical example at the low end of the range is as follows:—C, 0.30 to 0.40 per cent.; Si, 0.50 per cent. max.; Mn, 1.0 per cent. max.; S, 0.04 per cent. max.; P, 0.04 per cent. max.; Ni, 1.5 to 2.0 per cent., and Cr, 0.5 to 1.5 per cent.

A suitable heat-treatment given to this composition is as follows:—900 to 950 deg. C., cool in furnace; 830 deg. C., quench in oil; 620 deg. C., cool in oil. A typical test from a batch of castings given the above heat-treatment gave the following results:—Yield point, 36.0 tons per sq. in.; maximum stress, 46.8; elongation, 20.0 per cent.; reduction of area, 35 per cent.; Brinell hardness, 197; Izod impact, 34, 32, and 36 ft.-lb.

The above are examples of steel castings of comparatively low alloy content which have been selected as representative types. Various other compositions are frequently used, such as nickel-chrome-molybdenum, nickel-vanadium, nickel-molybdenum, nickel-manganese, chrome-molybdenum, manganese, nickel-manganese, etc. These by no means complete the list of compositions which have been found to yield satisfactory castings.

Certain compositions have to be cooled rapidly from the tempering temperature, otherwise, although the tensile figure may be satisfactory, the casting may be brittle. This phenomenon is called temper brittleness, and applies principally to nickel-chromium, manganese, and manganese-nickel compositions. It is clearly revealed by the Izod impact test, and, as this is not regularly taken on castings, it is consequently a point which should not be overlooked by the steel founder.

Heat-Treatment of Stainless Steels

There have been so many developments in the heat-treatment of stainless steels within recent years that it is only possible to mention a few representative types. For use in conjunction with super-heated steam, and for conditions of relatively mild corrosion, there is still a considerable tonnage of castings produced of the original plain chromium type.

The limits of analysis may be arbitrarily set as follow:—C, 0.20 to 0.35 per cent.; Si, 0.50 per cent. max.; Mn, 1.0 per cent. max.; S, 0.03 per cent. max.; P, 0.03 per cent. max.; Ni, 1.0 per cent. max.; and Cr, 12 to 14 per cent. As a rule, it is not necessary with this composition to subject the castings to a preliminary grain-refinement treatment. The heat-treatment generally given to them, therefore, is:—950 deg. C., cool in air or oil; 750 deg. C., temper, cool in air.

In most cases, cooling in air is sufficient. As a rule, it is not advisable for the chromium to exceed 14 per cent., otherwise difficulty may be experienced in obtaining satisfactory grain refinement by heat-treatment. It will also be observed that the quenching and tempering temperatures, compared with those previously mentioned, are considerably higher. This is due to the effect of chromium in raising the critical range of the steel. The minimum resistance to corrosion with this quality is found after tempering at 550 to 600 deg. C.,[7] but as the mechanical tests obtained after this heat-treatment are not of any special significance, this range is in any case seldom used.

After the above heat-treatment the following mechanical test specification is readily complied with:—Maximum stress, 45 to 55 tons per sq. in.; elongation, 20 to 25 per cent.; bend, 180 deg. not fractured.

Lower carbon alloys can also be readily cast and are given a similar heat-treatment to the above. Excellent mechanical tests are again obtained. The tensile range is generally about 10 tons per sq. in. lower and the elongation about 5 per cent. higher.

A composition possessing greater resistance to corrosion and particularly suitable for use in contact with brasses and bronzes is the 18:2 composition.

The analysis of this type is:—C, 0.10 to 0.25 per cent.; Si, 0.50 per cent. max.; Mn, 1.0 per cent. max.; S, 0.05 per cent. max.; P, 0.05 per cent. max.; Ni, 1.5 to 3.0 per cent., and Cr, 16 to 20 per cent. Excellent castings can be made from this alloy, but are not quite as ductile as the previous composition described.

The heat-treatment given to the castings of this composition is as follows:—950 deg. C., cool in air; 650 deg. C., temper, cool in air.

After this heat-treatment the following tests may be expected:—Maximum stress, 50 to 60 tons per sq. in.; elongation, 15 per cent. min.

Probably, however, the greatest quantity of stainless steel castings produced are of the austenitic variety, *i.e.*, sufficient nickel and chromium are added to depress the critical range so that on quenching the austenitic condition, stable at elevated temperatures, is retained.

A typical composition is as follows:—C, 0.10 to 0.25 per cent.; Si, 0.50 per cent. max.; Mn, 1.0 per cent. max.; S, 0.03 per cent. max.; P, 0.03 per cent. max.; Ni, 14.0 per cent., and Cr, 18.0 per cent. To render this quality completely austenitic, it is necessary to quench the castings in oil or water from about 1,050 deg. C.

After this heat-treatment the following range of mechanical test values are obtained:—Maximum stress, 30 to 40 tons per sq. in.; elongation, 40 to 60 per cent. This quality, even in the " as cast " condition, exhibits excellent ductility, and the heat-treatment, therefore, is principally carried out in order to render the steel in the best possible condition to withstand corrosion. Normally, if this type of steel is slowly cooled through the range of temperatures of 900 to 500 deg. C., the chromium carbides are precipitated at the grain boundaries. Under corrosive conditions rapid attack takes place at this point, and the casting consequently quickly becomes disintegrated. Fig. 10 shows the micro-structure of disintegrated metal in which the broadened grain boundaries will be observed. Fig. 11 shows the grain boundaries at exceedingly high magnification of 3,000 diameters in which the precipitated carbide particles will be observed.

It should be mentioned, however, that suitable compositions have now been developed which do not exhibit the undesirable feature of intergranular corrosion even after being subjected to the above temperature range. Other alloys to those mentioned above are also sometimes added to make the alloy particularly suitable for withstanding special corrosive conditions, but the heat-treatment of such castings follows the principles outlined above.

Heat-Treatment of Manganese Steel Castings

No review on the subject of heat-treating steel castings would be complete without reference to the reasons underlying the heat-treatment of high manganese steel castings for whose development industry is indebted to Sir Robert Hadfield, Bt. By suitable adjustment of the carbon and manganese contents it is possible by quenching from the correct temperature to retain the high temperature austenitic phase. Under the influence of cold work on the surface, this phase changes to extremely hard wearing martensite, and so the combination of the wear resisting surface and the toughness characteristic of austenite is obtained.

Fig. 12 shows the approximate relationship between the carbon and manganese content and the constituents present. This constitutional diagram is based on the work of Guillet, but lines XY and WZ have been added as the result of more recent investigations. Between these lines pure austenite may be obtained by quenching in water from about 1,060 deg. C. To the left of line XY is the zone of martensitic steels,

FIG. 10.—DISINTEGRATED AUSTENITIC STAINLESS STEEL WITH BROADENED GRAIN BOUNDARIES. × 100.

and to the right of WZ steels are found after quenching to contain free cementite.

The composition which is generally adhered to lies within the following limits:—C, 1.0 to 1.4 per cent.; Si, 0.30 to 1.0 per cent.; Mn, 10 to 14 per cent.; S, 0.04 per cent. max.; and P, 0.10 per cent. max.

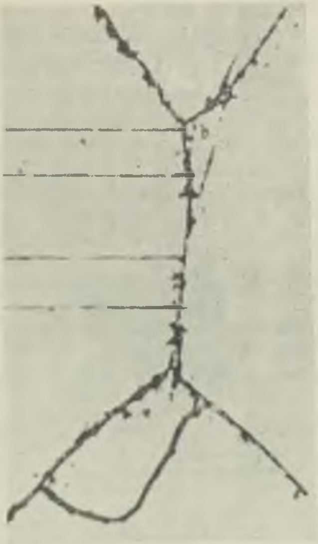

FIG. 11. — PRECIPITATED CHROMIUM CARBIDE PARTICLES IN GRAIN BOUNDARIES OF AUSTENITIC STAINLESS STEEL. × 3,000.

In the cast condition manganese castings are relatively brittle, partly due to the presence of free cementite and partly because, on slow cooling from the casting temperature, some of the austenite transforms to troostite or martensite. To obtain complete solution of the cementite and to obtain the steel in the austenitic condition, the castings are quenched in water from 950 to 1,050 deg. C.

Owing to the difficulty of preparing, mechanical tests are not regularly taken from manganese castings. The Brinell hardness can, however, sometimes be conveniently determined. In the quenched condition the Brinell hardness is generally 180 to 200.

A recent development[8] of this quality has been the addition of 3 to 5 per cent. nickel to it, whereby a simple normalising treatment is quite effective in producing the austenitic structure. It also retains its strength and toughness better at elevated temperatures.

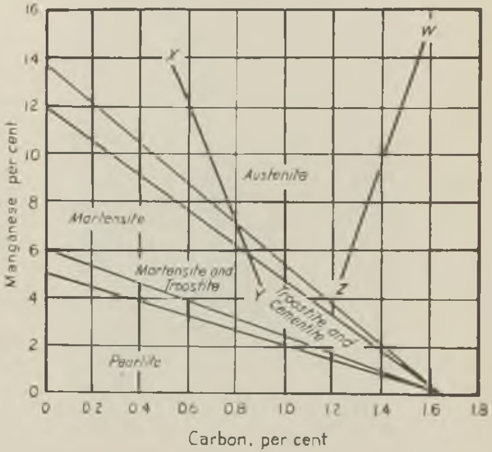

FIG. 12.—CARBON-MANGANESE CONSTITUTIONAL DIAGRAM.

Conclusions

In the foregoing an attempt has been made to give examples of the heat-treatment of steel castings of qualities which are most frequently manufactured for general engineering purposes.

This Paper is not intended to summarise all the various compositions and their respective heat-treatments, but is intended to explain in as non-technical language as possible the principles underlying the various heat-treatment operations. Once these are grasped, it should not be difficult for the founder to select the most suitable heat-treatment temperatures for his purpose.

While, in the case of carbon steels, it is customary to give the castings a preliminary grain-refinement treatment before hardening and tempering, this is not always done with alloy steels. To obtain the best mechanical tests, the preliminary treatment is recommended, particularly with low alloy steels, but sometimes it is not considered that the enhancement of properties so obtained is justified on economic grounds.

The author wishes to express his thanks to the directors of the Clyde Alloy Steel Company, Limited, for permission to publish this Paper, and to the various members of the staff of the same company who have assisted in its compilation.

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DISCUSSION

Melting Furnaces

MR. J. ROXBURGH (Branch-President) said he himself was concerned with iron foundry practice, but he felt that Dr. Hunter had dealt with the technical aspect of the heat-treatment of steel castings in a very practical manner. It would appear that the heat-treatment of steel castings had been developed to a remarkable degree, and those who were engaged in the iron foundries could learn much. The steel metallurgist seemed to be able to refer very frequently to his iron-carbon diagram, but unfortunately in the iron foundry a diagram for almost every composition of iron would be required. In regard to the annealing of steel castings and the length of time involved, he wondered in the case, say, of an anvil block or a casting of large section, how long it would be necessary to anneal it. He wished to know what type of furnace had been used for melting the various steels reviewed in the Paper.

DR. HUNTER said it was difficult to give a definite length of time for annealing a casting up to, say, 2 ft. in thickness, because it depended solely upon the nature of the casting.

In regard to melting furnaces, alloy steels could generally be manufactured in the same type as used for mild steel castings. The nickel and low-alloy steels were usually made in an open hearth or electric furnace, but the high-alloy chromium compositions were practically always made in the electric-arc or high-frequency furnaces.

Heat-Treatment of Carbon Steels

MR. T. R. WALKER asked for more information, if possible, on the treatment of carbon-steel castings. Some foundries did make manganese steel, stainless steel, alloy or other steels, but most foundries manufactured carbon-steel castings. He would also like information about the rate at which it was permissible to heat castings for annealing. Time was money, and if time could be saved in the heat-treatment of castings, so much the better. In the case of a casting of 4-in. section, at what rate in degrees per hour would it be permissible to heat the casting? Was it advantageous to soak the casting for the necessary time of one hour per inch of section, then remove it from the furnace, allow it to cool to 400 or 450 deg. C., and put it back in the furnace for tempering? Further, supposing it was then heated to 650 deg. C. for tempering. It would, of course, have to cool, and to what temperature should it be cooled in the furnace before it could safely be taken into the shop? Should it remain in the furnace to cool slowly until it was quite cold, or could it be removed, releasing the furnace for something else? In many foundries the heat-treatment of castings was carried out as a more or less continuous process in a three-chambered furnace. The first chamber was used for preheating, the second for soaking, and the third for cooling off. Usually, and they ought to be, castings were from the same cast, or at least were of the same composition. If all the castings were given the same treatment whether they were 1-in. sections or 4-in. sections, would it do any harm? Would the time fixed for the 1-in. section be inadequate for the 4-in. section?

Temper Brittleness

Dr. Hunter replied that the rate of heating to be applied for a 4-in. section would generally be about one hour per inch of thickness; *i.e.*, in a normally constructed furnace it would take about 4 hours to attain the necessary temperature. Usually a foundry was dealing with 3 or 4 tons of castings at a time, and it took about 9 or 10 hours to attain the annealing temperature. As a rule, it was not convenient to charge the castings directly into the furnace at the annealing temperature. He would not say there was a maximum rate of heating, because that depended so much on the shape and composition of the casting. With reference to Mr. Walker's question of the air-cooling of a casting to 400 or 500 deg. C. and then returning the casting into the furnace, he saw no reason why that should not be done. The advisability of cooling in the furnace from the tempering temperature depended on both the composition and the type of casting. Certain compositions must not be cooled slowly in the furnace; for example, nickel-chrome steel tended to exhibit the undesirable feature of temper-brittleness. The advantage of cooling in the furnace was that the casting would be much freer from stress than it would be by any other means. This might be an important consideration. If a steel that could be cooled in the furnace was wanted, one would have to use a composition that was not subject to temper-brittleness. Regarding the heat-treatment of castings of different sections, the common practice was to give a casting the heat-treatment necessary for the thickest section.

Stress Relief

Mr. R. C. **Tucker** said he was interested in the temper-brittleness of nickel-chrome steel castings. He had had occasion to test some small castings supposedly of the composition and heat-treatment mentioned by Dr. Hunter. He cut pieces from these castings and found Izod values of 1 ft.-lb. When he rejected the castings he was told by the steel founder that a cast-on test-bar would have given good Izod values. He maintained that this was not true, and that where pieces could be trepanned they gave a much better indication than cast-on test-bars which often caught the dirt.

He was very much interested in Dr. Hunter's remarks about stress relief, because many of the members present were more concerned with cast iron, which was a brittle material at any temperature. It was a surprise to hear that steel at high temperatures was just as brittle as cast iron. Much work had been done on the brittleness of cast iron and steel during the last few years because of the difficulty in which the steel founder found himself. The surprising thing was that he was surmounting the difficulties so well.

They were forced to the conclusion that cast iron bore some relation to cast steel for it had been shown that similar treatment would benefit both alloys. Regarding Dr. Hunter's remarks about the physical condition of manganese steel, he agreed that the preparation of test-pieces was an arduous procedure in normal machine-shop practice, but he saw no reason why manganese steel should not be ground finished with the modern methods available in industry. If manganese steel was required to stand certain tests more than a Brinell hardness test should be demanded, as this was very deceptive on such steel. A certain amount of ductility should be asked for in the body of the steel. Manganese steel was only a suitable material under abrasive conditions. As regards mere fractional resistance, manganese steel showed no advantage over some of the other alloy steels mentioned by Dr. Hunter.

Caterpillar Shoes

Dr. Hunter was pleased to learn that Mr. Tucker's experience of stress relief with cast iron had confirmed what he himself had mentioned. He supposed that steel and iron were related in that way, and that it was the carbon that constituted the greatest difference. For practical purposes, he thought, the preparation of manganese steel test-pieces was not worth the trouble. The Brinell test was usually taken to satisfy the inspector. If they wanted to use manganese steel under conditions of severe stress then a tensile test was justified, but as a rule this steel was wanted to resist abrasion accompanied by pressure. A more practical test would be to have some arbitrary standard wear test based on service requirements. In regard to a suggestion that steel was too ductile, he supposed that it was meant that it had too low a yield point so that in service stretching occurred. That might take place, for instance, in caterpillar shoes, where the stretching might throw the shoes out of pitch.

Art or Science?

Mr. Tucker asked Dr. Hunter if he would say that the heat-treatment of steel castings was just as much an art as the founding of steel castings.

Dr. Hunter said there was no doubt that the manufacture of steel castings was to a certain extent an art. It was an art that was controlled by science, but as far as the heat-treatment was concerned he would say that it was essentially scientific, and in his Paper he had sought not only to treat it from that angle, but also from a practical point of view. The heat-treatment process could be called an art because certain castings were difficult to heat-treat without cracking. He would say, however, that as a rule the steel founder tried to avoid that trouble. Generally speaking, he would use a more expensive composition to overcome the difficulty. He would say that there was, if anything, more science than art in this aspect, but the point was rather debatable.

Large Anvil Block Practice

Dr. C. J. Dadswell, speaking in regard to the heat-treatment of large anvil-blocks, said that the very largest blocks of the sort made in steel in this country weighed about 100 tons, and that the average time for annealing and tempering was about three weeks. The castings were released from the moulds in about a week or ten days after casting, when they were at about 500 to 600 deg. C. He was not quite sure whether or not Dr. Hunter said that the rate of heating was immaterial, and that one could heat at the highest rate possible in going up to the annealing temperature. At one time the anvil-blocks referred to, which were about 10 or 11 ft. square and 6 ft. deep, were heated at the rate of 5 to 7 deg. C. an hr. and the soaking time was between 50 and 60 hrs. This meant that the casting was in the furnace for over a month. In these days one required the maximum output from all plant including annealing furnaces, although at the same time one could not risk any mishap during annealing as the castings had to be as stress-free as possible, owing to the nature of their subsequent life. Mr. T. F. Russell, of the research department at the author's works, who was a member of the Iron and Steel Institute Committee on Alloy Steel Ingots, read a Paper on the rate of heating for large masses and he had calculated what the theoretical rate of heating and soaking time should be for certain typical shapes, such as these blocks. The result was that the total time of treatment was reduced.

Dr. Hunter, speaking in reference to his previous remarks about the highest rate of heating possible, said the rate of heating was one hour per inch of thickness. This, he emphasised, applied to ordinary castings, and as he had indicated, the rate largely depended on the type of castings concerned. In regard to the length of soaking time in relationship to the thickness of the sections the figures he had given were approximate ones which might be applied in ordinary circumstances, but with a special article like an anvil block, which differed from the ordinary type of casting, it was permissible to apply different rates. The question of decreasing the total time would depend on the rate of heating, because if the heating was slow there would not be a very great lag in temperature between the centre and the outside of the casting. He presumed that a mathematical calculation could be applied so that the time of heating might be reduced with safety above about 600 deg. C because steel exhibited a more plastic than elastic nature above this temperature, which would result in a lowering of the thermal stresses involved.

Mr. Tucker asked Dr. Hunter at what temperature they should temper mild steel castings

Dr. Hunter replied that many mild steel castings could be straightened at red heat and if it was considered necessary the casting could be re-annealed after straightening.

Thermal Conductivity of Austenitic Steels

Mr. E. J. Brown referring to previous speakers' remarks on the rate of heating, suggested that an important point was that the thermal conductivity of austenitic steels was considerably less than that of carbon steels. He believed that in the case of manganese steel it was about one sixth. He had experienced less trouble in rolling manganese steels if they were charged into the annealing furnace with a reserve of heat from casting, as distinct from heating from the cold. With regard to specifications he would not like to be a party to any retrogressive policy, but suggested that a case could be made out for not annealing electric-furnace mild-carbon steel castings, as evidenced by the fact that a 180 deg. bend could be comfortably obtained in the " as-cast " condition.

Dr. Hunter said that as far as the castings dealt with in his Paper were concerned he had refrained from the mention of heat conductivity. For one thing, alloying elements undoubtedly decreased the heat conductivity. He mentioned that stainless steels as a rule only had about half the heat conductivity of ordinary carbon steels.

Vote of Thanks

Dr. J. G. A. Skerl proposed a vote of thanks to Dr. Hunter, Mr. C. D. Pollard seconding, observed that although Dr. Hunter was a scientist he had given a practical Paper and had clearly demonstrated how science should be applied in practice. The vote of thanks was carried and Dr. Hunter briefly replied.

Scottish Branch

WELDING versus CASTING*

Paper No. 627.

Improving Foundry Technique to Meet the Competition

By Matthew Russell (Associate Member)

Fabrication

As a method of construction, fabrication has applications in many respects because the fabricated design is so simple, and credit must be given to the designers on this account. The designers of castings in most cases have no knowledge of patternmaking and moulding methods, and their construction often leads to prohibitive costs. For confirmation of this, one only requires to examine castings produced to drawing-office requirements.

This state of affairs has existed for so long that the engineers now look upon the pattern-shop costs as being too high on a competitive basis, and in their search for cheaper substitutes they are adopting weldings. In doing this the engineers are compelled to leave their designs in the welders' hands. If one compares the design of an article produced by this method with the original design called for as a casting, it is often found that there is a considerable saving in favour of the welded material, purely by simplified design alone.

This, surely, is not a fair comparison, as one may find that, merely by adopting the fabricated design, the position could be reversed in favour of the casting, providing that the moulder and coremaker keep their product to the desired thickness, and do not add anything up to 25 per

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* This paper was awarded the "John Surtees" Gold Medal.

cent. to the weights, owing to the fact that both their employer and themselves are being paid

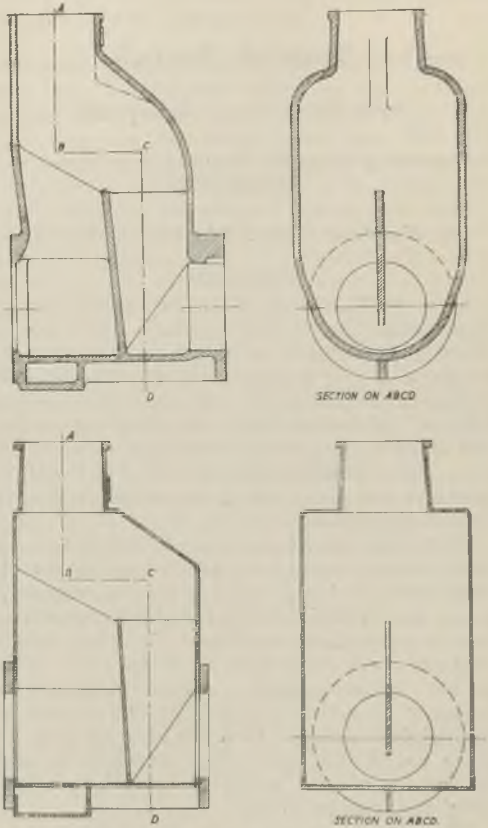


FIG. 1.—UPPER SKETCH "AS DESIGNED" FOR CAST IRON AND LOWER SKETCH "AS MADE" BY WELDING.

by weight. This increasing of weights may appeal to the founder as being good business, but it is a very short-sighted policy, and, in fact is craft suicide in face of competition with weldings.

A typical example is shown in Fig. 1 of a welded article submitted, as called for, as a casting; this shows the difference in design necessary when made as a welded job. The cost when fabricated is equal to that of casting, which would include half pattern and half corebox, with alteration pieces, *i.e.*, if the same design were adopted. This illustrates how increased costs are brought about in patternmaking by having to follow original design with large rounded corners, whereas if collaboration with the patternshop were adopted, as was done in this instance, castings would be cheaper after making one off, as subsequent castings would not carry the cost of the pattern.

This illustration and comparison was based on estimates taken from several firms specialising in weldings, and alteration in design was necessary on all of them. Had a rounded-corner design been insisted upon, their price would not have been comparable with the casting price, including pattern, by 30 per cent. Other illustrations will be given later of altered designs from the patternmakers' viewpoint, showing considerable savings which were only brought about by the competition of weldings; all of these were produced as castings and were definitely competitive. It might also be noted that castings were desirable due to their having greater rigidity and representing a better job.

Designs

It is difficult to understand how any designer can carry out his work competitively without having a general knowledge of patternmaking and moulding methods. This desirable condition of affairs, however, is more often found wanting than existing. One can imagine the draughtsmen declaring that it is impossible to expect this, but let them be assured that it is now being done, and is showing exceptional advantages as regards reduction of costs wherever adopted.

Comparison of results obtained under the best designed conditions, when the patternshop and foundry methods were subjected to proper planning before proceeding, have shown that, in the majority of cases, the castings were cheaper than weldings, and more satisfactory, being less liable to distortion.

It is obvious in many cases that the success of this method has been more or less brought about by the costly procedure of obtaining castings, that is to say, principally due to the cost of patterns where one-off jobs are concerned. No doubt many, whilst agreeing in this respect, do not consider the possibility of any remedy, but a personal recommendation is to specialise in design from the patternshop and foundry viewpoint, and there will at once be exceptional savings.

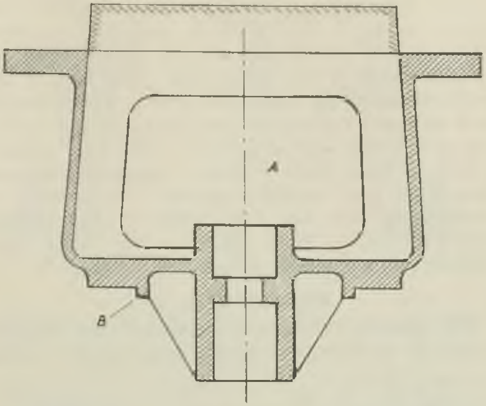
Several typical examples are shown in Fig. 2, *et seq.*, of actual work designed without the designer having shown any knowledge of or given any thought to patternmaking and foundry methods. It will also be noted that the alternative designs show definite savings in manufacture without any objectionable alterations.

Patternmaking

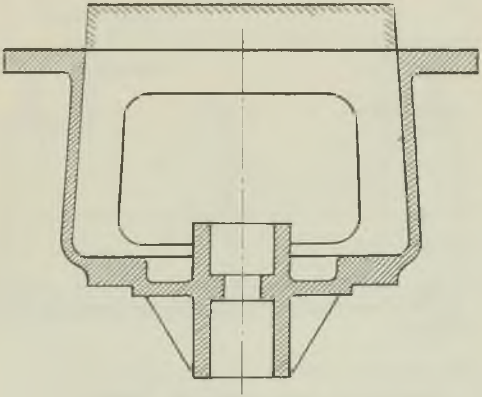
The same conditions exist with the patternmaker as with the designer on account of his lack of knowledge of foundry methods. He is often inclined to make unnecessarily expensive patterns and coreboxes, whereas, in many instances, shell patterns or skeleton patterns without coreboxes could be adopted. Typical examples are given in the sketches already submitted, which show simplified designs and alternative methods of making patterns with comparative costs.

Bearing Brackets

Fig. 2 shows bearing brackets as originally designed; the general practice would be to make two half patterns with prints shown etched and with separate cores for windows A, leaving end



BEARING BRACKET



BEARING BRACKET

FIG. 2.—UPPER SKETCH "AS DESIGNED," AND LOWER SKETCH "AS MADE."

B to be worked loose in the mould, and with half main corebox. The cost of this pattern would be £9 10s., including time and timber.

An alternative method.—To simplify the design make a half pattern and half corebox, and cut out a window on the pattern to the outside shape of the main core. The cost of this pattern including time and timber would be £6, and no more time would be added to the moulding cost. The only objection to the half pattern would be that most jobbing foundries maintain they have not suitable plant. A method of overcoming this was introduced by the author, and is working most satisfactorily (*vide* illustration and comments under " Moulding ").

Bedplate (Fig. 3)

The general practice for making this bedplate would be to have a pattern with corebox owing to the high sides A and B, whereas if the design were made with open sides, as shown at C and D, and webbed, a shell pattern leaving its own core would be made, thereby enabling the moulder to make gratings and to ram up the side cheek cores in place. A pattern of this description could be produced at half the cost of the general practice type, and is, moreover, simpler to mould.

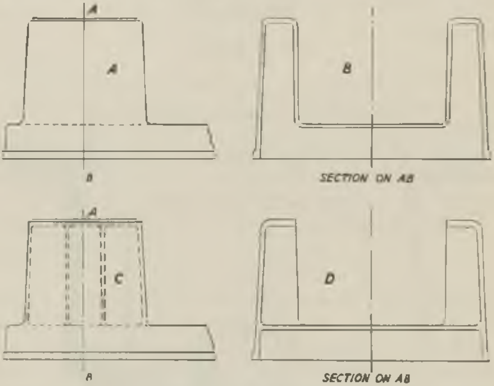
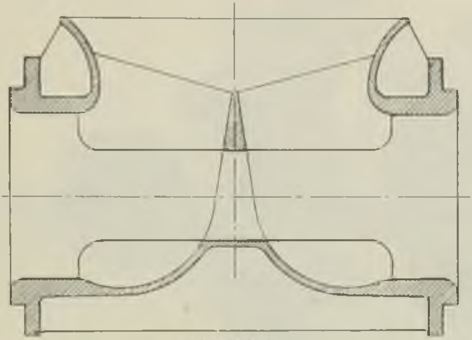


FIG. 3.—A BEDPLATE CASTING. UPPER SKETCH " AS DESIGNED," AND LOWER SKETCH " AS MADE."

Axial Casing (Fig. 4)

For this axial casing the usual method would be to have two half patterns and a half corebox, whereas the alternative design was made



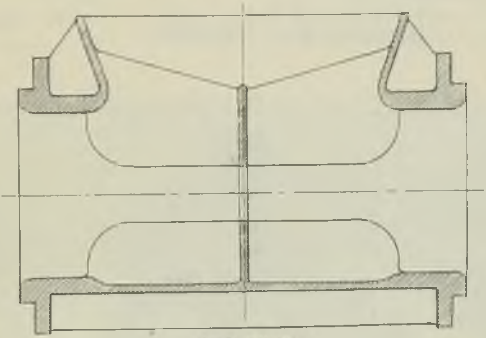


Fig. 4.—Upper Sketch "As Designed," and Lower Sketch "As Made."

with a half pattern and half corebox. By adopting the straight-line design instead of the streamline, the pattern was produced at about one-third of the cost, and no increase was made on the casting cost.

Runners and Risers o

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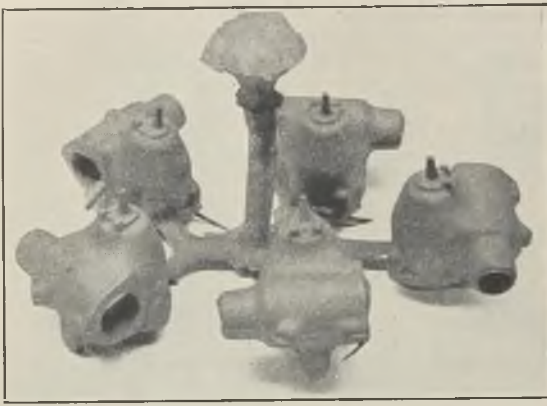

Fig. 1.—Steering Box Castings.

Fig. 2.—Sectio
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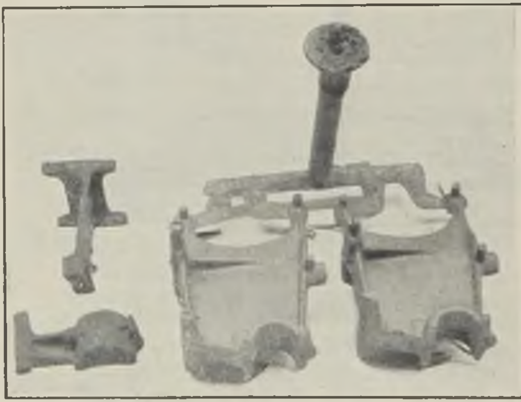

Fig. 5.—Successful Method of Running Bracket Casting.

Fig. 6.—E

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ING BOX CASTINGS
THICKNESSES.

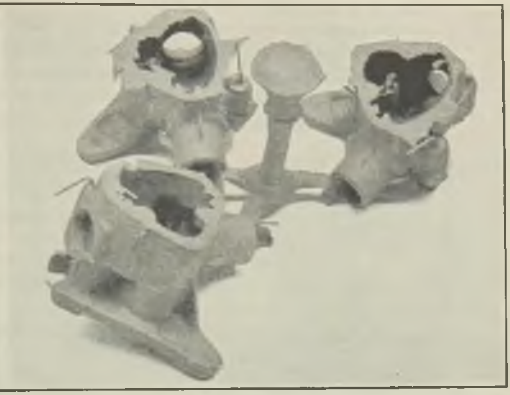

FIG. 3.—A HEAVIER TYPE OF STEERING BOX CASTING.

KET CASTINGS.

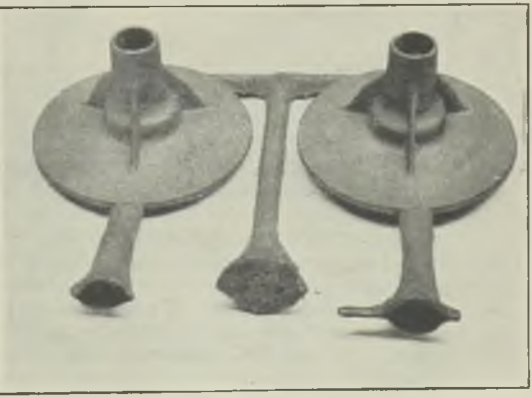

FIG. 7.—REAR AXLE COVER CASTINGS.

Pump Casing with Cast-on Stools (Fig. 5)

This pattern was parted on line AB, and previously was a standard pattern without stools. The draughtsman designed it as is shown, that is all cast as one and embodying the top and bottom bearing. The alternative design shows the top and bottom bearing with the stools cast separately, the same pattern being used for both stools with increased bottom base flange, thus making a very much simpler casting. As the component is now in three pieces, should there be a defective part, the cost of replacement would be considerably reduced. Patternmaking costs in this instance were reduced by 50 per cent., and the casting rate for stools was also reduced 10s. per cwt. compared with the cost of the centre casting.

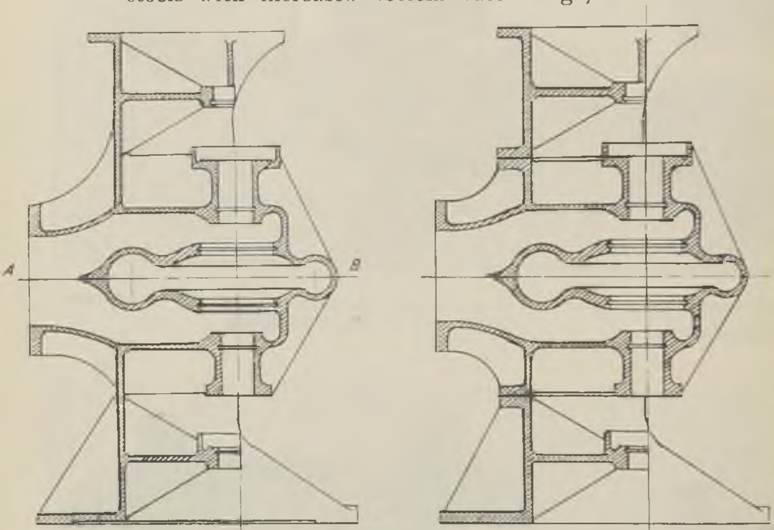

Fig. 5.—Left-hand Sketch "As Designed," and Right-hand "As Made."

The author has studied the simplicity of designs for the last two years, and the four cases submitted are representative of the hundreds that have been dealt with in this manner. If this system were adopted in general, there would be no fear of competition from weldings, as the author's firm are continually taking comparison costs, and can easily hold their own competitively. It must, of course, be realised that their patternshop lay-out is excellent, being considered in the same manner as in general machine-shop practice.

The reason for the adoption of fabrication in a great many cases is not the cost of the casting, but of the pattern. This is not surprising, as many patternshops are being run under the same conditions that have existed for the last 50 to 100 years. Very few firms give any thought to the patternshop lay-out with a view to improving these antiquated methods, although they spend thousands of pounds keeping the machine shops modern and condemning patternshop costs. Why this state of affairs should exist is beyond comprehension, as there are specialists in the manufacture of woodworking machinery, although most of their products are being used in the furniture and building trades.

Patternshop Lay-Out

The first operation involved is to secure and cut the timber. The wood rack is placed vertically at the extreme end of the shop, and not horizontally, as is the general practice. The reason for this is that the patternmaker can select the boards required without incurring the necessity of removing others. Alongside the wood rack, a cross-cut saw stands immediately behind a long table on which the timber to be cut is placed, and the saw is drawn forward by hand through the timber with very little effort on the part of the operator. All the machines are push-button electrically controlled, and self-contained. After the timber is cut to length, the next operation in the natural sequence of working is to reduce it to the desired width on the saw bench. A machine of the latest type is placed adjacent to the cross-cut saw and is suitable for dimension sawing, including ripping, mitreing, and angular cuts and bevels.

Still following the actual progress of the work, there is next the planing and thicknessing of the timber. To do this a surfacing machine is installed next to the ripping saw for straightening the boards before they are put through the thicknessing machine, which is adjacent to the surfacer.

The next machines are two band saws, one 30 in. and one 24 in. The reason for there being two is that as blades ordered for the large machine become shortened they may be used for the smaller machine, thereby making a saving. These machines are placed at convenient parts of the shop to save the patternmaker walking. There are also a large double disc sander and a double bobbin sander, which are suitable for finishing work straight from the band saw either hollow or round. In addition there are three 12-in. portable sanders, a portable 12-in. cross-cut saw, and a portable band saw; all of these can be placed alongside a job employing several patternmakers, thereby eliminating waste of the patternmakers' time in walking about the shop. There are five 6-in. electric planing machines which are placed between each two operators, and these eliminate hand planing, which would otherwise take up a great amount of time. Rotax drills placed on stands are used as small verticals for boring screw-nail holes. Patterns produced under these conditions are definitely modern, and show a 60 per cent. saving in costs as compared with general methods.

Moulding

The moulder, who is the victim of circumstances so far as design and construction of patterns are concerned, is generally blamed for increased costs in producing the castings, whereas if the originally suggested methods of procedure were adopted, namely, collaboration with designer and patternmaker, this unsatisfactory state of affairs would be eliminated. No doubt moulders will say "not practical," or "we have no time for this," but they are assured

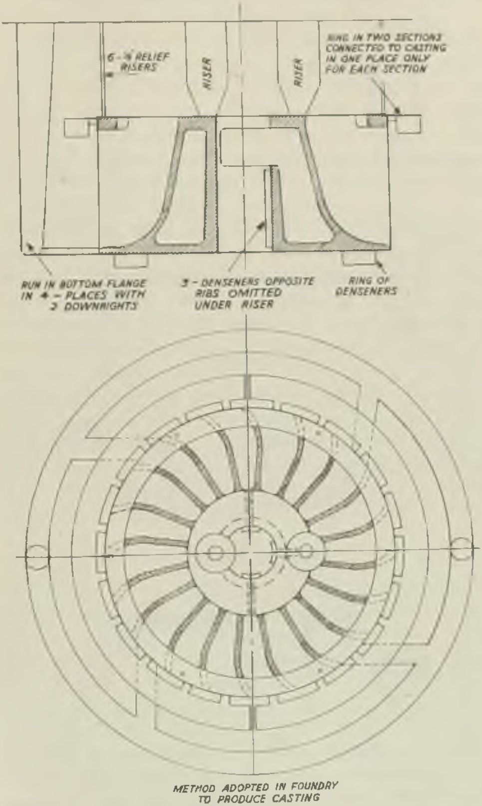

FIG. 6.—METHOD ADOPTED BY THE FOUNDRY TO PRODUCE ROTOR CASTINGS.

that, like the savings shown in the production of patterns, this is at present being done in a number of the foundries with which the author is connected, to the detriment of the adoption of weldings in a great many cases.

Recently a system of recording any job which gives trouble in making has been adopted, and this has been found a great advantage in eliminating defective castings. Welding

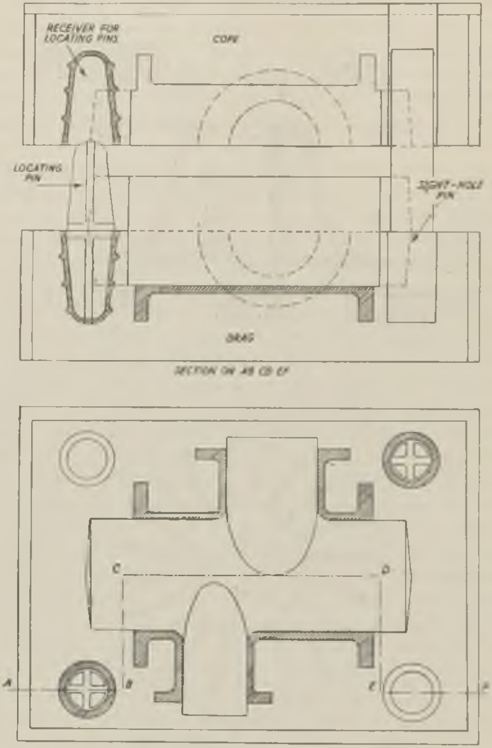

Fig. 7.—Upper Sketch: Section of Mould showing assembly of Cope and Drag. This was made from Service Plate, which enables the use of Half Patterns of a Symmetrical Nature.

specialists claim that their method of production involves no waiting for replacements, such as is associated with castings, and one has to admit that in most cases the chances of success or error in foundry methods are considerable.

A typical example of the method of recording is shown of a large rotor (Fig. 6), from which, prior to the adoption of this method, six bad castings were made. Since adopting the newer methods there have been no bad ones. The author is also a strong supporter of having gates and risers fixed on patterns, as, by so doing, consistency of method is assured.

Regarding the adoption of half patterns, a sketch of this lay-out is shown in Fig. 7, and this has been used in many jobbing shops where the boxes were very dilapidated, but it makes no difference if the plate is straight and of even thickness. This is the kind of gear that requires general adoption. The writer also does a great amount of work having skeleton patterns without coreboxes, the cores being made from clayed thicknesses. This method is found to have great advantages where one-off is wanted, and is definitely the kind of procedure necessary to compete with weldings.

Clay Thicknesses

It might be an advantage to explain briefly the method of clay thicknesses. The pattern is moulded in the usual manner, and a flat board with strips, say, 8 in. apart and about 12 in. long, equal to the thickness of metal required, is utilised for rolling out slabs of clay; these slabs are then put round the moulds. It might be considered that it would be necessary partly to bake the clay to ensure it being strong enough to resist the ramming of the cores, but when one becomes accustomed to the method, the clay can be made in such a manner as to eliminate this. Any part that may be carried in design, as regards internal rings, is made of wood and placed in the moulds. Core irons are then placed in the moulds, which are used as substitutes for coreboxes. This procedure is being adopted in quite a general way, and definitely shows considerable savings in pattern-making costs where one-off is concerned. The manner in which most jobbing foundries are laid out makes them anything but desirable places in which to work, yet no trade has greater possibilities for the man with initiative.

Regarding the mechanisation of foundries, this certainly has been done, especially in the motor car and mass production industries for which the author has quite a number of patterns made in the block system, the castings being made by semi-skilled labour. It is not here where the fear of interference from the welding producers can take place, but in general jobbing foundries, many of which, like most patternshops, are working in much the same way as 50 and 100 years ago. By adopting methods on the lines suggested, and incorporating, on a semi-mechanised basis, such departments as sand handling and mould production, the operations run in a sensible sequence, and the stoppage of the shop while the cast is taking place can be obviated.

Weight Saving

A large quantity of work has been secured by welding manufacturers principally on saving of weight. This question is not being competitively met in the proper manner by the designers of castings, as is illustrated by the following examples.

Two large Diesel engines were being manufactured by a well-known firm on the Clyde; the weight of each engine was 100 tons, and the welded parts were given the credit of having saved 40 tons per engine, although no credit was claimed for reduced costs beyond the saving of pattern charges. The top and bottom framing was approximately 30 ft. long, and if made as a casting would have been in two pieces, each 15 ft. long, and bolted together with internal flanges. On inquiring what thickness was allowed for the casting to give this enormous saving in weight in favour of the weldings, the author was informed 1¼ in., which seemed quite reasonable for a casting of this size. On the other hand, why could not this casting have been made in four pieces instead of two, thereby reducing the casting thickness to ¾ in.? This would have reduced the weight by 16 tons per set in ordinary irons. This saving could be further increased by the adoption of Meehanite iron, there being five processes of this exceptional iron, the price being controlled in accordance with the process required to suit conditions.

Basing the process on the cheapest class of Meehanite, which is superior in strength to ordinary iron, the thickness of the casting could be reduced 50 per cent. Disregarding the full advantage of this allowance, and instead of ⅜ in. thick, calling it ½ in., the weight will be reduced by 22 tons per set. This weight saving can still further be increased by adopting a combination of Meehanite for the bottom framing and silicon aluminium for the top framing, thereby making the castings competitive with welding in respect to weight and price, provided the designer, patternmaker and moulder collaborate. The design could be made such that one section of the top and bottom framing, with modifications, could be used as the pattern for the other three sections. The author has quite a number of combinations with brass and silicon aluminium, also iron, all of which are recognised by the Admiralty on a weight saving basis, and under these conditions welding cannot claim such large percentages of savings.

With the education of the designer, patternmaker, and moulder, by taking advantage of the many training facilities that now exist, closer relationship such as takes place in the welding industry will be possible. Provided these facilities are extended to the draughtsmen and apprentices, one need have no fear of weldings beyond their acting as a stimulant to force foundrymen to use their brains for further development of the industry, to the mutual advantage of all concerned.

DISCUSSION

In opening the discussion the Chairman (Mr. F. Hudson) said that personally he had never been much perturbed over the problem of fabrication *versus* castings, as he considered the progressive foundryman would overcome most of of the competition if some thought and action were given to the matter. Mr. Russell's Paper confirmed this statement and indicated in a very practical manner the methods to be adopted.

In any investigations that the speaker had conducted into welded structures, particularly so far as fusion welds made by the electric arc or the oxy-acetylene flame were concerned, he had always regarded the metal in the weld as being essentially a casting, and from this point of view the majority of welds were equivalent to an inferior casting. The striking feature of most welds was the low ductility of the metal coupled with unsound structure, cavities, oxide inclusions, etc. A good weld would only show 7 per cent. elongation, whilst an average weld might give 5 per cent. and a poor one nil. Furthermore, fatigue tests indicated that the metal in the weld had only about a quarter of the value of the steel itself. Welded structures could not possibly compete with castings, particularly grey iron, so far as wear and corrosion resistance were concerned. Keeping these facts in mind it should not be difficult for the founder to replace welding by the exercise of initiative along the lines suggested by Mr. Russell.

The manufacture of castings was an old-established industry, probably the oldest industry in the world, and Mr. Hudson asked himself whether foundrymen were taking things for granted, and philosophically tolerating the more aggressive tactics of that young offspring, "fabrication." In most iron castings the design was either antiquated or factors of safety were used that were unfair considering the great strides which had been made in improving cast iron during recent years. On the other hand, those responsible for the production of fabricated structures by welding were up to date in method and had no old-fashioned practices to live down. Often a job was changed to welding to lighten or cheapen it, but very often if, in its new design, it was presented to the founder and cast with one of the improved irons, it would probably cost less to make and be stronger and more robust. It was therefore a matter for the founder to change design as illustrated by Mr. Russell, and to show enough aggressiveness to have his improved design accepted by the engineer.

In the discussion which followed Messrs. D. Sharpe, J. Cameron, Junr., J. M. Primrose, J. Arnott, A. Lawrie, A. Marshall and R. D. Lawrie took part.

THE CHAIRMAN expressed the thanks of the meeting to Mr. Russell for his informative and interesting Paper, and the manner in which he had dealt with the discussion.

Birmingham Branch

Paper No. 628.

RUNNERS AND RISERS ON SMALL STEEL MULTIPLE CASTINGS*

By H. T. Langley (Associate Member)

A great many points have to be considered before deciding where to run and feed a steel casting. Steel has certain characteristics which cause it to be a very difficult metal in which to make clean, sound castings free from distortion, such as components for the mass-production machine shop.

There is a high liquid contraction, causing large cavities in the heavier sections unless properly fed; the solid contraction is very high, and the steel itself, in cooling, passes through a range of temperature at which it is very weak. In consequence, anything holding the casting, and preventing easy contraction, will result in cracks and, if held enough, large tears.

The next source of trouble is scabs and the resultant non-metallic inclusions in the casting, which cause so much trouble in the machine shop through the breakage of tools and brings the tool room manager to the foundry to make many not very flattering remarks. The chief cause of this trouble is that the molten steel, because it has such poor flowing properties, has to be forced into the mould as fast as possible, and mis-runs and cold shuts are not unknown even then. This leads to an abrasive action on the mould and a refractory suitable for moulding has not yet been discovered, which will withstand that action at the very high temperature of molten steel, which must be about 1,600 deg. C.

These, briefly, are the causes of most of the trouble in the steel foundry, and until an alloy

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* See also pp. 720 and 721.

is discovered which gives the same strength at the same cost, but without these failings, the foundry executive staff will have to keep devising ways of overcoming them.

Overcoming Fluid Contraction

For the fluid contraction, risers are cast over the heavier sections to act as reservoirs to supply the cooling casting with liquid metal. This involves much waste metal, as the feeder obviously must be larger than the sections to be fed, or it would freeze first and be useless. There is also considerable expense cutting them off, and they certainly do not improve the appearance of the casting. It is therefore worth serious consideration to reduce them as far as possible.

Much can be done in this direction by using denseners in the form of horse-nails or cast chills with spikes cast in them to hold them in position, but moderation is necessary or complete fusion between chill and casting will not take place, and when machined it will show as a fine crack which may result in the rejection of the casting after much expensive machining.

Solid Contraction

For the solid contraction proper ramming is necessary, care being taken to ensure that the face of the mould is hard enough to withstand the flow of metal, and the body of the mould soft enough to give to the cooling casting. This can often be done better by ramming up blocks of wood between projecting parts, and drawing them out, leaving a space for the rest of the mould to break into. This can, of course, be done with machine-made moulds, where difficulty may be encountered in obtaining uneven ramming.

The runners and risers should be placed, if possible, in such a manner as not to pull against each other, and to be well clear of any bars in the boxes. In addition, it is frequently necessary to have bars ready and to loosen all round as soon as the mould is poured.

Feeding Difficulties

Perhaps the most difficult problem is to get a clean casting, as when taken in conjunction with soundness, the two are nearly always in opposition to each other. The author knows of no sand suitable for green-sand casting which will withstand the metal being poured at the top of the casting without scabbing. Therefore, one has to resort to running most jobs at the lowest point and forcing the metal up the mould. This certainly gives a much cleaner casting, but it has the great disadvantage of having the hottest metal at the bottom of the casting, whereas for feeding purposes it is required at the top. With very small castings this does not appear to matter, but as the castings get larger it is very noticeable, and hot metal must be introduced into the feeders. This can be done quite satisfactorily in many cases by having branches off the downgate in as many places as required. This method is much quicker than filling the risers when the mould is a quarter full, as is usual with very big castings.

The Time Factor

The time factor is of great importance in steel casting. There is only about 100 deg. C. difference between really hot and cold metal, and all metal has to be poured when ready. Therefore, one has to cast in batches, depending on the size of the furnace. This makes it very difficult to determine the size of the runner when making large quantities of very small castings, and the runner which is too small on one heat may be too large on another, or at the beginning of the cast; but in practice the difficulties can usually be overcome, and the author has cast over 200 sprays of castings with one heat from a one-ton converter.

It is proposed to show how, in the author's foundry, the management has eliminated many risers, and produced steel castings suitable for mass-production machine-shop practice with an appearance which a few years ago was thought to be impossible.

Fig. 1 shows a box of steering boxes, each casting weighing $5\frac{3}{4}$ lbs. When delivered to the machine shop, they must be clean, sound and true to pattern, as they are all machined in a jig, and cross-joints or scabs would throw all the holes out of place.

There are eight holes drilled in this box, and each one involves a boss, which is a potential home for a draw cavity. Horse-nail chills are used to help to overcome this difficulty, and, cast as shown, there are very few returns, but if cast too hot, the boss nearest the runner will require welding in the corner nearest the runner. The solution of this has not yet been found.

It will be noticed that the downgate is very long to give height. This is important in order to get the top boss solid. By this method the risers have been reduced to a pencil thickness, so that they are easily cut off, save metal, and do not spoil the look of the casting. These dummies are by no means meant to feed the casting, but allow the gas to escape readily, minimising the possibility of a blow hole in the top. By their use the top boss is also more clearly defined, the metal running over just a little more readily.

Fig. 2 shows four sectioned steering boxes machined to indicate how the sections vary, and to show that they really are solid. Two are the same as are shown in Fig. 1, and the others have an additional plate with two fairly large bosses at each corner. This plate is $\frac{3}{16}$ in. thick and the bosses $1\frac{1}{2}$ in. long and 1 in. dia. The method of running is the same, but two dummies are cast over the extra bosses, and are $\frac{5}{8}$ in. dia. No trouble has been encountered since this addition was made, except that care must be taken in the fettling shop, or they will be distorted.

Fig. 3 shows a different type of steering box which weighs 9 lbs., and from a steel founder's point of view can only be described as a nasty piece of work. Unfortunately the illustration does not show to advantage all the bosses and corners, which are the founder's nightmare, but it is apparent how the section varies from $\frac{3}{16}$ in. on the wall of the box to $\frac{5}{8}$ in. on the holding-down flange. There is rather a heavy boss on the side and a heavy lump inside. These were first cast with the runner right at the bottom, and the result was a clean casting, but at every corner was a deep pull. The runner was then cut as shown, and the castings were greatly improved so far as pulls were concerned, but they cracked round the shoulders, where the small brackets are shown. These were put on afterwards and this stopped the cracking. Another complaint was a scab about the same place, which still persists unless very careful sand control is exercised. No risers are used, and horse-nails are used where necessary. The runner is again brought up well above the top of the castings.

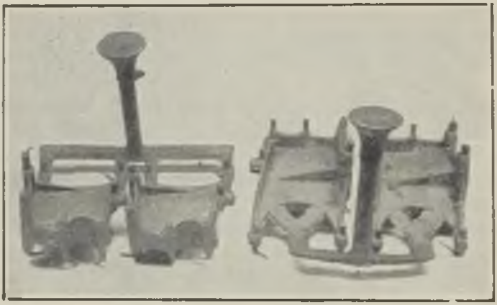


Fig. 4.—Bracket Castings.

Fig. 4 shows a bracket which weighs 4½ lbs. It is 10 in. long and 4½ in. wide, and the plate part is only $\frac{5}{32}$ in. thick. It is necessary to pour these castings with very hot metal. They were first run directly into the bottom bosses, and the castings so secured had a good appearance and machined perfectly, except at the bosses where the runner was situated. There was a draw where the boss joined the plate; nails at that point would be useless, as the force of the metal would just wash them away. To provide a large feeder was impracticable owing to the cost, and the distortion of the casting in removing them, so the runner was moved to the thin plate, as shown. The result was a sound casting as far as pull was concerned, but it was found impossible to stop the thin plate from scabbing. This spoiled the appearance of the casting, and there was the risk of broken or blunted machine tools, so another runner was tried.

Fig. 5 shows the runner cut with a right-angle turn into the side of the bosses; the result justified itself and the castings were quite sound. The turn in the runner apparently stops the lower portion of the runner pulling from the casting. The two pieces shown are cut from the same casting, and show how relatively thick sections cast into the thin section and give no trouble. They also show how difficult it was to find a really satisfactory place for the runner.

In Fig. 6 are shown three engine brackets. Of the top two, the smaller one weighs 8 lbs. and the larger 14 lbs. They have a solid boss with a groove in it 3 in. long by 2 in. dia. These grooves made the feeding of the bosses a difficult matter consistent with reasonable fettling costs, and it was found best to cast them on end, as shown. Not only was fettling simplified, but the larger casting in particular was much cleaner, as, when cast flat, the top plate part was generally dirty.

The bracket at the bottom of the illustration did not at first seem to offer any particular trouble, but this was not the case. The first few were cast flat, the opposite way up to that shown in Fig. 6, the metal being run in with two small gates. A small scab, however, would persist in appearing where the wash of metal took place. The next sample was cast the other way up, which gave rise to another trouble; this time pulling and cracks occurred in the fairly thick section where the bearing joins the plate, and holes were found in the two corners.

The next samples were cast in the manner illustrated, and were very satisfactory. As can be seen, they are cast on their side; the pattern is placed diagonally across the box and the metal introduced at the lowest point and flows off at the other end. Round chills are cast in each boss and afterwards drilled out. These chills must, of course, be smaller than the required hole, to ensure machining away any part where incomplete fusion between chill and casting might occur.

Since this photograph was taken, the management has been making these brackets two in a box, one above the other, thus effecting a saving in metal and moulding costs, with equally good results.

The rear axle covers, shown in Fig. 7, are 9 in. dia., with a $\frac{1}{2}$ in. thick outside plate, and where machined, $\frac{3}{16}$ in. thick on the centre part. These castings are tested with paraffin and the smallest scab is sufficient to cause rejection. When cast flat much difficulty was found through scabbing and various runners were tried, but by far the best results were obtained by casting them as shown. At first some trouble was experienced through the casting swelling and a rather larger runner and riser were used to take the strain off the mould, this method being much easier than packing the moulds with plates.

In Fig. 8 is shown an axle tube which weighs 84 lbs. It is full of potential sources of trouble, for it is 4 ft. long, the flange at the end is 1 ft. 2 in. dia. and the metal thickness runs from $\frac{1}{4}$ in. at the flange end to $\frac{3}{8}$ in. at the small end. The ball race (which can be plainly seen) is $\frac{3}{4}$ in. thick and there is no possible way of feeding this part of the casting except by the use of denseners. At first these axle tubes were poured from both ends, but the experiment was a complete failure; the casting tore nearly in two, apparently through the two runners pulling against each other, and the small end was very dirty through scabbing.

In the next attempt the tube was cast as shown, and although the metal had to be poured much hotter the casting was cleaner and free from *large* cracks. The brackets seen on the side were then put on and a green-sand top-half core used instead of an all-dried core. The top was also lifted off as soon as possible, the sand eased all round and the core knocked out. This was done with all the successive castings. Considerable distortion was found to occur in this casting, and the strip running the entire length was put on to prevent this. The arrangement was successful enough to warrant its being continued, but most of the castings still require setting, which is done when they are withdrawn from the normalising furnace. The small flow-off at the end was the cure for a small gas hole, apparently caused by the air not escaping sufficiently quickly.

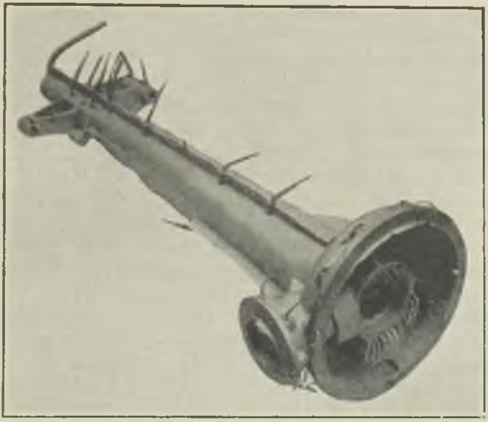


FIG. 8.—AXLE TUBE CASTING.

In conclusion the author wishes to thank all members of the Austin Foundry for their ready co-operation and assistance, and the Austin Motor Company for their permission to present this Paper and for the illustrations.

Vote of Thanks

Mr. H. G. Hall, in proposing a vote of thanks to the lecturer, said the lecturer had been dealing with one of the most difficult problems met with in ferrous metallurgy, that of founding a material possessing a high liquid shrinkage. He, himself, had to deal with a material possessing a similar complication, *viz.*, malleable cast iron. One of the problems was due to sand, which should be studied more intensively. If a sand could be found which would remain rigid until the casting was solid and then break up, great progress would have been made towards solving many of the problems encountered in ferrous founding. It was rather interesting to note that Mr. Langley did not blame the metallurgist for the cracking of his castings.

Mr. G. R. Shotton, who seconded the vote of thanks, said the Paper dealt with a problem in which all foundrymen were interested, and he was sure that the lecture had been most helpful. One interesting feature was that of the steering box cover, and he was struck by the fact that very little feeding was used, reliance being placed chiefly on the use of denseners. In order to make a similar casting in white iron, one would need to use heavy feeders on the boss.

Temperature and Shrinkage

Mr. W. Laverton, speaking with regard to the short run question, said one must remember that the higher the temperature of pouring, the more would be the shrinkage. He thought that Mr. Langley, by using 1,600 deg. C., was using the proper temperature for such castings. He would like to ask if any pyrometer was used.

He would also like to know what Mr. Langley thought was the maximum moisture content for green sand work. Mr. Langley thought that vertical running was very good, and should be the first method to be tried, as it gave a better casting. He (the speaker) was rather interested in the bracket castings, as no chills were used.

With regard to the axle covers, he would suggest that money might be saved by using curved chills to suit the radii of the casting, as this would produce a much nicer job.

Fusing of Denseners

Mr. E. W. Wynn said that he would like to know if the nails used as denseners were fused into the metal. In his experience, they did not fuse, and a hole was left. Turning the runner gate away from the casting rather than letting metal enter direct on to a flat surface of casting was good practice, as also was the running in at the thin portions of the casting. He was surprised at the low liquid shrinkage as shown by the runner bushes; he recollected that in making white iron castings for black-heart malleable iron the bushes had a big sink. In ironfoundry practice, the use of internal chills changed the structure from the centre to the edge of the casting, and caused a more dendritic structure to be formed.

Where Science Elucidates

Mr. J. J. Sheehan congratulated Mr. Langley on his Paper; the only criticism he had to offer was that it was too short. Mr. Sheehan said that the metallurgist could produce good metal to exact analysis; science could produce a good sand to make the moulds, but it required the art of the foundry foreman to produce sound castings by the proper application of gates and risers, denseners and chills, and it was only the intuition of an artist that could locate these details with success. The only alternative to this art, said Mr. Sheehan, was tiresome and uneconomic trial and error. Fig. 4 showed two unsuccessful methods of gating a thin bracket weighing 4½ lbs., being 10 in. long and 4½ in. wide, and Fig. 5 showed the successful method described by Mr. Langley, as follows:—The runner was cut with a right angle turn into the side of the bosses; the result justified this, as the castings are quite sound—the turn in the runner apparently stopped the lower portion of the runner pulling from the casting. Art initiated this method, continued Mr. Sheehan, and science explains it by pointing out that by simply changing the direction of the isothermal lines in the runner, rapid freezing is obtained over a small area (*i.e.*, at the angle) and the casting cannot feed back. Other examples occur, the man who first used coal dust in moulding sand for cast iron was certainly an artist, and scientists still find much pleasure in explaining its function, although the credit still belongs to an unknown artist.

Mr. G. M. Callaghan said that he was interested to hear Mr. Langley say he " banged " the metal into the mould. All the castings he had seen made were bottom poured. He was also impressed by the number of nails used. He himself had a great deal of trouble through the nails showing up on machining. He would like to know if Mr. Langley had found a good coating for chills. He had used blacking, but found that it tended to give discoloration on drying.

Mr. H. G. Hall remarked that no one would dispute that cracks were greatly increased if the metal were in an oxidised condition. Mr. Hall asked the lecturer if he used any special deoxidiser and whether he had used aluminium and and the alloy of aluminium, calcium and silicon.

Author's Reply

In reply to Mr. Shotton's remarks, the **Lecturer** stated that the steering boxes were not tested with paraffin, but were thoroughly tested by other methods, and except in isolated cases the denseners were found to have been fused into the metal. He expressed the opinion that the exceptions were those cast with the last and coldest metal.

Mr. Laverton had said that contraction troubles were the cause of a large percentage of his scrap, but he (Mr. Langley) found that the largest portion of the scrap was due to misruns.

With regard to the type of furnaces used and the moisture content of the sand, Mr. Langley explained that he was making very small castings, and the steel, although obtained hotter than in most foundries, was getting cold by the time he was finishing casting. The furnaces used were 1 ton Stock converters. He used a sand with a moisture content of 3 per cent. as he considered that the drier sand gave better castings, and there was less liability of gas holes or distortion being formed.

Mr. Laverton had been surprised at the absence of chills, and in reply he would say that he considered the use of chills a bad habit, as they tended to move troubles from one place to another rather than eliminate them.

Replying to Mr. Hall, the author said that the best pig-iron, low in sulphur and phosphorus, was used. Silicon and manganese were, of course, added at the finish of the blow, as was aluminium. Usually 4 lbs. aluminium per ton of metal was used. He had tried silicide deoxiders, but found them of insufficient benefit to warrant their continued use. The proportion of spongy metal was less than ½ per cent., and the chief cause of this was due to carrying the ladle from one end of the foundry to the other. In such cases a shell was present in the ladle, and tended to oxidise the next metal received. He usually added a little aluminium between each tap in such cases.

Newcastle-upon-Tyne Branch

Paper No. 629.

ESTIMATING FOR THE FOUNDRY

By C. M. Wight (Associate Member)

Estimating is the predetermining of the conditions connected with the production of work and is carried out principally for protection against accepting orders at a price which would not be a commercial proposition.

An estimate may be divided into two sections, one being simple arithmetic and the other a matter of judgment. In the former section are placed the primary factors, viz.:—The weight and value of material required and wages for each operation through which the work must pass. The latter division covers the secondary factors or those considerations which affect the result indirectly, such as:—The length of time that floor space or pit area is occupied compared with the value of the work; extra tackle required; the amount and position of machining relative to the position of casting where difficulty arises in clearing deposits from important machined faces while pouring, and risks of rejection due to awkward coring, trouble from uneven section, and failure to withstand specified tests.

Some foundries are more favourably placed for dealing with these factors, and it becomes obvious that no rules for price fixing can be made that would apply equally to all foundries, so that various methods of estimating have been adopted. The results produced by these systems are widely divergent and are to some extent, although not fully, responsible for the difference in quoted prices. The variations in prices are more noticeable in work that is not the general type handled by a foundry or district where prices have automatically become standardised.

Buyers of castings occasionally find the highest tender to be as much as double that of the lowest price offered, which is a source of wonder to both the prospective buyer and those who are also competing. If the reasons for the differences in prices be investigated it will invariably be found that all cases of extremely low prices are due to faulty judgment or errors in calculation, whilst those which are high may also be due to the same reasons, or it may be that owing to commitments for any particular class of work, a greater quantity cannot be produced without increasing the facilities for production and working overtime, which reflect in a higher selling value.

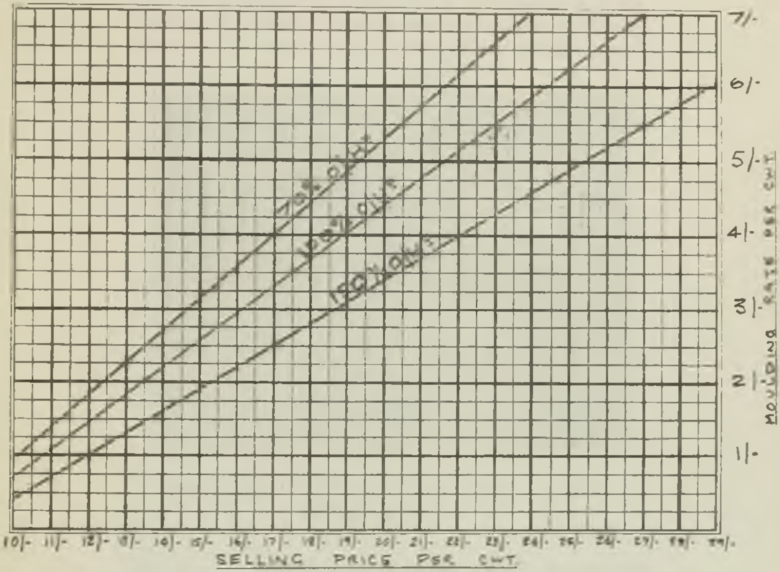


FIG. 1.—CHART SHOWING THE INFLUENCE OF OVERHEADS ON SELLING PRICE AT INCREASING WAGE RATES.

Methods of Estimating Examined

An investigation of some of the methods applied to foundry estimating shows the following:—(*a*) An estimate is based on a cursory glance at the pattern or drawing, and a price is quoted according to what the estimator assumes the order for the castings will be placed at, or use is made of a previous selling price for similar work; (*b*) castings are classed by weight considerations only, and prices quoted in inverse proportion to the weight; (*c*) castings are classed according to type and weight; (*d*) estimates are based on previous orders for similar castings; (*e*) estimates are fully considered and prepared from the calculations of weights, and wages for each process in the course of production.

Fig. 2.—The Six Cylinder Block taken as an Example.

The first of these methods is guess-work and for obvious reasons should be discouraged. The second method is but little improvement on the first, as casting weights cannot in themselves be a guide to a selling price. The third and fourth methods are nearer to approximating a true selling price, but are complete only so far as similar work is concerned, and difficulty arises when no precedent is available.

In foundries where payment by result is on the basis of fixed rates per cwt. for various classes of castings, the system of quoting on type and weight is more fully justified, if considered with other conditions of manufacture.

When basing selling prices on previous records, changes in the method of production, rates of labour and cost of material must be taken into account. Old records should be used with caution, and a knowledge of the circumstances under which the work was previously executed is essential. The last method (*e*) is recommended for the reason that all points affecting the final price are considered.

Handling an Inquiry

On receipt of an inquiry, the specification is first examined for clauses that are difficult to meet, care being taken to see that no clause is so worded that the founder is liable for incidental or consequential damages in case of any failure of the casting when in working position, or for unavoidable suspension of delivery.

The next step is to examine the drawing, and if this is deemed suitable for manufacture, a check on the difficult points and a calculation of the weights are made. The method of moulding and the tackle required is also examined; then the mould and core wages can be determined. In the case of large jobs, these figures are probably best arrived at by dividing the job into sections and allocating so much per man per day. The wages for small work are on the basis of the number of castings made in a stipulated time. To the above wages must be added the dressing charges and war bonus.

Overhead Charges

The next factor is overhead charges. It is not in the scope of this Paper to recapitulate in detail the different methods by which overhead figures are obtained; perhaps it will suffice to point out that there are various methods, each equally good, of allocating overhead charges. For example, overheads may be based on tonnage output; on mould and core labour; on so much per hour for each operation; on a percentage on wages for each operation; on the total over the whole foundry, and, finally, so much on shop on-cost, taking all wages against production and adding a percentage for standing charges, which covers rates and taxes, executive staff, office and sales expenses.

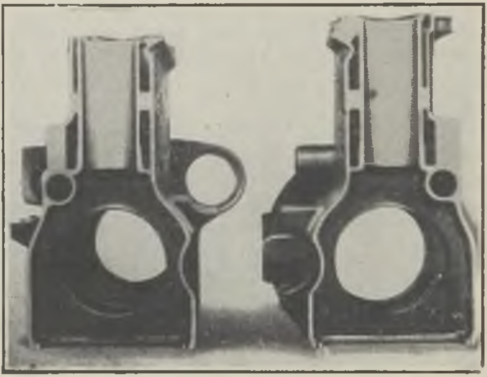


FIG. 3.—SECTIONS OF THE CASTING SHOWN IN FIG. 2.

Any one of these methods may suit a particular foundry better than another, but the deciding factor is whether the overheads are absorbed or otherwise. Therefore, it is only possible to decide on figures from "costs" and experience of the actual working of the foundry in question. It must be assumed that the overhead figures have been compiled from an efficient costing system, and can be used with confidence by the estimator.

The estimator in turn has but little control in the manipulation of the overheads, as he does not decide the type of work for which inquiries are received. Only one thing is certain, that overheads can only be allocated to the work according to its type. For instance, ordinary plain firebars are sold at 7s. to 9s. per cwt. for the reason that this class of work need not carry more than 60 to 70 per cent. of the overhead costs, whilst jobs weighing 20 to 30 tons would require to carry 150 to 200 per cent. overhead, so that the estimator must decide on suitable overheads for each type of job and quote accordingly, keeping in mind the fact that small castings, such as firebars or brake blocks, do not need the handling or the use of cranes such as are required on large castings.

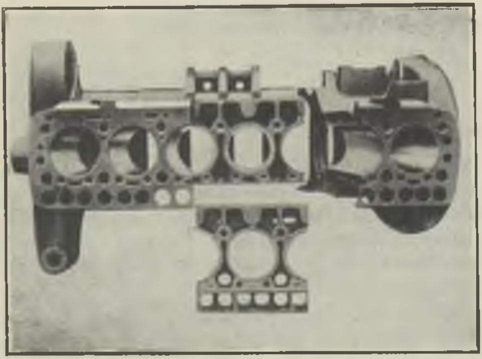


Fig. 4.—Sections of the Casting shown in Fig. 2.

The price of metal can only be obtained from actual melting costs, which are influenced by such factors as the efficiency of the cupola or furnace in use; handling charges before melting; overheads, and the percentage of good castings delivered per ton of metal melted. The figure for this would probably be between 60 and 75 per cent.

Metal Costs

The method of obtaining metal costs is given as follows:—

	£	s.	d.	
1 ton of metal charged at, say	3	15	0	
Cost of melting	0	15	0	
Making a total of	£4	10	0	
Allowing 5 per cent. loss, then weight of metal is 19 cwts., and the cost equals	4	15	0	per ton.
For each ton of metal melted assume 14 cwts. of good castings are delivered and 6 cwts. of scrap credited at, say, 3s.	0	18	0	
	£3	17	0	
which is equivalent to	£5	10	0	per ton.

Figures which appertain to one foundry are rarely of use or interest to others, as in both cases of overhead and metal costs, so many variations occur that each foundry must settle these questions in accordance with its own requirements.

Adjustments to accommodate variations in the cost of labour or material can easily be anticipated, once actual figures for overheads and melting have been proved.

A résumé of the foregoing remarks shows that the three principal items are as follow:—

		s.	d.	
Wages	mould	5	6	6s. 6d. = 3s. 3d. (2 cwt.)
	core	1	0	
	dressing	1	6	
	war bonus	2	0	
Overheads at 100 per cent.		10	0	
Metals at 5s. 6d. cwt.		11	0	
		31	0	

In the first column are placed wages, overheads, and metals; the wages in the second column have been sub-divided and values for overheads and metal have been allocated. In column 3, assumed values have been placed against each item, and the total value divided by the delivered weight, which in this case is 2 cwts. and gives a rate of 15s. 6d., to which must be added the carriage rate and profit.

TABLE I.—*Influence of Overheads on Estimated Selling Price.*

	Overhead, per cent.		
Mould and core	70	100	150
	s. d.	s. d.	s. d.
Wages, per cwt.	1 0	—	—
Dressing	0 9	—	—
War bonus	0 5	—	—
Total	2 2	2 2	2 2
Overhead	1 6	2 2	3 3
Metal	5 6	5 6	5 6
	9 2	9 10	10 11
Profit, 10 per cent.	0 11	1 0	1 1
SELLING PRICE	10 1	10 10	12 0
Mould and core	—	—	—
Wages, per cwt.	5 0	—	—
Dressing	0 9	—	—
War bonus	1 4	—	—
Total	7 1	7 1	7 1
Overhead	5 0	7 1	10 7
Metal	5 6	5 6	5 6
	17 7	19 8	23 2
Profit, 10 per cent.	1 9	2 0	2 4
SELLING PRICE	19 4	21 8	25 6

This is a typical example of the general type of estimate where no contingency or extra tackle are required.

It will be observed that the overhead cost figure covers all sundry labour, and the war bonus is based on piece work rates.

Attention is drawn to the figure of 3s. 3d. on the extreme right-hand side of the Table. This is obtained by dividing the mould and core wages by the weight in cwts, and is termed the moulding rate. This figure is to some extent a check on the estimated wages and can be used to facilitate further calculations as follows:—

Let it be assumed that the moulding rate is 1s. in one case and 5s. in another, and proceed to obtain equivalent selling values for each at 70, 100, and 150 per cent. overheads. This is set out in Table I.

Use of Standard Graph

In column 2 are shown wages and bonus, also dressing, which has been taken at an average of 15s. per ton piece price, and a normal profit of 10 per cent. is included. It is now an easy matter to plot these points and obtain curves from which any selling value can be determined, and Fig. 1 shows a set of curves determined from the previous figures; it will be seen that the figure of 3s. 3d. referred to previously is equivalent to a selling value of 17s. These curves can be extended to accommodate almost any selling price and apart from saving a separate calculation for each item the results are automatically checked. Further reference to the curves shows to what extent a difference in weight or wages affects the final price.

Let it be assumed that the estimated weight of a casting is 20 cwts. and the wages for mould and cores is £4 10s.; then the moulding rate is 4s. 6d. per cwt., which is equivalent to a selling value of 20s. 4d. per cwt. If it should happen that the actual cast weight was 18 cwts., the wages being as before, the moulding rate would then be equal to 5s. and the equivalent selling price would equal 21s. 8d., which absorbs 6½ per cent. of the estimated 10 per cent. profit.

On the other hand, if the wages be underestimated and a price of £5 has to be paid, then the moulding rate is 5s., which is equivalent to a reduction in weight to 18 cwts. It is, there-

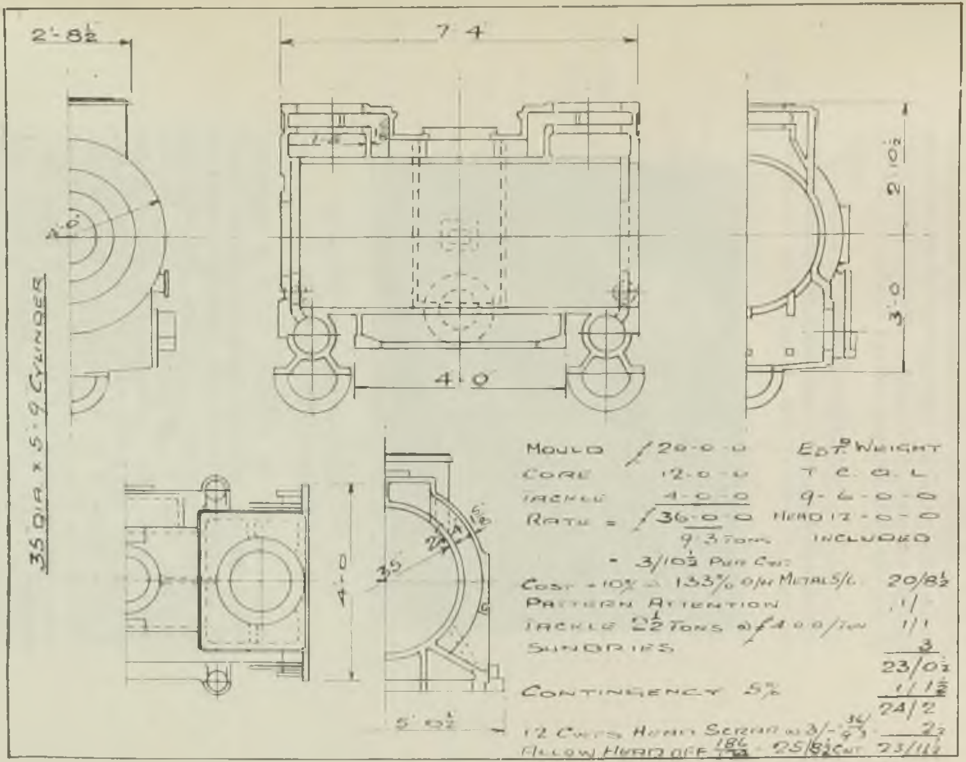


FIG. 5.—FILING RECORD OF TYPICAL BASIS CONDITIONS FOR ESTIMATING.

fore, obvious that close attention must be given to both weights and moulding wages. This especially applies to light work and low rates of labour where the increase of say 1d. on 9 lbs. is 1s. 0½d. per cwt., and would raise a selling price of 24s. to 26s. 9d. per cwt.

Apprentice Labour

When dealing with low rates of labour, such as boy or semi-skilled labour, the overhead charges should be adjusted, as it is apparent that a normal overhead rate charged on 1d. or 2d. per casting would not contribute much to the foundry expenses. To meet the case the overhead cost is increased *pro rata* to the wages saved. For instance, if a man's wages were £1 and overheads were £1, the total is £2. A boy's wages at 7s. would require first 100 per cent on 7s., that is, a total of 14s. and 100 per cent. overhead on wages saved would equal 13s., making a total of £1 7s., against £2 at full rate.

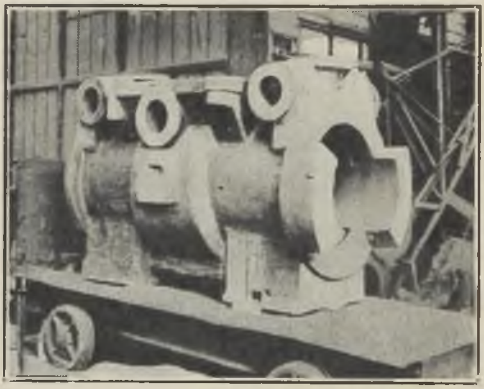
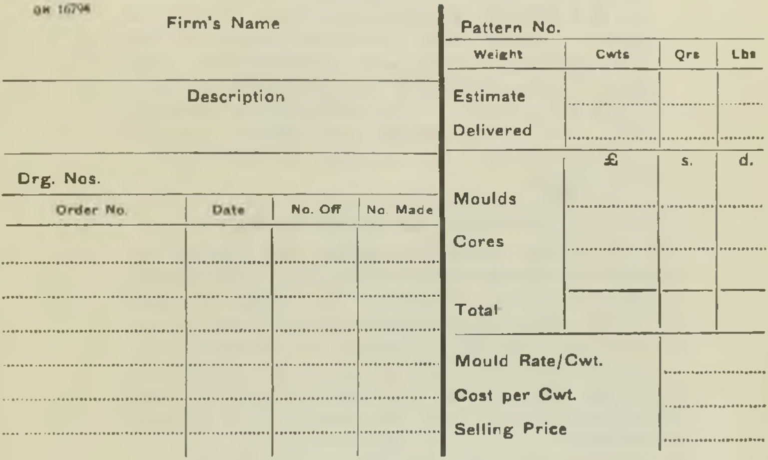


Fig. 6.—The Casting for which an Estimate is shown in Fig. 5.

In the case of estimates for castings which can be machine-moulded, the first considerations are the size of casting and number off. The first item decides the number which can be obtained per box, and the number required determines whether or not the amount of work in setting up will be repaid by the reduction in moulding wages.

No useful purpose will be served by endeavouring to define exactly the minimum number or type of casting that can be economically manufactured by machine-moulding processes, as each estimate must receive consideration in relation to the nature of the castings to be produced. Generally speaking, not less than three large castings, say of about 3 cwts. each, or ten of a smaller type, each sufficient to fill a 16 in. box, could be machine moulded economically.



GH 16794

Firm's Name

Description

Drg. Nos.

Order No.	Date	No. Off	No. Made

Pattern No.

Weight	Cwts	Qrs	Lbs
Estimate			
Delivered			

	£	s.	d.
Moulds			
Cores			
Total			

Mould Rate/Cwt.	
Cost per Cwt.	
Selling Price	

FIG. 7.—TYPE OF RECORD FOR FILING FOR FUTURE QUOTATIONS.

The ideal condition for machine moulding is where several hundred castings are required, when the pattern costs per casting are negligible. The difference in wages should be in the ratio of one for machine moulding to between three to five for hand moulding. This apparent saving on prime cost of production must therefore be adjusted in the estimate to provide for upkeep, power and depreciation of the machine.

An example of machine moulding is given in Fig. 2. The casting is a motor six-cylinder block, and weighs $6\frac{1}{4}$ cwts. In this case the difference between machine- and hand-moulding wages is 12s. 6d. per casting, or a ratio of one to two machine to hand moulding. Perhaps a greater saving would have been expected, but the finishing, coring, and closing were fairly heavy items, which will be appreciated on examining Figs. 3 and 4. In the right top corner of Fig. 2 is a half mould, and below it is the machine lay-out; and on top left-hand side is the casting.

Estimating for Heavy Castings

For heavy work the method and basis of an estimate are the same as for light work, excepting for some additions. To illustrate these points fully, it is assumed that an inquiry has been received for a cylinder to a drawing such as is shown in Fig. 5, and to a specification which only called for normal tensile and hydraulic tests, and was clear of all binding clauses.

Examining the drawing, it is quite obvious that the cylinder should be moulded on end, and that a head or part head will be required to prevent a draw at the change of section under the top heavy flange and to carry away dross, etc.

The thickness of the cylinder body is $2\frac{1}{4}$ in. finished and other scantlings as $1\frac{5}{8}$ in., so that under these conditions the jacket cores should not present any difficulty, especially as there are ample venting facilities. It will next be seen that draw-backs will be required to form the two sides of the mould carrying the valve ports and at the front and back for the foot. This will involve a matter of $2\frac{1}{2}$ tons of tackle in the form of binding plates, and it will be necessary to mould in a pit of 11 ft. 6 in. by 8 ft. 6 in. by 9 ft. 6 in. deep minimum size. The mould and core wages can now be ascertained and times allocated, as follow:—

	Hrs.
Preparing bed and setting boss	24
Ramming up to top joint	70
Finish draw-back joints	20
Draw-back left-hand side	68
,, ,, right-hand side	30
,, ,, head	18
Ram top	38
Finish ready for dryers	62
Close and cast	62
	392

This figure represents approximately the normal time in which the mould could be made, so that for the total of 392 hours at the standard rate of 48s., it gives the equivalent of £20 wages.

The price for the cores was made up in a similar manner and amounted to £12 (235 hrs.). The extra cost of special tackle was £4. This gives a total of £36 and a calculation of the weight gave 174 cwts. plus 12 cwts. of head. The moulding rate is £36 divided by 9.3 tons, which equals 3s. 10½d. per cwt., and represents a selling price of 20s. 8½d. per cwt., when carrying 133 per cent. overheads and using metal at 5s. 6d., which is calculated on the delivered weight of the casting.

A comparison of the weight of the job with the length of time that a pit should be occupied was in this case normal, and therefore does not affect the price.

To this price must be added allowances for the following:—(1) Tackle material; (2) pattern boards and attention of patternmaker during moulding and closing; (3) sundries, and (4) contingency.

The tackle is calculated at £4 per ton, which allows for scrap value on the metal returned and makes an addition of 1s. 1d. per cwt.

Pattern charges are at 1s. per cwt., and sundries at 3d. per cwt.

The contingency allowance is, of course, purely an arbitrary factor. In the case under consideration the risk of loss was only normal, and as the work on the whole did not present apparent difficulties a contingency allowance of 5 per cent. was assumed and the price now amounts to 20s. 8½d. plus 2s. 4d. plus 5 per cent., or a total of 24s. 2d. per cwt. This figure is still further modified by taking into account the head, which gives 25s. 8½d. as the final result.

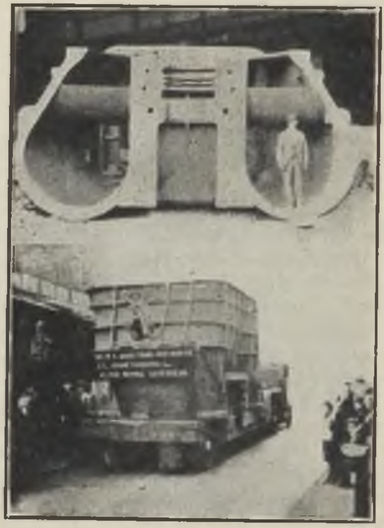


Fig. 8.—Exceptionally Heavy Type of Casting.

Fig. 6 shows the cylinder casting ready for delivery; the head was stopped off in way of the steam ports, and the joints of the drawbacks down the sides can also be clearly seen.

These draw-backs were divided into sections over the length of the cylinder.

It is of interest to note that the weight of the casting was 9 tons 5 cwts. 1 qtr., with a deduction of 7 cwts. for the head returned, which gives a net weight of 8 tons 18 cwts. 1 qtr., against the estimated weight of 9 tons 6 cwts gross and 8 tons 14 cwts. net, which was to the benefit of the job.

Unknown Factors

In the earlier part of this Paper reference was made to the judgment acquired after the arithmetical side of the estimate is finished. This covers the factors in the latter part of the example which has just been considered. It is, generally speaking, not possible to forecast at the estimating stage the class of pattern that may be received, particularly from a new customer, also the exact amount of wages for pattern attention, and the total amount of new gear necessary, especially in a jobbing foundry, where there is a continual variation in the work undertaken.

The selling price to be quoted may not altogether be comparable with that estimated, for it is an important condition that the estimator should have a complete knowledge of the market value of the work passing through his hands and be in a position to take advantage of the best terms that can be obtained.

Commercial Considerations

It must be borne in mind when deciding on the selling price that the full loss on defective castings cannot be charged up to the customers, so that if the capacity or equipment of a foundry is such that a price could be quoted for any particular class of work which is well below that of competitors in the district, the estimator has the opportunity of counter-balancing possible losses on other sections of work, and ought to maintain a price just sufficiently low to obtain the order. In an estimating department records which are easily and quickly accessible are essential, as a customer may require a price quickly for a repeat of an order, or a similar casting based on a previous job.

If reference again be made to Fig. 5, an example of such a record is given. This figure was reduced from the customer's print on to a loose leaf sheet of squared paper measuring 10 in. by 8 in. Only the principal dimensions and thickness are included, together with the full particulars of the estimate and final costs. Only a short time is required for a junior employee to make this sketch, and it is well compensated for in the saving of storage space for drawings, etc. These records are only made for what are considered to be outstanding jobs of high total selling value. They also serve as a check on future estimates for similar work.

For the smaller class of work where a large number of different patterns is in operation, records are also kept of each job, but only consist of written particulars such as shown in Fig. 7. A card on which these details are printed is issued to the foundry foreman for all jobs, large or small, and the piece price for mould and cores together with the estimated weight is indicated.

It is the foreman's duty to make the best terms possible with his men and fix prices which are to their satisfaction, as well as his firm's, but not to exceed the figures given without special permission. The final prices arranged are entered on each card, which is returned to the office for inspection and completion, and filed as a record. It will be observed that all references to prices have dealt with piece work, but the principles of estimating are the same for time work with the adjustment for an increase of war bonus.

It is not intended in this Paper to discuss the comparative merits of piece and time work, but so far as estimating is concerned, it is a definite advantage to have an agreed price fixed in the early stages of the work, for the approximate cost is apparent as soon as the piece price is fixed. It may happen that although every care has been taken in preparing an estimate an unexpected difficulty may arise, perhaps in the way tho pattern is made or some difficulty peculiar to a particular type of casting which only becomes evident from experience. If it be seen that the job will not be a profitable proposition, the best terms possible can be made, while there is still time to make some saving on the work.

The work of estimating for a foundry making practically all classes of castings rarely becomes monotonous, for the inquiries change from day to day, and although castings may be grouped into types, or classed in some convenient manner, there is invariably some point which calls for separate consideration.

Inquiries for a cast-iron bar weighing a few pounds or a casting such as that shown in Fig. 8 may be received. The estimate for the latter was made up in a corresponding manner to the example already given, with the exception that no heads were required. The weight of this casting was over 30 tons, and it was poured from three different points on the mould. At the stage whereat all the weights and wages are settled, the estimator's work on that job is finished until the actual weight and wages are checked up and records completed.

Incidentally, if it happens that a mistake be made in the moulding of any casting, which causes a waster, it is impossible for the estimator to assist. Neither is it possible for the foundry to make an under-estimated job pay.

No Swings or Roundabouts

It is sometimes argued that gains on one class of work compensate for losses on another; this may be so, but from the estimating point of view such an idea should not be entertained. Each job should stand alone, both in the case of wages paid and final costing. In poor trading periods, prices are cut, and there is a tendency to accept work at low figures and to fill the foundry with work to help the overheads. This is a procedure which should only be followed with caution. The amount by which a normal selling price can be reduced depends, of course, upon the corresponding reduction in overhead charges.

As part of the overheads are directly work charges, fluctuating with production, only general charges are to be considered. Therefore, the price can only be reduced to such level as will cover all works costs and possibly a percentage only of the standing charges.

The Buyer

While the buyer, justly or otherwise, complains of the variation in the prices quoted by the foundries, it is often in his power to alter this condition. For instance, if an inquiry be sent out which does not contain sufficient information to enable the estimator to arrive at a definite conclusion as to the actual requirements, it is obvious that a careful estimator will cover for a much higher contingency factor. Also, in cases where the drawing is such that a weight cannot be calculated, it is impossible for the estimator to offer the lowest price.

Telephoned inquiries should only be for repeat, or similar jobs, and be very carefully confirmed in case of variation if the order should mature, for it may happen that after quoting a price for certain castings, the order is received, and if it does not comply with the quotation, the whole question has to be reviewed, with the attending annoyance and waste of time.

In the North-East Coast area, one of the most common verbal inquiries is for propellers. The particulars given are generally the diameter and pitch, from which the estimator must assume the weight, irrespective of the fact that for, say, a 10-ft. dia. propeller weights of actual jobs have varied from 29 to 47 cwts., and a price has to be decided on, which would cover the worst case.

The buyer can also help to obtain a speedy reply to his inquiry by giving the weights of the castings when these are available. It has already been pointed out how the weight influences the price, so that it is necessary to calculate each weight fairly accurately, and when a number of estimates are in hand at one time, with perhaps an average of six castings each, a good deal of time could be saved.

London Branch—East Anglian Section

Paper No. 630. TIME CONTROL IN THE MANUFACTURE OF REPETITIVE CASTINGS

By Bernard Brown, B.Sc. (Member)

Definition of Time Control

The phrase "time control" means simply labour control or management methods for ensuring a fair day's work for a fair day's pay. This statement may sound controversial, but there appears to be no other true way of stating the facts. Whatever opinions may be possessed on the subject, there must be agreement that some form of labour control is essential to any factory or foundry. There are three main methods of doing this.

Day-work payment is usually made at such a level as to maintain good relations between the men and the directorate of the company, and the foreman has his own particular methods of maintaining discipline. This system is satisfactory if exactly the right type of foreman is available, but this is not easy, especially when many foremen have to be engaged to cover the activities of hundreds, and sometimes thousands, of operatives. For the men the system is not so satisfactory, since, however hard they work, they are paid the same, and furthermore, they are subjected to the whimsicalities of their foreman.

The second method of control is that commonly known as incentive payment or payment by results. This enables the man to earn more money if he produces faster, though not always in equal proportion. Piecework, premium bonus of its various types, the Rowan system, tonnage bonuses, etc., all come within this category. It may be wondered why a system of incentive payment can be regarded as a method of time control, and it may be argued that it is introduced to allow the man to make more money if he cares to work harder. This is definitely not the modern conception of incentive payment. Piecework, or bonus, when set, must be earned, and the amount earned or lost forms the means of time control.

The third system is that where men are paid high day-work rates and must maintain a definite level of output, any fall of production meaning a reprimand.

Importance of Time Control

The importance of time control in any foundry depends naturally upon the ratio of labour cost to production cost. It might be contended that in certain classes of work, where the average weight per casting is a ton or more and the class of moulding relatively simple, time control matters very little, since it is completely overshadowed by the cost of pig-iron and scrap. To a certain extent this is true, but for the purpose of the present Paper consideration is only given to foundries producing a light type of casting (averaging, say, ten pounds each) in large quantities, but of such varying types as to render what might be termed continuous production nearly impossible. In this case the labour/material ratio might be of the order of one to one, that is to say, labour is equally important as material. Nevertheless, it must be borne in mind that, no matter how small labour may appear as compared with material, it is important, since, more often than not, it is the one factor under the direct control of the management. Raw material prices are controlled by market conditions, and, although an astute buyer may economise by a fraction of 1 per cent., this becomes increasingly difficult.

Industrial Position of Time Control

Time control was first used in the old-time piecework gangs where a master moulder was paid so much per job and engaged his own labour, naturally retaining as much of the proceeds as possible for himself. Besides this, there were innumerable bonus schemes based on tonnage. In explanation of Taylor's system, it may be stated that Taylor refused to guess or evaluate by experience the time which ultimately controls profits, which should be allowed for a particular job, and instead, devised means for measuring it. Taylor's experiments have been the basis of formidable ramifications of time and motion study from which have been evolved conveyors and recorders, micro-motion study and slow motion cine-camera work. Most activity along these lines has been displayed in America, where quantities are high, as also are labour rates. In Great Britain, time study was first adopted by the newer industries, such as automobile and the light electrical enginering companies, though now it is commonly encountered in almost every branch of industry. In the

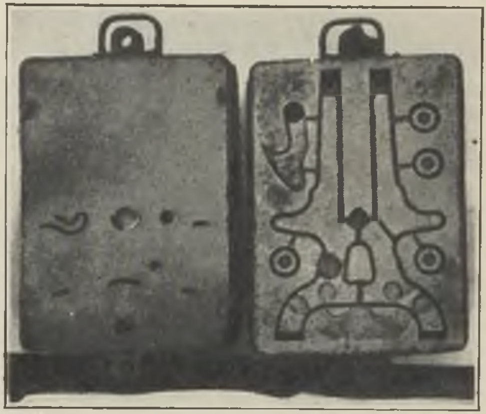


FIG. 1.—SIMPLE MOULD PRODUCED ON A PNEUMATIC MOULDING MACHINE.

opinion of the writer, it may be regarded as perhaps the greatest advance in industrial organisation.

Rational Rate Setting

The most elaborate methods of determining a time are made with the single object of fixing a particular rate of working for an operative. The old-time foreman set his rates or prices by his experience of what he thought was accomplished. For example, he knew that one operator always produced sixty-three 16 in. by 12 in. boxes a day, and he therefore set his piecework price per box.

Fig. 2.—Mould Produced on a Moulding Machine using Snap Flasks and Vibrating Pattern Plates.

A modern time-study man with his stop-watch, performance and fatigue curves arrives at a rate of working which should be achieved by a man of average intelligence and average application to his job. By various devices he endeavours to eliminate from his calculations the human factors of the particular individual, working only for the average. He endeavours to measure the energy required for the performance of a particular operation and to translate this into a time or piecework price. Neither of these methods is correct. The old-time foreman only knew what had been achieved, not what should have been done, and he automatically made his price so that it compensated for waiting for metal and the like during a normal day. On the other hand, the too scientific time-study man frequently makes so many corrections for the innumerable factors appertaining to the performance of work that he often dares not submit his findings without obtaining some confirmation from the foreman.

Good rate fixing, which is not too often encountered, is a combination of scientific observation and common sense. The actual time of a job is, obviously, the time which that job takes, yet there are men who argue for hours on how long a particular operation would take, avoiding for their own obvious reasons an actual trial against time.

Quite a common statement is that all types of work cannot be timed, but the author has not encountered any jobs upon which a time cannot be set, though not always with advantage under the particular existing circumstances. If a time cannot be set reasonably easily on the majority of repetition jobs, it may be taken as fairly indicative that there is something radically wrong with the methods employed. For example, if a drilling operation is being timed and the operator spends twenty minutes at the stores in obtaining a $\frac{5}{8}$th reamer, it is fairly apparent that something is amiss with the system and must be corrected before one makes any further effort at settling rational rates.

The author contends that foundry work can be rate-fixed by normal engineering methods employing the stop-watch. From the viewpoint of the rate fixer or time-study man, the foundry presents certain difficulties, as, for example, the wide divergence of operative dexterity between different moulders, but these are not insuperable barriers to reasonable accuracy. The foundry does have some advantage in that the basic materials used are simple and not likely to cause trouble. Thus, give a moulder a pattern plate, boxes and sand, and he will produce moulds, but in other engineering shops many things may go wrong.

Time Control Further Explained

It must be pointed out that time control is almost invariably associated with incentive payment. When reference is made to piecework or bonus actually a labour time is meant. Time control is: (1) the setting of a time by rate fixing, and (2) the recording of the time the operator or moulder has taken whilst on the job and a check of the amount of work, *i.e.*, the number of castings produced.

In many factories it is found that one element of time control is in operation without the other. Sometimes there is an elaborate rate-fixing department which sets times very accurately, whilst the organisation takes no particular care that these times are met or that there is an exact count of the parts produced. In just the same manner there will be found factories with clocking-in systems and rigid rules against latecomers and similar delinquents and complete omission to check that men are working whilst in the building. It is sometimes said that the cost of running an elaborate piecework system may more than offset the economies thereby introduced, but this need not be regarded seriously.

The type of incentive with which this Paper is principally concerned is that known as the "standard time" or "time piecework system," which, in the experience of the author, is the simplest, most direct, easiest-applied and of widest application. The standard-time system is similar to the premium bonus scheme in so far that a time is set for every job and the operator gains by the amount he is quicker than the set time. However, the operator gains the total amount instead of a fraction as in the case of the premium system. This is simply time-piecework, a particular time at a particular rate per hour being allowed for a particular job. Obviously 15 minutes at 1s. an hour = 3d., which is equivalent to a price piecework.

It may not immediately be apparent why a time is preferred to a price when they amount to the same thing. A little consideration will show that times possess numerous advantages. For example, those familiar with piecework systems know the trouble ensuing when a job with a piecework price designed for a boy has temporarily to be done by a senior grade of labour. In foundry work this is particularly noticeable. Sometimes graded piecework prices are set to be applicable according to the age or experience of the labour, but really each particular job should have its assigned grade of labour. In the standard-time system, however, a job may be transferred from one operator to another with perfect fairness, since the time allowed per job is taken at the rate of the operator. This does not mean that a foreman may change the grade of labour on the job just as he pleases, for, on the contrary, the grade of labour to be used on the job is specified, a convenient one being "junior," "medium" and "senior," though some firms grade much more finely, depending upon the size of the concern and the number of men available. It is naturally not worth while grading closely when one employs only a few dozen hands.

A further advantage accruing to the use of times is that one is enabled to pay for a rate of work rather than for the completion of a particular job. Studying the question logically, it is evident that the employer, in introducing an incentive system, is endeavouring to "speed up" production, or, in other words, make his employees work faster, and, as an inducement, he is willing to pay them more money for increased effort. It is obvious that he is not expecting them to speed up one job, slow down on the next and so on; nor is he expecting them to speed up on piecework jobs and immediately slow down when a certain amount of day-work has to be booked. It is absurd to pay piecework on the job, and instead it should be paid upon a summation of the jobs taken over a period such as a week. At the beginning of the next week an operator starts afresh, and is not perpetually in debt. The standard-time system makes it possible for this summation of jobs to be carried out extremely quickly and simply in the pay-roll department, as will be explained later. The standard-time system also simplifies the planning of work. If the piecework price of a job is, say, 2d., it is difficult to convert this cash amount into number of boxes per hour. Finally, the direct use of time as a measurement of work is so obvious and logical as to appeal to anyone if only by virtue of its extreme directness and simplicity.

How a Standard Time is Set

There is a vast difference between a correctly set standard time and a simple floor to floor stop-watch reading. In the first place, the untrained observer is incapable of determining how long even the simplest job should take, though he uses the most accurate stop-watch. It would be out of place in this Paper to describe the various methods adopted in determining the correct floor to floor time of an operation. Nevertheless, it may be said that a short series of stop-watch observations, modified by the experience of the rate-fixer, form its basis. An experienced rate-fixer can usually determine in ordinary foundry work a sufficiently accurate time by a series of not exceeding three observations, providing, of course, he has previously logged certain fundamental times applicable to the particular foundry. It is particularly to be emphasised that the time observed, say, for the moulding of a box is not necessarily the one used in the setting of a standard time, since the moulder may be slow or superlatively fast.

In normal machine shop practice, there are certain standards for the usual manual operations which have been determined by many hundreds of observations as applicable to the average operator. Thus, for example:—(1) Reading a micrometer, 7 secs.; (2) feed to stop in small capstan lathes, 4 secs.; (3) raise table of milling machine from 4 to 0 inches, 7 secs.; (4) index head of capstan, 3 secs.

In the foundry, although it may not immediately be evident, a similar set of constants may be obtained. For example, some of them are:—(1) Place a 16 in. by 10 in. box on two dowels on machine, 11 secs.; (2) dust average pattern with parting powder, 4 secs.; (3) weight down boxes, 5 secs.; (4) make runner or vent hole 1 in. diameter, 11 secs.; (5) place and position core up to 3 in. by 3 in. in mould, 16 secs.

The actual time allowed for a job is a combination of average observed times like the above, modified by the observations taken by the rate-fixer, and, as it were, bound together by his experience. Having in this manner determined the actual or net floor to floor time of the job, the standard time is prepared as below.

Two further percentages are added, the first being what may be called the bonus time which is determined by the percentage bonus which the average man is supposed to earn when working normally. Usually, this varies from between 20 to 50 per cent., though 25 per cent. is quite a common and recognised figure. The second addition is the contingency allowance. This may be taken to cover fatigue, temporary stops and absences, and the normal trivial happenings which tend to cause lowering of a man's rate of work. If a particular job actually takes 1 minute to produce, probably between 40 and 55 will be produced in an hour, depending on the type of job. All this has been dealt with many times in great detail, and is applied most scientifically, notably in the Bedaux system. Thus, the standard time consists of the actual or floor to floor time plus a bonus time plus a contingency. Contingency allowance is usually expressed in the form of a so many minute-hour. Thus, for example, in the foundry the following figures have been found and proved by experience to be suitable:—

(1) Snap flask work on hand, squeeze machine, 48 minute-hour.
(2) Hand ramming with stripping plate and metal boxes, 45 minute-hour.
(3) Plate moulding on floor with boxes up to a size capable of being lifted by two men, 40 minute-hour.

These figures are respectively equal to one-fifth, one-quarter and one-third additions to the actual or net time.

Fig. 1 shows a simple type of mould made on a pneumatic Tabor type machine. It will be seen that it presents no peculiarities except that in practice the direct squeeze was found insufficient, and a certain amount of hand ramming had to be employed. The time allowed for the performance of this job is shown in Table I, which also indicates how this particular standard time was compiled.

TABLE I.—*Standard Time for a Simple Moulding Machine Job.*

	Min.	Secs.
Net rate fixed time	1	7
Bonus (25 per cent.)	0	17
Contingency (48 min.-hour = 1/5) ..	0	13
	1	37

Application in the Foundry

Fig. 2 shows a similar type of mould produced on the familiar Farwell type of machine utilising snap flasks, and vibrated pattern plates. The time study relating to this particular job is shown in Table II. It will be seen that the floor to floor time is 185 secs., which, when the contingency and 25 per cent. bonus are added, equals 4 min. 30 secs. For convenience of transmitting the information to the moulder, the time is frequently converted into an output of so many per hour, in this case 16½ to make 25 per cent. bonus.

TABLE II.—*Time Study for Moulding Mangle Top Sides.*

Method :—Snap flask with pneumatic lift. 1 operator —medium.

	Secs.
Place bottom of box on table	2
Assemble pattern plate	2
Clean off (air)	3
Assemble top of box on pattern plate	5
Dust with parting powder	5
Sieve facing sand	20
Assemble band	4
Shovel sand	13.5
Ram down	10
Smooth off	3
Assemble bottom board	5.5
Turn over	2.5
Dust with parting powder	4.5
Assemble band	6
Sieve facing sand	14
Shovel sand	10
Smooth off	3
Assemble pressure board	5
Press in machine	8
Tap plate and remove	3
Make runner hole	3.5
Lift top (vibrator)	18
Tap and remove plate	14
Close up (and remove flask)	12
Place down	8
	184.5

This example shows, perhaps, the simplest case of utilising time study and standard-times in the foundry, as when applied to a moulder completing both parts of a mould in a single operation and carrying his completed job and placing it ready for pouring.

TABLE III.—*Time Study of Moulding Mangle Top Sides.*

No. per box : 1. Machines : Two Tabor power squeeze 4-ft. Operators : Medium.

Operation.	1st study.		2nd study.		3rd study.	
	Bottom.	Top.	Bottom.	Top.	Bottom.	Top.
	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.
Clean off (air)	4.0		4.0	2.5	3.4	3.0
Place box on table	7.0		7.0	5.0	8.0	5.0
Put down box lever.. ..	4.0		—	—	—	—
Dust with parting powder ..	3.0		3.0	—	3.0	—
Placing facing sand in box by hand	7.0		7.0	3.0	7.0	3.0
Shovel sand from floor ..	7.0		7.0	5.0	5.0	—
Hand ram	9.0		9.0	3.0	—	—
Release hopper	5.0		4.5	6.0	5.0	6.0
Squeeze	5.0		5.0	5.0	5.0	5.0
Ram down by hand ..	4.0		5.0	—	—	—
Tap to release	4.0		4.0	3.5	4.0	4.0
Smooth off	3.5		3.5	3.0	3.5	3.0
Lift	4.5		4.5	5.0	4.0	5.0
Place down	4.0		3.5	4.0	5.0	4.0
	71.0		67.0	45.0	52.9	38.0

A more complex case occurs where a pair of moulders are employed working on the respective halves of a job, and Table III shows first the rough conditions persisting when the original time study was taken, where it was found that one moulder was taking 71 secs. and the other 47 secs. The time of production of one completed mould was obviously that of the longer job, *i.e.*, 71 secs. A simple revision of the operations of the two men combined and resorted is shown in the second study in the lower part of Table III, where it will be seen that these are now more closely balanced. The third study shows a further reduction due to the elimination of unnecessary operations, but still exhibits the loss due to unbalance, which is an almost inherent feature of two-operator machine moulding.

It may be objected that this is a somewhat obvious case and that skilled men make this correction themselves. To a certain extent this is true and the author has observed cases where men knowing nothing of stop-watches or rate-fixing have yet balanced their times very accurately. However, it must be pointed out that with machine moulding and the grade of labour encountered, such refinements are not easily appreciated. Indeed, it is often difficult to make one of a pair understand why he should do a certain amount of work which apparently belongs to his neighbour.

So far only those cases in a foundry have been considered which may be regarded as direct labour, *i.e.*, moulding. However, when one considers the total foundry costs it is quickly apparent that moulding may represent only a half of the normal labour charges of the department. A very important group is the pourers, and their work may be reduced to a standard time basis in a similar manner to that previously described. Owing to the fact that the pourers work as a gang or series of small gangs and not as individuals, the standard-time set would apply to a group which is equivalent to group piecework. Setting rigid times on moulders implies that they must be supplied continuously with metal, sand and a service for the removal of the castings. It is absurd to operate a foundry with moulders on incentive payment and pourers on day-work, since, assuming a limited supply of boxes or floor space, the moulder is entirely dependent upon pouring and floor clearance for the continuance of his activities. Within the space available it is not possible to present all the details of the time studies which go to the determination of the actual time necessary for pouring a box. It may, however, be remarked that all factors considered, it was found possible to set standard times per box of a particular dimension. Some standard times used are:—

(1) Average snap flask box on Farwell machine, 1 min.

(2) Average 16 in. by 10 in. metal boxes on mechanised loop, 1 min. 40 sec.

(3) Average large mangle bottom side boxes, 2 min. 30 sec.

When the investigation of standard times for pourers was made the question of a bonus on tonnage was considered. The facts, however, demonstrated irrefutably that this would not be satisfactory. The times set above are allowed per box, and they embrace metal carriers, ladle attendant and crane driver. For example, if one hundred 13 in. by 9 in. snap flask boxes were poured, this meant that the time allowed was 100 by 1 min., which equals 1 hr. 40 min. divided between, say, one crane man, five metal carriers and one ladle attendant. The division of payment at the end of the week takes place according to the number of hours worked by each man and also according to the rate per man.

It is to be emphasised that although this is a group system of payment it is not in any sense of the word a bonus scheme; it is direct-time piecework, and must be maintained by the foreman manipulating either the number of men working or the hours they work, according to the fluctuation of boxes produced.

The question of sand blast is somewhat complex and unless the foundry is extremely large it will usually be found better to pay the sand-blast operators a percentage of the earnings of the fettling shop which they supply. Generally speaking, it is found by normal experience that for a particular sized foundry one must have one, two, three or more sand-blast operators continuously at work. If the number becomes considerably higher, then standard times for each casting can be set in exactly the same manner as for dressing or moulding, though naturally they will be lower and will probably be expressed per 100 castings.

In setting times for the preparation of sand and other foundry materials, local conditions will determine the method, though the devices used are similar to those previously mentioned. There is not a job connected with the foundry which cannot be placed upon a reasonable incentive basis.

There is, however, one distinct difference between the individual standard-time set for a moulder as compared with the time set for a group of, say, pourers. The moulder is, within limits, a completely free agent and can continue with his work so long as he has sand and boxes. which means so long as the pouring and knock-out departments are dealing satisfactorily with their sections of the work. If they are not, the moulder immediately communicates with the office in a manner later to be described, and books waiting time, which would be deducted from the bonus earnings of the section causing his delay. In the case of a group of men such as the pourers, no waiting time is allowed, and this means that to ensure the men make money at their job their hours must be regulated by the foreman in accordance with the daily output of the foundry. If the number of moulders be reduced while the number of pourers remains constant, then the pourers cannot possibly earn a bonus unless either their number or their hours

TABLE IV.—*A Process Layout Form.*

V.S. FLAT TOP BRACKETS

Layout No. 1102
Issue No. 1

PROCESS LAYOUT.

Programme No. . .3288
No. Per Model. .2
Date to be Cast. .21/1/37
Parts Reqd. . .120
No. of Moulding Boxes. .30 + 2
No. of Cores. .120
Moulders' Names
Average Weight Each. .2 lbs.
Size Box. .16 × 10
Type of Machine. .Farwell
No. Per Box. .4

FOR COST DEPARTMENT ONLY

OP. NO.	DESCRIPTION	DEPT.	LAB. CLASS	STD. TIME OR P. W. R.	O'ATOR'S NO.	REC'D BY
1	Make Green Core	24	J	0. 34.		
2	Bake	24				
3	Dress Core	24	J	0. 7.		
4	Set Patterns and Check					
5	Mould and Cast (11)	23	M	1. 42.		
6	Fettle	22	G	1. 00.		

No. of Fettled Castings. . . . .
No. of Firm's Scrap. . . . .
No. Moulder's Scrap. . . . .
Final Delivery Weight. . . . .

Table IV—*continued.*

V.S.
Programme No...3288

PROCESS LAYOUT.

No. Per Model..2
Date of Issue..19/1/37 Parts Reqd...120
MATERIAL

Layout No. 1102
Issue No. 1

TOP BRACKET CASTINGS. 4217D	FOR COST DEPARTMENT ONLY
	2 lbs.

Programme No...3288
No. Per Mould..2
MATERIAL.

PROCESS LAYOUT.

Date of Issue..19/1/37 Parts Reqd...120

Layout No. 1102
Issue No. 1

FOR
COST DEPARTMENT
ONLY

TOP BRACKET CASTINGS. 4217D

OP. NO.	DESCRIPTION	DEPT.	LAB. CLASS	STD. TIME		O'ATOR'S NO.	REC'D BY
				MIN.	SEC.		
1	Drill	30	M	1	6		
2A	Set Up	30	M	12	00		
2	Drill and Tap	30	M	1	35		
	Pass to Part Finished Stores						

Part..FLAT TOP BRACKETS
Drawing No. 437
TO BE COMPLETED BY..25/1/37

Model..VICTOR V.S. MANGLES
ALL SIZES

be reduced. This is where the foundry foreman should take the necessary action to maintain correct labour balance.

Time Recording and Control

As mentioned earlier in the Paper, time control consists not only of setting time by methods previously described, but also of checking or recording the specified rate of work. A moulder is paid on the number of castings his moulds produce less those number scrapped due to his own faults. Checking the number of castings may conveniently take place after fettling and before they are passed to the casting stores for despatch. Checking times, numbers, weights, etc., usually involve paper work, which is undesirable in any factory department, especially a foundry. Although a certain amount of paper work is necessary, most of it can be avoided, while all the necessary data may still be obtained. Only one paper form need enter the foundry, the remainder being kept in the offices, where they may be suitably handled. In Table IV is shown a "process lay-out." Only the top section refers to the foundry, the lower ones being for use later in the stores and machine shops, and for the present purpose they may be disregarded. This lay-out combines in itself the authorisation for the foundry to produce a certain number of a particular casting. It is first routed to the pattern setter, who obtains and checks his patterns and then passes the lay-out on to the core shop, which commences work and prepares the necessary cores. The standard-time is shown clearly on the lay-out. In the particular example it will be seen that 34 secs. each is the standard-time for making the green-sand cores and 7 secs. are allowed for dressing.

These cores should be ready at the end of the day, when the pattern setter prepares the moulding machine for the next day's work. The cores will be delivered with the lay-out to the moulder whose name has previously been written in by the foreman allocating the job. After moulding, the castings are removed for sand blast, grinding and trimming and eventually, still followed by the lay-out, are passed to the casting stores, where the number is checked. While the castings go to the stores the lay-out is returned to the pay-roll and cost department. Actually, with the three-section type of lay-out shown, the top section only is torn off, the remainder being used for the re-issue of castings to the machine shop when the other standard-times, etc., are utilised.

FIG. 3.—TIME BOOKING CENTRE.

At this juncture it may well be reiterated that reference is being made to the manufacture of castings in large numbers where runs do not usually exceed a day, but are repeated at frequent intervals. The lay-out form described thus constitutes the order to the foundry, pattern setter, core maker, moulder, dresser and also the receipt of the casting stores for the good castings. It is finally used not only for the payment of all these men, including pourers, casting removers, etc., but also for costing purposes, and it is the only piece of paper which need enter the foundry.

Booking time in foundries is usually regarded as a difficult matter, and is rarely carried out with any degree of accuracy, time sheets and the like being " made up " at the end of the week with the usual combination of imagination and optimism. This difficulty may be eliminated in a very simple fashion. Fig. 3 shows the time booking centre for a particular factory embodying not only a fairly large foundry, but also machine and assembly shops, wood-working departments, despatch and the usual subsidiary departments of a company producing a finished sales assembly. At the back of the room illustrated there will be seen a loud speaker, and before the girl a microphone. Throughout the factory are a series of simple telephone booths, as shown in Fig. 4. By using one of these telephones in any part of the factory, contact is made with the central control table where one is heard through the loud speaker, communication the other way being established by the microphone. The start and finish of every job is reported by each individual operator, except in the case of line assembly, where the chargehand speaks.

Recording of these times takes place on cards which are for convenience sake held in folders where the summation of the standard-times against the times taken are shown. It is to be emphasised that every individual on the factory has one of these tickets at the central control table, and he reports the lay-out number and operation number of the job on which he is starting and at the same time mentions the standard-time. On the completion of the job, he telephones through and the time taken is the difference between the times of his calls. Back booking is not permitted. On the completion of his job, he states also the number of parts which he maintains he has completed, which is later checked and usually amended on the return of the lay-out with the official number received by the stores marked thereon. Incidentally, it is to be understood that the finish of one job and the start of the next are one and the same thing, no gap being allowed. If an operator has no next job on which to book, he telephones "waiting time," for which he is paid day-work rate. If he is waiting more than a quarter of an hour the telephone is used to communicate with his foreman, and in any case the waiting time is booked against the department, usually against the foreman's bonus.

Fig. 4.—A Telephone Booth in the Factory for Communicating with the Time Booking Centre.

As a matter of interest, the table illustrated in Fig. 3 each week handles some ten thousand entries, and, in the experience of the author.

a single table can usually handle all the time booking required for a factory employing a thousand operatives, though naturally this depends to a certain extent upon the nature of the work. The telephone system employed is, it is thought, unique and embodies a low-frequency amplifier and no exchange. It would be possible for operators on all the telephones to speak at once, but in practice this does not occur. The normal time for the taking of a reading is 7 seconds. Contrary to what might have been expected, operators do not object to using the telephone and in a very short space of time become remarkably efficient in giving their information.

The advantage of this system is evident, since it keeps paper work in the offices. Furthermore, all information is current, and there is no question of back booking or men waiting for many hours. The depression of a button on the table rings a bell in the particular booth in the shops and at the same time lights a small bulb. It is thus possible for the operator at the central control table to ring to each one of the departments, though this measure is to be regarded as an emergency and not to be normally followed. The system is definitely a special purpose one and does not in any way replace normal inter-departmental telephones.

Planning Foundry Output

Of the foundry producing large quantities of castings, it may be said that the daily output as regards tonnage may be reasonably constant, but exactly when a particular batch of castings will be available is a matter which is usually not capable of being predicted too closely. When castings are supplied for the general trade and rail and road traffic may be blamed, the delay of a day or so is not a serious matter, but when castings have to pass through one's own machine and assembly shops, the matter becomes more serious. In the particular foundry under consideration the following procedure is adopted:—

On the first day cores are made; on the second castings are produced; on the third they are fettled and passed to stores; on the fourth they are machined; and on the fifth they are assembled in complete mechanisms with their attachments, painted and usually despatched. This somewhat rapid progressing is not adopted merely in search of speed, but is necessitated by the bulk of mechanism turned out which renders it impossible to make direct for stock.

Actually, at the end of each week, the orders for complete models—that is to say in the particular instance, mangles, mowers, sports goods, scales, spring balances, etc.—are collected and compared with stock position. From a consideration of these two an assembly programme for the whole week is prepared. From the assembly programme is produced a machining programme, and from the machining programme a foundry programme, the last mentioned being 5 days in advance of the first. The foundry programme is naturally split into component castings for each of which is issued one of the lay-outs previously illustrated and described. These are not, of course, typed out afresh each time, but are withdrawn from files where they are held *en bloc* relating to completed assemblies.

Thus, the foundry manager has in hand a foundry programme showing what should be produced each day, together with a quantity of lay-outs holding all the information for the production of each casting. Each job must then be allocated to each moulder throughout the week, so that the minimum of time is wasted in set-ups and errors, such as the over-use of a particular sized box in one day. The task would, of course, be simple providing it were possible to interchange jobs and moulders as desired, but in practice certain moulders can handle only particular jobs with efficiency.

The best way of planning such a scheme is by means of the horizontal line chart shown in Fig. 5. Since standard-times are available,

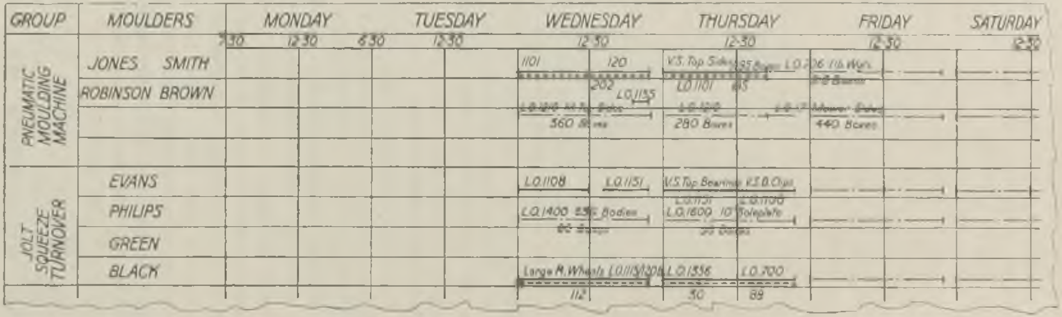


FIG. 5.—A HORIZONTAL LINE CHART FOR PLANNING FOUNDRY OUTPUT.

these may be used in showing exactly how long a job should take. The small section of the chart shows the whole of one week for a few moulders, but this can be extended to cover the complete foundry for longer periods. The top line is the planning line, which shows what should be achieved, and the bottom line is drawn in afterwards, showing the actual achievement. If this be less than the standard time, steps must be taken, or otherwise the programme will break down. This planning may seem somewhat difficult in practice, but nevertheless the foundry does work closely to programme.

It is usually easy enough to keep a foundry busy when orders are plentiful, but planning does more than this—it makes the foundry produce what is wanted at the correct time, meanwhile keeping the men fully occupied. Sometimes the assembly programme demands the impossible, due to a peculiar combination of moulding machines or similar factor. In those cases as soon as the error is discovered the assembly programme itself is modified.

Standard-Costs and Estimates

Much has been written on the subject of foundry costing, and it is not proposed here to deal at all fully with the subject. Some mention must, however, be made of it, since the adoption of standard-times brings one inevitably to what are known as standard-costs. So far as labour is concerned, and assuming errors to be non-existent, a job will always cost the same when performed by an operator of the same hourly rate making a bonus. In practice, however, errors are constantly being made. In the standard-cost system the actual cost of any article is measured by what may be called a variation or loss factor. Supposing a particular job takes exactly one hour to perform and the rate is 1s. per hr., then unless something seriously goes wrong the cost of that job will be a shilling. However, the job may be moulded correctly but spoiled in pouring, when obviously its cost must be higher, since it has to be done again.

In standard-costing the perfect or theoretical cost of every article produced is known clearly from the times set and the rates employed. A simple clerical arrangement measures the total labour losses of the foundry which consist of waiting time, lost time through operators "going down" on their jobs, and that time devoted to the replacement or remaking of castings spoiled in the first place. This is considerably more simple than the usual manner, since, fortunately, even in the worst conducted foundries the sum total of scrap is less than that of good castings.

A simple example of the standard-costs is shown in Table V. This is made by combining the completed lay-outs previously described with the completed time tickets. It will be noted that at the end of the standard-cost there is shown a labour loss factor of 5.81 per cent. This latter is determined by finding the percentage of labour losses over total labour. It will be noted that the material cost is shown as £5 8s. 6d. per ton, and this includes pig-iron, scrap iron, sand and all direct foundry materials together with material loss. There are logical reasons for this procedure which will not be dealt with in the present Paper. The method used in estimating follows very similar lines to the standard-cost, as might be expected. Table VI shows an estimate of a simple casting. It will be noted that core making, moulding, pouring, removal and fettling are shown as direct times, and also that a percentage is added to core making time, and to the fettling time. These percentages cover the oven attendant in the case of the core shop and the sandblast operators in the case of the fettling shop. Fixed charges are expressed as £3 per ton, based on the average weekly tonnage.

This method of estimating may appear elaborate when compared with the normal method of adopting a figure per hundredweight dependent upon the type of casting. It is interesting to note that checks on a number of cases show that this method produces results practically identical with those arrived at by an experienced

TABLE V.—*Foundry Standard-Cost for a Casting.*

Description.	Standard-Time.	Operator's Rate. Pence.	Standard-Cost. Pence.
Cores	0.34	6½	0.061
Oven attendant: 17 per cent. of direct core cost	—	—	0.010
Moulding	1.42	10½	0.298
Pouring (4 per box)	1.00	11	0.046
Removal	25.00 per 100	10½	0.044
Foundry (indirect cost); 15 per cent. of direct moulding, pouring and removal cost	—	—	0.062
Fettling	1.00	10	0.167
Sand blast; 33 per cent. of direct fettling cost	—	—	0.056
Fixed charges at £3 per ton	—	—	0.643
2 lbs. material, at £5 8s. 6d. per ton	—	—	1.255
			2.642

Total standard cost = 2.642d.

Actual cost—		
Labour	0.744	
5.81 per cent variation	0.043	0.787
Material	1.898	
1.43 per cent. variation	0.027	1.925
Total actual cost		2.712d.

foundry estimator. The advantage of the system is that it can be handled by non-technical men and also that due to being split into a number of factors there is less likelihood of error. Furthermore, it is logical to use this method in connection with the use of standard times and costs.

TABLE VI.—*Foundry Estimate for a Casting.*

Description.	Standard-Time.	Operator's Rate. Pence.	Standard-Cost. Pence.
Cores	0.40	7	0.078
Oven attendant: 17 per cent. of direct core cost	—	—	0.013
Moulding	1.40	10½	0.291
Pouring (4 per box) ..	1.00	11	0.046
Removal	28.00 per 100	10	0.047
Foundry (indirect cost); 16 per cent. of direct moulding and removal cost	—	—	0.065
Fettling	1.10	10	0.194
Sand blast; 33 per cent. of direct fettling cost	—	—	0.065
Fixed charges at £3 per ton	—	—	0.643
2 lbs. material at £5 8s. 6d. per ton ..	—	—	1.255
			2.697

Summary—		
Labour	0.799	
6 per cent. contingency ..	0.048	0.847
Material	1.898	
1.5 per cent. contingency ..	0.028	1.926
		2.773
Estimated cost ..	2.773d.	

Relation of Time Control to Mechanisation

Foundry mechanisation may be described as a specialised development of the conveyor principle of manufacture, in which there are a certain number of men in line performing progressive operations which give a final product. A conveyor does two things: (1) it provides a means of transport, thus saving manual labour and (2) by its uniform rate of travel it maintains the time factor and keeps work moving forward at a predetermined rate. Obviously, if the conveyor is properly designed it will perform the first function, but if a conveyor is to show considerable economy in labour the time of the various operations carried out along its length must be approximately balanced as regards time.

If along an assembly line (not in a foundry) there are sixty people, some performing tasks which take one minute, some two minutes, some three minutes, some four minutes and some five minutes, then the total labour loss of that line will be very high. Each position along the line must be balanced to within a few seconds, for it must be remembered that with a correctly balanced line, if an operator waits for one minute the whole line must wait for an equal period. When balanced conveyor systems are running correctly they can produce surprisingly good results, but immediately they go wrong they can waste money faster than any other device of modern production. In the mechanised foundry conditions are neither so stringent nor is correct balance so important, but it must be borne in mind that unless this principle of balance forms a basis of labour allocation then the available economies will not accrue.

Economic Value of Time Control

Nothing is more redundant in industry than technicalities for the sake of being technical. Card systems, microphones and stop-watches may all be useful, but how do they help the manufacturer? Time control, *per se*, when properly carried out will prevent waste labour and will thus automatically effect a cost reduction in any department into which it is introduced. In the experience of the author, idle time in foundries is higher than in any other section of industry so far encountered.

Time control provides a means of gradual though rapid—if the paradox be permitted—improvement. Every time a new moulding machine is introduced a fresh series of standard-times lower than the previous ones is introduced. Each time a pattern is changed to effect simplification, the standard-time is reduced. Since estimates are prepared in a similar fashion the patternmaker when preparing his plate knows that his object is to lower the times set on the estimates. An awkward method of working will raise the standard-time above the estimate.

The actual monetary economies which may be achieved by the full adoption of standard-time control, with the fullest possible support of the foundry management, foreman and chargehands is very high indeed, but it must always be remembered that paper systems, no matter how good, do not in themselves make profit, but only point the way to the elimination of errors and waste.

Apart from the profit-making viewpoint standard-time control provides absolute uniformity of costs with the provision against unstable labour rates and raw material prices. Further, it ensures far better than any other means a fairness of wage payment. Rate fixing can be carried out to a degree when the " good jobs " and the " bad jobs " are almost non-existent. Rigid time-control enables wages to be raised while still maintaining an economic level of costs. Most men will work harder when they realise that extra effort means extra money at the end of the week, and that they are neither being driven nor lured into giving something for nothing.

Difficulties in the Introduction of Time Control

The main difficulty experienced in the introduction of time control in a foundry is the persistent belief in the methods of one's ancestors.

In certain sections of industry, rate fixing and its accessories are regarded as essential to manufacture, but in other sections, notably the heavy and basic industries, time control has yet to become an established part of routine. The average working man has a natural objection to the time-study man with his stop-watch, and the more skilled is the man the greater will be his objection. This has in the first place to be overcome by tact, firmness and a certain understanding on both sides. The author has found that the average foundryman understands fairness when he appreciates it as such.

The main difficulty in the introduction of time control in the foundry is to obtain the backing of the management, the foremen and the chargehands. There is more than a tendency for them to believe that principles which apply to machine shops, assembly shops, electro-plating, cellulose spraying, the manufacture of biscuits, and even die castings cannot possibly apply to the ordinary foundry. To this attitude it is definitely stated that performance of work in a foundry can be controlled just as well as that in a machine shop.

Before foundries can rank as a modern section of industry, they must study, appreciate and finally embrace time control as essential to their working. There is a vast scope for improvement in the foundry industry to be achieved by the whole-hearted adoption of time control. If, instead of installing an expensive mechanisation, foundrymen were to spend a few hundred pounds and their earnest and active support in the right direction on time control, they would in a few years' time be able to mechanise without a disastrous drain on their resources.

DISCUSSION

Time *versus* Money Allowance

After Mr. C. H. Kain had proposed a vote of thanks, Mr. R. Dunnett, who seconded it, referred to the difficulty of using a stop watch in a foundry. In his opinion and experience, provided it was used with common sense there would be no difficulty or trouble whatsoever. He did not agree that the average man resented being timed, and once the employees appreciated they were being given a square deal, they would give an honest return. Over a period of 10 years, during which his foundry had been working on time study, a feeling of confidence had been built up with the men. In connection with obtaining standard data, he had reduced some 3,700 jobs to a formula which has been operating for over two years and had been producing satisfactory results. An important point in connection with foundry control was that the men must, as far as possible, be interchangeable and it was necessary to have a reserve man ready to fill any vacancy which might occur. Mechanised foundry piecework rates must include all operators in the shop, because each man was so interelated in the whole system that any delay affected the whole of the shop. As regards the system of payment, he personally preferred the money-allowance rather than the time-allowance system, because it was easier for the men to understand and much simpler for the payroll department. Mr. Dunnett favoured the settlement of piecework at the end of each job. If loss was made on a particular job, either the machine or the rate of working was wrong and if the latter, some error had occurred in the time allowance.

Weekly Payments

Mr. B. Brown, replying to Mr. Dunnett, said he had found that the average man resented the stop watch, but over a period of ten years, almost anything could be done by gradually building up confidence with the men. As regards paying jobs by the week, this depended to a certain extent on the length of the job, though when there were short runs, he much preferred payment by the week, and over long experience, had found this to be the better method. He disagreed with Mr. Dunnett and in his own experience with a number of factories, time piecework was far simpler than money piecework. He also stated that time piecework was capable of being operated by no more than half the staff required for money piecework.

Mr. L. Tibbenham then read a communication from Mr. V. Delport, chairman of the Costing Sub-Committee.

Methodical Records Essential

Mr. Delport wrote that the Paper was of considerable interest to him in view of its relation to the proposed uniform system of costing which the Costing Sub-Committee was endeavouring to establish. One of the principal recommendations of the system envisaged—and, in fact, of any costing system—was the correct and methodical keeping of records, and whilst time control was not actually a part of a costing system, a proper record of the time taken to effect various jobs was essential. Labour costs constituted one of the principal items of expenditure, and whether they were based on day work or piecetime work, wages must have a direct relation to time.

One of the principles of the costing system about to be recommended by the Sub-Committee was that overhead charges be allocated as a percentage of direct labour. When moulders were paid piecework wages, it was necessary that those wages be correctly calculated, otherwise there would be discrepancies in the allocation of overheads; in such cases it was not the costing system that was to blame, but the method of fixing the wages. As there should be a direct relation between the wages paid and the time taken to do a job, the same arguments would apply if the costing system had for its principle the allocation of overheads on a time basis. A personal opinion was that if times were always correctly calculated and checked in all foundries, there could be no objection to allocating overheads on a time basis.

Referring to Mr. Brown's sub-division of labour, the lower rates of wages paid to apprentices in a foundry must be taken into account in allocating overheads. It would be ideal if foundries were organised in such a way that the simple and cheap jobs could be given to the apprentices. In practice, where there was a variety of castings of different shapes and sizes produced, this could not be done systematically. The principle of planning the foundry output in advance was of interest in connection with the calculation of overheads based on so-called normal production.

With reference to the section headed "Standard Costs and Estimates," the author referred to the replacement or remaking of spoilt castings or wasters. Actually, it was the cost of making a waster that must be taken into account, allowance being made for metal returned to scrap.

The writer could not quite follow the example of standard costs cited in the Paper, as he had not the illustration available. With reference to the method used in estimating, he agreed with the general principle enunciated, but would ask on what basis the overhead percentage was arrived at where the author said that "overheads are expressed as £3 per ton based on the average weekly tonnage." Was the percentage based on labour or time? It was assumed that "average weekly tonnage" meant the tonnage of good castings produced.

Mr. Brown, in a written communication, replied to Mr. Delport's discussion as follows:—

Allocation of Overheads

Keeping correct and methodical records was actually the basis of the system described. Personal experience was that piecework or any system of incentive usually failed lamentably when it was not definitely associated with a foundry order or lay-out. It would have been noted that in the standard-time system described, each moulder was given a lay-out which gave the type of job, the weight of castings, times allowed, etc. These lay-outs were passed through with the job and finally returned to the office when they were used for costing purposes.

Although the allocation of overheads was outside the scope of the present Paper, it could be stated that in general there was no reason why overheads should not be applied on direct labour as was used commonly in the machine shop and other manufacturing departments. However, this depended largely upon the class of work undertaken by the factory, and the overheads applied on a tonnage basis might be quite satisfactory if the class of casting and weekly tonnage were reasonably constant.

So far as overheads generally were concerned, the author had found that it was essential that these be checked at least monthly as otherwise it was probable that the nominal percentage would be applied month after month when actual conditions had changed so that considerable errors were incurred.

The overheads of £3 per ton referred to were based on the average weekly tonnage, no percentage being deducted, but the total overheads of the factory were divided by the average weekly tonnage giving a figure of £3. Certainly the "average weekly tonnage" meant the tonnage of good castings produced. It was, of course, appreciated that this method might not be generally applicable where the work varied considerably.

Considering the various interesting points brought forward by Mr. Delport, the author regretted that the scope of his Paper did not embrace foundry control generally instead of simply time or labour control.

The Metallurgist and His Mixture Cost

MR. H. H. SHEPHERD said he could not allow the statement that a metallurgist was unable to reduce his mixture cost to remain unchallenged. He did not know any foundry where the metal mixture had been standardised in such a way that the metallurgist could not have made some saving, unless the standardisation had been brought about largely by himself. One could not standardise to any definite degree, although the metallurgist had certainly to bear in mind a number of factors which were not always confined to quality.

He had seen a certain amount of trouble caused by the use of the stop watch. He wanted to make it quite clear that the whole system of time control was useless if the human element was not considered. This was the only point he wanted to stress. The question of the man going in fear of losing his job did often arise, and mechanisation ultimately meant that the man in the foundry had to be careful that he did not become replaced labour. This was a vital point to foundrymen.

Time Control's Influence on Apprentice Labour

Mr. W. L. Hardy said that he had worked piecework for fifteen years, and the machine moulder only worked on a piecework rate to increase his money. He had found great trouble in getting lads to enter the foundry, and if this matter of splitting seconds was to be pursued, there would be a still greater shortage. As regards output, any practical man could tell a manager more accurately how many moulds could be made than a man who had dealt only with machine shops and the like, since the foundry could not be regarded in the same way. Picking up sand was vastly different from picking up a micrometer.

Mr. Brown said that time control was essentially fair and any "twisting" would certainly fail. As regards reducing the man's earnings, he had always been able to pay the man more, and, so far, had reduced the price of the product at the same time. If time control was properly applied, the man worked harder, but was paid proportionatly more for doing so. The main object was to eliminate delays, since most of the waste was not that the man did not work hard enough, but was idle a large part of the time. He disagreed with the suggestion that the practical man knew more about output than the time-study man or rate-fixer; the latter was a specialist in his own class of work. He also emphasised the accuracy that could be obtained in presetting times from built up constants.

Waiting Time

Mr. Slater asked how the men could make a bonus if, as had happened, there were five gangs of men and only one crane, as in this case four gangs would have to wait to be able to use it. There appeared to be some difficulty about this question, which it eventually transpired was connected with heavy castings in singles.

Mr. Tibbenham explained that Mr. Brown's Paper dealt only with repetitive castings. **Mr. Brown**, confirming this statement, stated that he could not reply to the particular question, but in any case waiting time could not itself be cured by any paper work, but only by reorganisation of the foundry itself. He would state that all waiting time which was not the fault of the man would normally be paid for at day-work rate and logged against the department.

Day-Work Rate Guaranteed

Mr. McInnis inquired whether it was Mr. Brown's experience that in this country the men were guaranteed day-work rate. In America, day-work rate was not guaranteed, and therefore the men had even more incentive to work.

Mr. Brown replied that, generally speaking, in this country the day-work rate was guaranteed, and he personally would not subscribe to any system where day-work was not guaranteed.

Mr. McInnis said that if there was a big variation between the day-work rate and the bonus, there was an incentive for the man to work harder, but, of course, if the day work was not guaranteed, he had to work hard to live.

Mr. Brown said that piecework prices were set for a man to earn. If he did not earn them, he was not a success. There was a certain class of man that did not want to work and was satisfied with a low rate.

Mr. Tibbenham said that if anyone queried whether the telephone system illustrated worked in practice, he would be pleased to see them at his works, where they could see it in operation.

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