H. WINTERTON.

*President,* 1936–37.

Mr. H. Winterton is Chairman and Managing Director of William Cumming & Company, Limited, of Glasgow, Bilston, Chesterfield, etc., and is one of the oldest members of the Institute, having been elected in 1906. He has presented numerous Papers on Mould Facings and Refractories to various Branches, and was President of the Scottish Branch in 1929–30. He is a Past-President of the Foundry Trades' Equipment and Supplies Association and of the Refractories Association of Great Britain. He has taken an active part in Municipal and County adminstration, and is now Senior Bailie of the Burgh of Milngavie, Dumbartonshire.

# PROCEEDINGS OF THE . . . INSTITUTE OF BRITISH FOUNDRYMEN.



VOLUME XXIX. 1935-1936.



**Containing the Report of the Thirty-Third Annual Conference, held at Glasgow, June 9th, 10th, 11th, and 12th, 1936; also Papers and Discussions presented at Branch Meetings held during the Session 1935-1936.**

**Edited by T. Makemson, Secretary.**

**Institute of British Foundrymen.**

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# THE INSTITUTE OF BRITISH FOUNDRYMEN

## OFFICERS 1936-36

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VICE-PRESIDENTS:

C. W. Bigg, "Selworthy," Burley Lane, Quarndon, near Derby.

J Hepworth, J.P., M.P., Wood Lawn, Apperley Bridge, near Bradford.

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

R. Buchanan. (Deceased, 1924.) 1904-1905.
H. Pilkington. (Deceased.) 1906-1907.
F. J. Cook, M.I.Mech.E., 31, Poplar Avenue, Edgbaston, Birmingham, 17. 1908-1909.
P. Longmuir, M.B.E., D.Met., 2, Queen's Road, Sheffield. 1910-1911.
C. Jones. (Deceased, 1923.) 1912.
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W. Mayer. (Deceased, 1923.) 1915.
J. Ellis. (Deceased, 1930.) 1916-1917.
T. H. Firth. (Deceased, 1925.) 1918.
John Little. (Deceased, 1932.) 1919.
Matthew Riddell. 1920.
Oliver Stubbs. (Deceased, 1932.) 1921.
H. L. Reason, M.I.Mech.E. 1922.
Oliver Stubbs. 1923.
R. O. Patterson, Pioneer Works, Blaydon-on-Tyne. 1924.
J. Cameron, J.P., Cameron & Roberton, Limited, Kirkintilloch, Scotland. 1925.
V. C. Faulkner, M.Inst.M., 49, Wellington Street, Strand, London, W.C.2. 1926.
J. T. Goodwin, M.B.E., M.I.Mech.E., Sheepbridge Coal & Iron Company, Limited, Chesterfield. 1927.
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F. P. Wilson, J.P., "Parkhurst," Middlesbrough. 1930.
A. Harley, The Daimler Company, Limited, Coventry. 1931.
Victor Stobie, M.I.E.E., Langholm South Drive, Harrogate. 1932.
C. E. Williams, J.P., "Coniston," Cefn-Coed Road, Roath Park, Cardiff. 1933.
Roy Stubbs, 36, Broadway, Cheadle, Cheshire 1934
J. E. Hurst, "Ashleigh," Trent Valley Road, Lichfield, Staffs. 1935.

HON. TREASURER:

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

SECRETARY AND EDITOR AND GENERAL OFFICE:

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

AUDITORS:

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## COUNCIL

### *DELEGATES ELECTED AT ANNUAL GENERAL MEETING:*

Prof. J. H. Andrew, D.Sc., Department of Metallurgy, St. George's Square, Sheffield, 1.

A. Campion, F.I.C., 8, Thorn Road West, Bearsden, by Glasgow.

V. Delport, Caxton House East, Westminster, London, S.W.1.

J. W. Gardom, 39, Bennetts Hill, Birmingham, 2.

B. Hird, 17, Tinwell Road, Stamford, Lincs.

E. Longden, 11, Welton Avenue, Didsbury Park, Manchester.

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

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

D. H. Wood, "Kingswood," Park Road, Moseley, Birmingham, 13.

### *BRANCH DELEGATES:*

*(Branch represented shown in brackets.)*

R. Ballantine, Duncruin, North Street, Motherwell, Scotland. (Scottish.)

W. N. Cook, B.Sc., 10, Stanley Road, Heaton Moor, Stockport. (Lancashire.)

J. W. Donaldson, D.Sc., Scott's Shipbuilding & Engineering Company, Limited, Greenock, Scotland. (Scottish.)

E. B. Ellis, 36, Kings Road, Monkseaton, Northumberland. (Newcastle.)

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C. H. Kain, Lake & Elliot, Limited, Albion Works, Braintree, Essex. (London.)

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A. L. Key, 161, Northgate Road, Edgeley, Stockport. (Lancashire.)

G. T. Lunt, "San Simeon," Newbridge Crescent, Wolverhampton. (Birmingham.)

W. G. Morgan, 301, Broad Lane, Coventry. (Birmingham.)

N. McManus, M.B.E., The Argus Foundry, Thornliebank, near Glasgow. (Scottish.)

A. E. Peace, The Rose & Crown Hotel, Brailsford, near Derby. (East Midlands.)

A. Phillips, 1, Melfort Avenue, off Edge Lane, Stretford, Manchester. (Lancashire.)

C. D. Pollard, "Chilton," Hollies Road, Allestree Lane, Derby. (Sheffield.)

R. J. Richardson, "Glenthorne," Llan Park Road, Pontypridd, Glam. (Wales and Mon.)

N. D. Ridsdale, F.C.S., 3, Wilson Street, Middlesbrough. (Middlesbrough.)

H. J. Roe, 29, Park Road, Moseley, Birmingham, 13. (Birmingham.)

J. N. Simm, 61, Marine Drive, Monkseaton, Northumberland. (Newcastle.)

W. G. Thornton, "Riverslea," Cottingley Bridge, Bingley, Yorks. (W.R. of Yorks.)

A. Whiteley, 5, Stumperlowe Hall Road, Fulwood, Sheffield, 10. (Sheffield.)

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

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

## *BRANCH PRESIDENTS AND SECRETARIES*

(Ex-officio Members of the Council.)

### BIRMINGHAM.

G. W. Brown, M.I.Mech.E., Austin Motor Company, Limited, Longbridge Works, Birmingham.
A. A. Timmins, A.I.C., 21, St. Paul's Square, Birmingham.

### EAST MIDLANDS.

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B. Gale, "Parkdale," Boulton Lane, Alvaston, Derby

### LANCASHIRE.

J. Hogg, 321, Manchester Road, Burnley, Lancs.
J. E. Cooke, 1, Derbyshire Crescent, Stretford, Manchester.

### LONDON.

V. Delport, Caxton House East, Westminster, London, S.W.1.
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### MIDDLESBROUGH.

H. E. Woolley, 5, Albion Terrace, Saltburn-by-the-Sea.
D. R. Kinnell, C. P. Kinnell & Company, Limited, Vulcan Iron Works, Thornaby-on-Tees.

### NEWCASTLE AND DISTRICT.

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W. Scott, Sir W. G. Armstrong Whitworth & Company (Ironfounders), Limited, Close Works, Gateshead-on-Tyne.

### SCOTTISH.

F. Hudson, Glenfield & Kennedy, Limited, Kilmarnock, Scotland.
J. Bell, 60, St. Enoch Square, Glasgow, C.1.

### SHEFFIELD.

J. Roxburgh, 583, Manchester Road, Sheffield, 10.
T. R. Walker, B.A., The Priory, Oughtibridge, near Sheffield.

### WALES AND MONMOUTH.

S. Southcott, "Wood View," Ynysymaerdy, Briton Ferry, South Wales.
J. J. McClelland, 12, Clifton Place, Newport, Mon.

### WEST RIDING OF YORKSHIRE.

J. Hepworth, J.P., M.P., Wood Lawn, Apperley Bridge, near Bradford.
S. W. Wise, 110, Pullan Avenue, Eccleshill, Bradford.

### SOUTH AFRICAN BRANCH.

T. Nimmo Dewar, Union Steel Corporation, Limited, Johannesburg.
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.

J. Timbrell, "Cedar," Hasland Green, Chesterfield.
E. R. Walter, M.Sc., The Technical College, Lincoln.

## LANCASHIRE—BURNLEY SECTION.

J. Lowe, 175a, Dill Hall Lane, Church, near Accrington. Lancs.
W. Haworth, 37, Westbourne Avenue, Burnley, Lancs.

## LANCASHIRE—PRESTON SECTION.

W. D. Knagg, 5, Starkie Street, Preston, Lancs.
P. Leyland, 7, Ashley Terrace, Farington, Lancs.

## LONDON—EAST ANGLIAN SECTION.

L. J. Tibbenham, "Frandon," 1, Temple Road, Stowmarket, Suffolk.
J. L. Francis, Ranelagh Works, Ipswich, Suffolk.

## SCOTTISH—FALKIRK SECTION.

N. A. W. Erskine, 21, James Street, Falkirk, Scotland.
H McNair, "Braewick," Larbert Road, Bonnybridge, Scotland.

## SCOTTISH—EDINBURGH COMMITTEE.

A. D. MacKenzie, O.B.E., B.Sc. (Chairman), 213, Colinton Road, Edinburgh.

## WALES AND MONMOUTH—BRISTOL SECTION.

I. Rees, 6, Irby Road, Ashton Gate, Bristol.
A. Hares, 648, Stapleton Road, Bristol, 5.

## *HONORARY CORRESPONDING MEMBERS OF COUNCIL.*

### AUSTRALIA.

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

### CZECHO-SLOVAKIA.

Prof. Dr. Mont Fr. Pisek, Technical High School, Brno.

### FRANCE.

E. Ronceray, 2, Rue Saint-Sauveur, Thiais.

### GERMANY.

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

### ITALY.

Dr.-Ing. Guido Vanzetti, Via Bianca di Savoia, 10, Milan (115).

### SOUTH AFRICA.

A. H. Moore, Standard Brass & Iron Foundry, Limited, Benoni, Transvaal.

# AWARDS 1935-36

## THE "OLIVER STUBBS" GOLD MEDAL

1936 Awards were made to—

Mr. F. HUDSON,

"For the work that he has done in promoting scientific foundry practice, and particularly his investigation work with relation to moulding sands, most of which has been made known to the Institute through the various Papers that he has presented from time to time."

and 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."

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.—Emeritus Professor 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, E. Longden } Two awards.

## MERITORIOUS SERVICES MEDAL

1936 Award to Mr. JAMES SMITH,

"For his continual efforts to promote the development of the Institute since he became a member in 1905."

The Meritorious Services Medal has been awarded as follows:—

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

## DIPLOMAS OF THE INSTITUTE

were awarded to—

Mr. G. L. HARBACH, for his Paper on "Relationship in Cast Iron Test Results," given before the East Midlands Branch.

Mr. A. PHILLIPS, for his Paper on "Some Points in the Modern Production of Castings," given before the Burnley Section of the Lancashire Branch.

Mr. J. McGRANDLE, for his Paper on "Metal Moulds for Cast Iron," given before the Scottish Branch.

# CONTENTS.

**Papers presented to Branches :—**

# The Institute of British Foundrymen

## THIRTY-THIRD ANNUAL CONFERENCE AT GLASGOW

### ANNUAL GENERAL MEETING

The annual meeting of the Institute was held in the Grosvenor Restaurant, Gordon Street, Glasgow, on Tuesday evening, June 9, with the retiring President, Mr. J. E. Hurst, in the Chair.

The minutes of the annual general meeting held at Sheffield on July 2, 1935, were taken as read, approved, and signed by the President.

The Annual Report of the Council for the session 1935-36 was presented.

#### ANNUAL REPORT

This report covers the period May 1, 1935, to April 30, 1936, and the accounts are for the year ended December 31, 1935.

In the last Annual Report a small decrease of membership was reported; it is satisfactory to note that this decrease has been more than neutralised, and on April 30 the membership showed a net increase of 112. The total number of new members added during the year is 265 and the loss due to deaths, resignations and other causes is 153. This increase is due, partly to the improved trade conditions, also to the increased regard in which the Institute is held throughout the industry.

Table I shows the changes in membership 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.

### His Majesty King George V

A resolution of sympathy was forwarded on behalf of the members of the Institute to Her Majesty Queen Mary, and Her Majesty graciously acknowledged receipt of this message.

### Honours Conferred upon Members

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

Sir Robert Hadfield, Bart., has been awarded the Albert Medal of the Royal Society of Arts "for his researches in metallurgy and his services to the steel industry," and has also attained the Diamond Jubilee of his connection with the firm of Hadfields, Limited.

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

Mr. G. T. Lunt was re-elected President of the Foundry Trades Equipment and Supplies Association.

Dr. A. M'Cance was re-elected President of the Glasgow and West of Scotland Iron and Steel Institute, this being the fourth successive year that Dr. M'Cance has occupied this position.

Mr. J. A. Thornton has been re-elected President of the Manchester Association of Engineers.

Mr. E. R. Walter has been elected President of the Lincoln Engineering Society.

Mr. A. Edwards has been elected a Member of Parliament.

### Deaths

It is with great regret that the Council reports the death of 16 members, amongst whom are several who have been prominently identified with the Institute for a number of years, including:—

The Right Hon. Arthur Henderson, M.P., who was elected an Honorary Member of the Institute in 1926. Mr. Henderson was identified with the foundry industry for most of his

TABLE 1.—*Changes of Membership.*

| | Subscribing firms. | Members. | Associate members. | Associates. | Associate students. | Total. |
|---|---|---|---|---|---|---|
| At April 30, 1935 .. .. .. .. | 49 | 729 | 901 | 98 | 3 | 1,780 |
| Additions and transfers from other grades | 3 | 85 | 114 | 47 | 16 | 265 |
| | 52 | 814 | 1,015 | 145 | 19 | 2,045 |
| Losses and transfers to other grades | 3 | 36 | 89 | 25 | — | 153 |
| At April 30, 1936 .. .. .. .. | 49 | 778 | 926 | 120 | 19 | 1,892 |

life, and was a notable figure in public life, having held office as President of the Board of Education, Home Secretary, Foreign Secretary and President of the Disarmament Conference. He was awarded the Nobel Peace Prize in 1935.

Mr. F. W. Finch, who died at the age of 89, was one of the founders of the Institute, and for some years was Secretary. He then became Honorary Treasurer, a position which he held for a period of twenty-five years. He was awarded the Meritorious Service Medal of the Institute in 1933.

Mr. T. Wilkinson, a prominent member of the Middlesbrough Branch, and a former Mayor of Stockton-on-Tees.

Mr. F. Biggin, who for many years was intimately associated with the Sheffield Branch.

Mr. C. W. Kent, who had been a member of the Council of the Lancashire Branch, and was elected a member of the Council of the West Riding of Yorkshire Branch a short time before his death.

Mr. W. J. Flavell, J.P., a Past-President of the Birmingham Branch and a representative of the Institute on Committees of the B.S.I. and the City and Guilds of London Institute.

The Council also note with regret the death of Mr. B. H. Johnson, Vice-President of the American Foundrymen's Association, who was well known to many members of this Institute.

### Finances

Referring to the Balance Sheet and Income and Expenditure Account, the report states that increases have been necessary in certain items of expenditure due to increasing activities, on the other hand there have been economies in other items, particularly in the expenses of the Branches, and the Council wishes to express its thanks to the Branch officials for their endeavours to manage their respective Branches as economically as is consistent with efficiency.

TABLE II.—*Analysis of Membership, April 30, 1936.*

| Branch. | Subscribing firms. | | Members. | | Associate members. | | Associates. | | Associates (students). | | Total. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Birmingham .. .. | 3 | (3) | 121 | (108) | 124 | (117) | 16 | (14) | 4 | (—) | 268 | (242) |
| East Midlands .. | 3 | (3) | 49 | (44) | 82 | (85) | 5 | (3) | — | | 139 | (135) |
| Lancashire .. .. | 14 | (15) | 111 | (119) | 213 | (228) | 31 | (27) | — | | 369 | (389) |
| London .. .. | 6 | (5) | 171 | (147) | 97 | (73) | 6 | (8) | 1 | (—) | 281 | (233) |
| Middlesbrough .. | — | | 20 | (21) | 34 | (38) | 5 | (7) | — | | 59 | (66) |
| Newcastle .. .. | 7 | (6) | 31 | (28) | 30 | (26) | 44 | (21) | 9 | (—) | 121 | (81) |
| Scottish .. .. .. | 4 | (5) | 95 | (86) | 183 | (180) | 8 | (11) | 1 | (—) | 291 | (282) |
| Sheffield .. .. | 6 | (6) | 82 | (81) | 57 | (60) | 3 | (5) | 1 | (—) | 149 | (152) |
| Wales and Mon. .. | 2 | (2) | 32 | (30) | 33 | (28) | — | | 3 | (3) | 70 | (63) |
| W. R. of Yorks .. | 3 | (3) | 43 | (38) | 62 | (62) | 2 | (1) | — | | 110 | (104) |
| Unattached .. .. | 1 | (1) | 23 | (27) | 11 | (4) | — | (1) | — | | 35 | (33) |
| | 49 | (49) | 778 | (729) | 926 | (901) | 120 | (98) | 19 | (3) | 1,892 | (1,780) |

There has been an increase of income due to a large amount of arrears of subscriptions having been recovered during the year, and also to increased membership. In spite of the increased expenditure, the excess of income over expenditure was £166 18s. 4d.

During the year £300 was invested from the surplus funds in 3 per cent. Funding Loan. The cash at the bank, namely, £389 9s. 8d., includes the sum of £117 9s. 8d. transferred from the surplus funds in the hands of the Branches.

A special Sub-Committee has closely investigated every item of income and expenditure, and the Council has no hesitation in reporting that the expenditure is under very close control and constant review. Although the financial position is satisfactory, the Council is conscious of the necessity of continuing to exercise a policy of wise economy.

### Board of Development

In the autumn of 1935, the Council agreed on the suggestion of the President to the appointment of a Development Committee, which consists of the Executive Committee and a number of additional members. The function of this Committee is to review the whole field of the Institute's work and to recommend improvements and new developments. An important report dealing with the annual volume of "Proceedings" and other Technical publications of the Institute has already been submitted by this Committee to the Council, and is under consideration at present.

### Sheffield Conference

The Thirty-Second Annual Conference was held in Sheffield from July 2 to 5, 1935. On the evening of July 2, members and ladies were entertained to a Reception in the Town Hall by the Lord Mayor of Sheffield, Alderman P. J. M. Turner, and the Lady Mayoress, Mrs. Turner.

At the opening meeting of the Conference on July 3, members were welcomed by the Lord

Mayor of Sheffield; the Master Cutler, Mr. A. Williamson and the President of the Chamber of Commerce, Mr. A. K. Wilson. Mr. J. E. Hurst was installed President in succession to Mr. Roy Stubbs, and Messrs. H. Winterton and C. W. Bigg were installed respectively, to the offices of Senior and Junior Vice-President.

The thanks of the Institute are tendered to the Lord Mayor of Sheffield and the Lady Mayoress; to the firms who arranged visits for members and ladies; to the staffs of those firms; to the authors of Papers; to the President, Mr. Hurst and Mrs. Hurst, who entertained the members and ladies at a garden party; and to all who subscribed to the funds or assisted in the organisation of the Conference.

The Council wishes particularly to record its indebtedness to the Council and members of the Sheffield Branch who were responsible for the organisation of the Conference; to the Branch-President, Mr. A. Whiteley; to Mr. T. R. Walker, Secretary of the Branch and to Mrs. Walker, Secretary of the Ladies' Committee.

### Edward Williams Lecture

The Edward Williams Lecture was established to commemorate the very successful year of office as President of Mr. C. E. Williams. The first lecture was delivered on the opening day of the Sheffield Conference, on July 3, by Sir Wm. J. Larke, K.B.E., on the subject of "Man and Metal." The second Edward Williams Lecture will be delivered during the Glasgow Conference on Thursday evening, June 11, by Professor A. L. Mellanby, D.Sc., and the subject will be "Cast Iron."

### Other Technical Organisations

The Institute continues to maintain close relations with other organisations, particularly those serving the engineering industry. Several of the Branches arrange joint meetings with the local Branches of these organisations from time to time. The Institute takes an increasingly close interest in standardisation work, and is represented on most of the important British Standards Institution Committees which are of interest to the foundry industry.

### British Cast Iron Research Association

Important investigations in progress at the present time include shrinkage and contraction of cast iron, the formation of graphite (to be dealt with in part in a Paper to the Glasgow Conference), synthetic moulding sands, metallurgical coke and alloy additions to cast iron.

On development work the number of practical problems dealt with on behalf of members is approximately four per working day. Over one hundred Balanced Blast cupolas have been installed in this country and an additional number overseas, and the furnace is found in the works of about 20 per cent. of members. Apart from other advantages, the resulting economies in fuel are estimated to reach, on a conservative estimate, over three times the total industrial income received.

The report presented at the annual meeting of the Association in October, 1935, indicated that the year 1934-35 had been a record, the total income exceeding £13,000 for the first time. To do this the industrial income had been raised by extension of membership and the £300 remaining to make up the minimum of £7,000 required to earn grant of £5,000 was made up by a group of members in addition to their normal subscriptions. Further efforts are being made during the current year to ensure the necessary minimum being reached entirely by way of annual subscriptions, and the membership of all firms in the industry is sought, in the belief that firms who make full use of the services available will find membership an economical proposition.

### Foundry Exhibition

By courtesy of F. W. Bridges & Sons, Limited, the organisers of the Shipping, Engineering and Machinery Exhibition, in conjunction with which the Foundry Exhibition was held in September, 1935, the Institute was permitted to organise a stand which was in charge of the Technical Committee and to which further reference is made in the Technical Committee's report. Appreciation is hereby expressed to Messrs. Bridges for this courtesy, for their invitation to the members of the Council to luncheon and their further invitation to the whole of the members of the Institute to tea.

### British Industries Fair

Thanks are tendered to the Birmingham Chamber of Commerce who kindly invited the members of the Council to lunch at the British Industries Fair on February 27.

### Relations with Overseas Associations

The International Foundry Conference in 1935 was a European conference and was held in Brussels in the buildings of the Universal Exposition. Over twenty countries were represented and some thirty-five members and ladies of the Institute of British Foundrymen represented Great Britain, headed by the President, Mr. J. E. Hurst, and the Senior Vice-President, Mr. H. Winterton.

The Council takes this opportunity of thanking Mr. J. Leonard, President of the Association Technique de Fonderie de Belgique, and the members of this Association for their very sincere hospitality and for the many courtesies which were shown.

A meeting of the International Committee of Foundry Technical Associations was held in Brussels during the Conference and was attended by the President and Mr. V. C. Faulkner, representing Great Britain, also by Mr. T. Makemson as Secretary of the Committee and Mr. V. Delport, the European representative of the American Foundrymen's Association. At this meeting Mr. J. Leonard, who is an Honorary Member of this Institute, was elected President for the year 1936, and Mr. V. Delport was elected Vice-President.

A meeting of the International Committee on Testing Cast Iron was also held in Brussels during the Congress, and the Institute was represented by Dr. A. B. Everest and Mr. T. Makemson.

The next International Foundry Conference will be a world conference, and will be held in Düsseldorf from September 17 to 22, 1936. Arrangements will be made for a party of members and ladies to attend this conference, and further details will be circulated to members of the Institute later.

Mr. H. H. Beeny was the author of the official Exchange Paper presented to the International Foundry Congress in Brussels, and Mr. P. A. Russell presented the official Exchange Paper to the French Foundry Congress in Paris, which was held in connection with the International Congress of Mines, Metallurgy and Applied Geology.

Exchange Papers to forthcoming Overseas Conferences will be presented as follow:—

American Foundrymen's Association, Detroit —The President, Mr. J. E. Hurst.

French Foundry Conference, Lille—Mr. G. L. Harbach.

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

At the Institute's forthcoming Conference in Glasgow in June, Papers will be presented on behalf of the American, French, and German Foundry Technical Associations.

## Branch Activities

It will be seen from a perusal of this and previous reports, that the Institute is becoming increasingly interested in various movements of a national character, designed to promote the technical development and educational progress of the foundry industry. The Council, however, is fully conscious of the great importance of the work which is done throughout the year by the various Branches and realises that the only contact which many members make with the Institute, is through the work which the Branches carry out. The officials of the Branches, particularly the Honorary Secretaries, give much devoted service and it is with great pleasure that the Council records its thanks to them for those services.

During the year, about one hundred Papers have been presented at various Branch meetings and in addition there have been several discussions and also the annual addresses of the Branch-Presidents.

Thanks are also expressed to the proprietors and staffs of the various works which the Branches have visited, to the authors of all Papers given to the Branches and to the firms with whom they are associated.

A two days' meeting of the London and East Midlands Branches was held for the second successive year, on this occasion at Derby and Loughborough and was well attended.

### Educational Work

The educational work for which the Institute has been responsible, or in which it is actively interested, is of a graduated character intended to cover the requirements of various types of persons engaged or about to be engaged in the trade. This work includes:—

(*a*) The encouragement of the establishment of part-time evening classes in patternmaking and foundry practice, arrangement of examinations and the award of certificates which are endorsed by the President. This work is carried out by the City and Guilds of London Institute through a Committee on which the Institute of British Foundrymen is largely represented; the results of the 1935 examinations are as follows:—

| | No. of candi-dates. | Pass 1st class. | Pass 2nd class. | Percen-tage of passes. |
|---|---|---|---|---|
| *Patternmaking*— Intermediate grade | 29 | 5 | 11 | 55.2 |
| *Patternmaking*— Final grade | 21 | 6 | 8 | 66.6 |
| *Foundry Practice and Science* | 61 | 13 | 21 | 55.7 |

Prizes were awarded to:—

PATTERNMAKING—INTERMEDIATE GRADE.

Mr. W. Brindley, of Wolverhampton, Bronze Medal of the C. & G. of London Institute.

PATTERNMAKING.—FINAL GRADE.

Mr. J. C. Wall, of Coventry, Silver Medal of the C. & G. of London Institute, and Buchanan Prize of the Institute of British Foundrymen.

Mr. H. W. Carter, of Poplar, Buchanan Prize.

Mr. L. Harrop, of Huddersfield, Buchanan Prize.

Mr. W. Watson, of Coventry, Buchanan Prize.

FOUNDRY PRACTICE AND SCIENCE.

Mr. J. Scobbie, of Derby, Bronze Medal of the C. & G. of London Institute and Buchanan Prize of the Institute of British Foundrymen.

(*b*) The endorsement in respect of special foundry subjects by the President of the Institute, of National Certificates in Mechanical Engineering, issued by the Board of Education and the Institution of Mechanical Engineers. During the last twelve months 33 National Certificates have been so endorsed, making a total of 136 since the commencement of the arrangement.

The National Certificate courses are intended for young men who are prepared to take longer and more advanced courses in order to fit them for positions of responsibility.

(*c*) The Degree Course at the Sheffield University, which is intended for the increasing number of young men who wish to have a University degree before entering the foundry industry. This course is now in its second year, and a number of students are enrolled in the course.

The initial funds for the commencing of the course were raised by a Committee of this Institute, which, having completed its work has now been dissolved. Further funds are required, and an advisory Committee formed by the University of Sheffield upon which the Institute is represented, will now be responsible for advising on the Course and for the raising of further funds.

In addition to the foregoing, the Council wishes to call attention to the valuable work being done by the British Foundry School at Birmingham, established through the efforts of the British Cast Iron Research Association and Mr. Pearce.

The School, which is a specialised course of one year's duration for men of practical experience in the industry and suitable preliminary education, who wish to equip themselves for the highest posts in the industry, opened in October, 1935, with thirteen students. Mr. J. Bamford, B.Sc., was appointed Lecturer-in-Charge and over one hundred lectures have been given by outside specialists in the industry. Foundry visits are paid each week. The diploma examination will be held in July and entries of students for the second year, commencing in September, 1936, can now be made. The President, Mr. J. E. Hurst, represents this Institute on the governing body, which is formed of representatives of the dozen or so institutions supporting the scheme, together with representatives of the Board of Education and Birmingham Education Committee. The income required for the first year's working has been raised, the financial year ending in April, 1936, and it is hoped that the School will become permanent.

There are now in operation courses suitable for all grades of workers in the foundry trade, and the Council appeals to all those who have young men under their control to encourage them to take advantage of these educational facilities, further particulars of which can be obtained from the Secretary of the Institute.

### Awards

No award was made of the Oliver Stubbs Medal in 1935. The rules have now been amended to permit of the award being made for services over a longer period and not necessarily service given during the previous year.

### Meritorious Service Medal

The third award of this Medal was made in July, 1935, to Mr. H. Bunting, who had recently retired from the Secretaryship of the East Midlands Branch after twenty years' devoted work in that capacity.

### Diplomas

The announcement of the award of Diplomas to the following members was made at the Sheffield Conference. The Diplomas were given in each case, for Papers given before Branches which are named in the list:—

W. H. Bamford, Birmingham Branch.

W. Machin, Lancashire Branch (joint Paper with M. Oldham, who was then a non-member).

J. Roxburgh, Sheffield Branch.

P. A. Russell, London and E. Midlands Branches.

T. Tyrie, Scottish Branch.

T. R. Walker, Sheffield Branch.

### Surtees' Memorial Examination

The 1936 examination was held by the Scottish Branch, and the results were:—

Matthew Russell, *Gold Medal.*

Douglas Robertson, *Silver Medal.*

### Employment Bureau

The Employment Bureau has been the medium by which a large number of members have found suitable employment, though it has not always been possible to find men with the type of experience required by the inquiring employers. It is satisfactory to note that due to improved trade conditions, a lesser number of members are disengaged.

The Institute is indebted to the proprietors of the " Foundry Trade Journal " for the facilities they give in connection with the Employment Bureau.

### Council

Four meetings of the Council and more than twenty meetings of standing and special Committees have been held. The Council Meetings have been at Sheffield, Newcastle, London, and Middlesbrough, the average attendance being 42.

The Technical Committee has held four meetings and there have been two meetings of the Technical Council. Additionally, upwards of 40 meetings of Sub-Committees of the Technical Committee have been held.

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 of the Institute.

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 9 are:—

Messrs. A. Campion, J. W. Gardom, B. Hird, R. A. Miles, J. M. Primrose.

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

The Council wishes to express its grateful thanks for the services of Mr. W. B. Lake, J.P., Honorary Treasurer, whose guidance in connection with the Institute's finances has been invaluable, and to Mr. J. W. Gardom, Convener of the Technical Committee.

### Annual Conference

The thirty-third Annual Conference will be held at Glasgow from June 9 to 12, 1936, when Mr. H. Winterton (President-elect) will be installed President of the Institute.

J. E. HURST, *President.*
T. MAKEMSON, *Secretary.*

# BALANCE SHEET, DECEMBER 31, 1935.

## Liabilities.

| | £ s. d. | £ s. d. |
|---|---|---|
| Subscriptions paid in advance | | 86 2 0 |
| Sundry Creditors .. .. | | 442 19 7 |
| Secretary's Policy Fund .. | | 18 8 8 |
| The Oliver Stubbs Medal Fund :— | | |
| Balance from last Account | 211 13 5 | |
| Interest to date .. .. | 9 13 10 | |
| Income Tax Refund .. | 1 14 6 | |
| | 223 1 9 | |
| *Less* Cost of Medal .. | 9 15 0 | |
| | | 213 6 9 |
| The Buchanan Medal Fund :— | | |
| Balance from last Account | 122 12 3 | |
| Interest to date .. .. | 4 12 6 | |
| | 127 4 9 | |
| *Less* Cost of Medal and Prizes .. .. .. | 4 10 0 | |
| | | 122 14 9 |
| International Conference Fund :— | | |
| Surplus included in General Investments .. .. | | 40 18 11 |
| Accumulated Fund :— | | |
| Balance at December 31, 1934 .. .. .. | 1,697 12 4 | |
| *Add :* Excess of Income over Expenditure for the year ended December 31, 1935 .. .. .. | 166 18 4 | |
| | | 1,864 10 8 |
| | | £2,789 1 4 |

## Assets.

| | £ s. d. | £ s. d. |
|---|---|---|
| Cash in hands of Secretaries :— | | |
| Lancashire .. .. | 30 19 7 | |
| Birmingham .. .. | 20 17 9 | |
| Scottish .. .. .. | 19 19 7 | |
| Sheffield .. .. .. | 32 15 10 | |
| London .. .. .. | 55 18 0 | |
| East Midlands .. .. | 19 15 2 | |
| West Riding of Yorkshire | 22 15 9 | |
| Wales and Monmouth .. | 0 15 9 | |
| Middlesbrough .. .. | 1 6 0 | |
| | | 205 3 5 |

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Cash in Hand :— | | | | | | |
| Secretary's Policy Fund .. | | | | 18 | 8 | 8 |
| Sundry Debtors :— | | | | | | |
| Subscriptions due and subsequently received .. | | | | 65 | 12 | 6 |
| Lloyds Bank Ltd. .. .. | | | | 389 | 0 | 8 |
| The Oliver Stubbs Medal Fund :— | | | | | | |
| £342 5s. 7d. Local Loans £3 per cent. Stock at Cost | 200 | 0 | 0 | | | |
| Balance at Lloyds Bank | 13 | 6 | 9 | | | |
| | | | | 213 | 6 | 9 |
| The Buchanan Medal Fund :— | | | | | | |
| £125, £3 10s. 0d. per cent. Conversion Stock at 78¼ | 98 | 6 | 9 | | | |
| Balance at Midland Bank | 24 | 8 | 0 | | | |
| | | | | 122 | 14 | 9 |
| Investments Account :— | | | | | | |
| £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 :— | | | | | | |
| Per last Account .. .. | 84 | 19 | 0 | | | |
| *Less :* Depreciation 10 per cent. .. .. .. | 8 | 9 | 11 | | | |
| | | | | 76 | 9 | 1 |
| Superannuation Insurance :— | | | | | | |
| Unexpired Premium .. | | | | 18 | 8 | 7 |
| | | | | £2,789 | 1 | 4 |

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 25, 1936.

## INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1935.

### Expenditure.

| | £ s. d. | £ s. d. |
|---|---|---|
| Postages .. .. .. | | 124 12 3 |
| Printing and Stationery, including printing of "Proceedings" .. .. .. | | 696 14 0 |
| Council, Finance and Annual Meeting Expenses .. | | 119 15 10 |
| Medal for Past President .. | | 3 0 0 |
| Branch Expenses :— | | |
| Lancashire .. .. | 118 5 5 | |
| Birmingham .. .. | 62 10 3 | |
| Scottish .. .. .. | 88 0 5 | |
| Sheffield .. .. .. | 38 4 2 | |
| London .. .. .. | 35 5 8 | |
| East Midlands .. .. | 43 10 7 | |
| Newcastle .. .. .. | 37 15 3 | |
| West Riding of Yorkshire | 24 14 3 | |
| Wales and Monmouth .. | 28 11 6 | |
| Middlesbrough .. .. | 32 16 0 | |
| | | 509 13 6 |
| Audit Fee and Accountancy Charges .. .. .. | | 12 12 0 |
| Incidental Expenses .. | 88 6 0 | |
| Subscription, Iron and Steel Inst. Welding Symposium | 10 0 0 | |
| Subscription British Foundry School .. .. .. | 5 0 0 | |
| Foundry Exhibition .. .. | 23 11 0 | |
| Legal Charges *re* Secretary's Insurance Policy .. .. | 6 11 5 | |
| | | 133 8 5 |
| Salaries—Secretary and Clerks | | 675 13 0 |
| Superannuation Insurances (Secretary) .. .. .. | | 36 17 3 |
| Rent, Rates, &c., of Office, *less* Received .. .. | | 90 4 4 |
| Subscription International Committee .. .. | | 2 10 0 |
| Depreciation of Furniture .. | | 8 9 11 |
| John Surtees Memorial Examinations Grants to Branches .. .. .. | | 7 6 10 |
| | | 2,420 17 4 |

| | £ s. d. | £ s. d. |
|---|---|---|
| Excess of Income over Expenditure carried to Balance Sheet .. .. | | 166 18 4 |
| | | £2,587 15 8 |

INCOME.

| | £ s. d. | £ s. d. |
|---|---|---|
| Subscriptions received :— | | |
| Lancashire Branch .. | | 469 1 6 |
| Birmingham .. .. | | 356 13 0 |
| Scottish .. .. .. | | 354 7 6 |
| Sheffield .. .. .. | | 249 18 0 |
| London .. .. .. | | 389 0 8 |
| East Midlands .. .. | | 168 0 0 |
| Newcastle .. .. .. | | 158 0 6 |
| West Riding of Yorkshire | | 132 6 0 |
| Wales and Monmouth .. | | 100 10 0 |
| Middlesbrough .. .. | | 76 2 6 |
| Unattached Members .. | | 46 4 0 |
| | | 2,500 3 8 |
| *Add :* Subscriptions in Advance, 1934 .. .. | 123 18 0 | |
| Do. due 1935 .. | 65 12 6 | |
| | | 189 10 6 |
| | | 2,689 14 2 |
| *Less :* Subscriptions in Advance, 1935 .. .. | 86 2 0 | |
| Do. due 1934 .. | 122 17 0 | |
| | | 208 19 0 |
| | | 2,480 15 2 |
| Sale of " Proceedings," &c... | | 15 13 4 |
| Interest on Investments and Cash on Deposit .. .. | | 59 7 1 |
| Income Tax Refund .. | | 6 17 6 |
| John Surtees Medal Fund, Surplus .. .. .. | | 22 11 6 |
| Profit on Sale of Badges .. | | 2 11 1 |
| | | £2,587 15 8 |

### Adoption of Report

In proposing the adoption of the Report the PRESIDENT mentioned that last time the Conference was held in Glasgow 11 years ago, the membership of the Institute numbered 1'525, while this year it numbered 1,892.

MR. R. A. MILES seconded, and the report was unanimously adopted.

### Balance Sheet and Accounts

On the motion of MR. W. B. LAKE, the Hon. Treasurer, seconded by MR. VICTOR STOBIE (Past-President), the Balance Sheet and Accounts were unanimously adopted.

### Report of Technical Committee

MR. J. W. GARDOM, Convener, proposed the adoption of the Technical Committee's Report, which was seconded by MR. C. E. WILLIAMS (Past-President).

MR. DANIEL SHARPE (Scottish Branch-President), in commenting on the Report recalled that it was suggested at the last meeting at Middlesbrough that the two Papers referred to in the Report should become the subject of discussions at one meeting during the forthcoming session, and he thought it would be worth while giving some consideration to that suggestion. He thought they might profitably have a discussion night during the forthcoming session in connection with each Branch.

The Report was unanimously adopted.

## FOURTH ANNUAL GENERAL REPORT OF THE TECHNICAL COMMITTEE

The Technical Council consists of certain *ex-officio* members of the Technical Committee together with two members elected by each Branch of the Institute; the Technical Committee consists of the Technical Council together with a number of members who are co-opted by reason of their special knowledge of the work covered by one or more of the sub-committees of the Technical Committee.

During the year some reorganisation has taken place with regard to the meetings of this Committee. It has been realised that the important work is done by the various specialised sub-committees, and in order to prevent encroachment upon the time available for the meetings of these sub-committees, the meetings of the full Technical Committee have been shortened considerably and meetings of the Technical Council are now held only occasionally, instead of one per quarter as was the previous arrangement. The benefit of this arrangement has already been seen, in that the Sub-Committees are able to give more consideration to the details of the work which they have in hand and more rapid progress is being made. Details of the work of each sub-committee are given in the sub-committee reports which follow this report.

Additional to the Sub-Committee work, there are certain activities for which the Technical Committee, as a whole, is responsible, some of these are briefly described as follows:—

(*a*) Foundry Exhibition. The Technical Committee was the medium by which the Institute participated in the Foundry Exhibition held at Olympia in September last. By courtesy of the organisers, F. W. Bridges & Sons, Limited, a stand was placed at the Institute's disposal and the organising and staffing of the stand was undertaken by members of the Technical Committee.

The exhibit included castings in special irons; recommended methods of gating malleable cast iron and non-ferrous metals; specimens showing the behaviour of refractories under varying conditions; a display of sand-testing apparatus; numerous charts of technical interest and reports on foundry costing.

As a result of this exhibit, members of the Institute were enabled to see the part which the Technical Committee is taking in connection with the development of foundry technique, and the interest of a number of non-members was aroused, with the gratifying result that some twenty applications for membership of the Institute were received.

(*b*) Representatives on other National Committees. The Technical Committee is the medium by which the Institute is represented on the appropriate Committees of the British Standards Institution, and also on appropriate Committees of other Technical Societies whose work is of interest to ourselves. The Institute directly participates through the Technical Committee, in the preparation of specifications.

(*c*) Nomenclature. The Sub-Committees in their work have found it necessary to give a correct definition of certain foundry terms, and to attempt to standardise these terms. The Technical Committee is engaged in compiling a list of standard definitions and terms which will be of increasing value and which it hopes to publish in due course.

(*d*) Inquiry Bureau. This was established a few years ago and continues to give useful service to members who may require specific information upon some problem of foundry technique or guidance as to where information can be found. Inquiries are submitted to the appropriate Sub-Committee, and if necessary, other Sub-Committees are consulted; as far as possible the inquiry is treated confidentially.

(*e*) Tolerances on Dimensions of Castings. The Malleable Cast Iron Sub-Committee has recently tabulated the variations in dimensions of castings which may reasonably be expected under given conditions, and as a result is convinced of the desirability of specifying tolerances in specifications covering the ordering of castings. The work has been extended in collaboration with other Sub-Committees who cover castings in other metals than malleable cast iron and a comprehensive report on the subject will be presented at the Annual Conference at Glasgow.

### Committee Reports

In addition to the report on tolerances mentioned above, the Non-Ferrous Sub-Committee will also present a Paper to the Conference in Glasgow dealing with "Some Recommendations of the Non-Ferrous Sub-Committee for Specifications for Two Leaded Gunmetals."

It is hoped that the written discussions on these reports will bring out additional information and suggestions which will increase their value to the industry.

The Costing Sub-Committee has followed its work on Melting Costs by preparing a tentative report on Moulding Costs. This has been submitted to a number of Branches of the Institute during the Winter Session and a fuller report will be prepared embodying the criticisms and suggestions made on the report by the various Branches.

From time to time the Sub-Committees have found it necessary to enlist the co-operation of various firms in the industry either by submitting a questionnaire or by conducting a certain amount of experimental work. The Technical Committee wish to tender its thanks to those firms who are co-operating with the Sands Sub-Committee in making practical tests of a number of sand mixtures.

The Convener takes this opportunity of expressing his thanks to the members of the Committee and particularly to the Sub-Committee Conveners, for the large amount of important work which they have performed during the year, and for the considerable amount of travelling which all members have undertaken at their own expense. The work which the Technical Committee does is intended to benefit the Institute and the industry as a whole, and it cannot be emphasised too strongly that all this work is done voluntarily and in a public-spirited manner.

J. W. GARDOM,
*Convener, Technical Committee.*

## REPORTS OF SUB-COMMITTEES

### Sub-Committee on Cast Iron

The proposed alterations and additions to the B.S.I. Specifications for Cast Iron have occupied the attention of this Sub-Committee throughout the year. The Sub-Committee has played a prominent part in assisting the British Standards Institution to frame the requirements for the new high-duty cast-iron specification; it is expected that this will shortly be available in draft form. They have also kept in close touch with the proposed modifications to the standard test bars, which work is proceeding satisfactorily.

The second series of typical microstructures is now completed and it is hoped that these will be published shortly. This series, which has been compiled in collaboration with the British Cast Iron Research Association as before, includes typical structures of various irons not shown in the first series, martensitic and austenitic cast irons, examples showing deep etching to reveal phosphide eutectic, and a separate section on malleable cast iron which the Malleable Sub-Committee has drawn up.

Continuing its work upon the soundness of castings the Sub-Committee has given attention to the subject of the gating and feeding of castings. This is a vast subject, and as a preliminary they are compiling a drawing showing various types and parts of runners and risers, with agreed nomenclature.

The list of physical data for cast iron, issued in 1932, is being reviewed in the light of information published since that date, with a view to re-issue.

In consequence of the reorganisation of Sub-Committee work, this Sub-Committee has lost the services of Messrs. L. W. Bolton, B. Hird, and F. K. Neath. Mr. E. B. Ellis has joined the Committee and Messrs. G. L. Harbach and A. A. Timmins have been co-opted. The six meetings of the Sub-Committee held during the year have been well attended.

P. A. Russell,
*Convener.*

### Sub-Committee on Costing

Since the last Annual Report, the Sub-Committee has gone into the question of costs in the moulding department. The result of the discussions on this subject was embodied in a Paper that was presented before a number of Branches during the Session 1935-36.

As a result of the discussions that followed the reading of that Paper, we have gone further into the subject and we are now coming to the end of our investigations with regard to moulding costs.

We are now going to investigate costs in the core department, and this will be followed by the other departments of the grey iron foundry.

A Paper covering the extent of our researches to date will be ready by about February, 1937. It is scheduled for discussion before the London Branch in March, and will be available to other Branches.

We hope that we may, perhaps, be in a position to complete our work on costs in the grey iron foundry in time to present an interim report at the Derby Conference in 1937.

V. Delport,
*Convener.*

### Sub-Committee on Malleable Cast Iron

As previously reported this Committee has, during the last few years, been investigating the subject of specified tolerances on the dimensions of castings. The Steel Castings, Non-Ferrous, and Grey Cast Iron Sub-Committees have cooperated in this work, which is being published at the Glasgow Conference.

A number of photomicrographs of Malleable Cast Iron have been contributed for inclusion in Series No. 2 of Typical Micro-Structures, published by the Cast Iron Sub-Committee.

The investigation which has been in progress for some time, considering the possibility of utilising a standard test bar with specified different test requirements to represent various sections of metal, has progressed during the year but has not yet been completed.

The correlation of physical properties of malleable cast irons with micro-structure has occupied the attention of the Sub-Committee for a very long time, but during the last 12 months no work has been accomplished because of the urgency of other investigations.

It is expected that during the next year the Sub-Committee will put information before the British Standards Institution's Committee which is considering the revision of malleable cast iron specifications.

A. E. Peace,
*Convener.*

### Sub-Committee on Melting Furnaces

The principal work of this Sub-Committee has been concerned with the preparation of the Paper on melting furnaces which was mentioned in the previous Annual Report. It was intended that this Paper should be presented at the Glasgow Conference, but as it was not possible to include data on all types of furnaces envisaged, the Paper has been withheld for the present and will be published later.

Considerable progress has been made with the assembly of data on cupola and rotary melting furnaces for cast iron.

F. K. Neath,
*Convener.*

### Sub-Committee on Non-Ferrous Castings

The work of the Sub-Committee on Non-Ferrous Castings during 1935-36 has been largely concerned with collation and correlation of data for assembly into the Paper presented at this year's Glasgow Conference.

When this Paper is in print, it is proposed to ascertain the views of even a wider circle of users on the general suitability of the two lead gunmetals which have been proposed by the Sub-Committee in the Paper. A good deal of similar work has been done by the Sub-Committee during the year on the subject of lead phosphor bronzes which find extensive use in industry for bearing bronzes particularly where soft or semi-hard journals are concerned. It is proposed during the coming year to take this matter further with the view to the submission of a similar Paper to that presented at this conference embodying the Sub-Committee's recommendations as to the most suitable alloys to employ, their physical properties, and suggestions for standardisation.

F. W. Rowe,
*Convener.*

### Sub-Committee on Refractories

The Sub-Committee has considered the characteristics which are desirable in cupola firebricks and has drafted for presentation to the Technical Committee, a tentative specification. The tests suggested are based, with necessary modifications, on the Standard Specifications for Gasworks, issued by the Institution of Gas Engineers in July, 1934.

Preliminary consideration has been given to the testing of cupola ganister, and in due course it is hoped that it will be possible to draft a specification and indicate simple methods for testing and evaluating this material.

In furtherance of the work of this new Sub-Committee, the Convener has addressed the Birmingham, Sheffield, and Lancashire Branches, on the general subject of cupola refractories.

W. J. Rees,
*Convener.*

### Sub-Committee on Sands

In the last Annual Report, reference was made to the questionnaire on moulding sands, which had been circulated to a number of firms, and in which they were invited to make practical tests of a number of sand mixtures to enable the Sub-Committee to check the results on the sand testing apparatus they had recommended

One hundred and four replies have been received. These have been tabulated by Dr. J. G. A. Skerl, and are now being studied by the members of the Sub-Committee. The conclusions arrived at will be published later.

Work is being continued on dry compression strength testing, the testing of dry sand and loam having been thoroughly discussed, and oil sands are now being studied. It is expected that definite data will be ready for publication next year.

Mr. N. D. Ridsdale has submitted a series of tests on permeability by the orifice method, using the method on A.F.A. types of apparatus and eliminating time, measuring pressures only. The Sub-Committee has decided to recommend this method for shop routine tests.

The Committee has dealt with a number of inquiries from other Sub-Committees on the subject of sands, and participated along with other Sub-Committees in organising the Technical Committee exhibit at Olympia last September.

Since its formation, the Sub-Committee has been known as the Sands and Refractories Sub-Committee; all matters dealing with Refractories will in future be undertaken by the Refractories Sub-Committee under the convenership of Mr. W. J. Rees, and this Committee will cover all matters connected with moulding sands.

B. Hird,
*Convener.*

## Sub-Committee on Steel Castings

During the year the Committee has been reorganised and enlarged; this has somewhat delayed the work, but a very full programme of investigation has now been undertaken. These investigations include:—

(*a*) A research into the effects of heat treatment, undertaken after receiving a report by one of the members.

(*b*) An investigation into the soundness of steel valve castings.

(*c*) A consideration of and research into all the possible factors affecting the occurrence of defects in steel castings, with especial reference to hot tears or pulls.

In beginning this work, considerable preliminary work by individual members was necessary, also it was thought desirable to arrange co-operation with other scientific bodies interested in the same subjects. These arrangements are now satisfactorily complete.

C. H. Kain,
*Convener.*

### Oliver Stubbs Gold Medal

In announcing the award of the Oliver Stubbs Medal, the President intimated that the Council this year had decided to award two medals, one to Mr. F. Hudson and the other to Mr. E. Longden. He remarked that the members were all familiar with the amount of valuable work Mr. Hudson had done recently on the subject of moulding sand, while in the case of Mr. Longden they were also familiar with the work he had done on the subject of soundness, shrinkage and distortion in castings.

### Meritorious Service Medal

Mr. H. Winterton, the President-Elect, announced that it had been decided to award the Meritorious Service Medal this year to Mr. James Smith of Newcastle. He added that Mr. Smith was unfortunately unable to be present that night to receive the medal, but he expected to be able to be present on Thursday night on the occasion of the second Edward Williams Lecture, when the formal presentation would be made.

### Awards of Diplomas

The Secretary announced that the council this year had agreed to the award of three Diplomas: the first to Mr. G. L. Harbach for a Paper on "Relationships in Cast Iron Test Results," the second to Mr. A. Phillips for a Paper on "Recent Foundry Developments," and the third to Mr. J. McGrandle for a Paper on "Some Notes on Using Metal Moulds for Cast Iron."

### E. J. Fox Medal

In formally announcing the establishment of the E. J. Fox Medal, the President stated that just over a month ago Mr. E. J. Fox in a letter to himself had indicated that he would like to present a capital sum of £500 to create an award to be within the gift of the Institute and to be awarded for services and outstanding work in connection with metallurgy, particularly with reference to Foundry Metallurgy. That letter had been considered by the council, and, needless to say, the gift had been very gratefully accepted. Since that time a Sub-Committee of the council had met Mr. Fox and discussed with him in detail the proposed constitution of the new award. At the council meeting held that afternoon it had been decided that the medal be known as the E. J. Fox Medal, and a series of rules governing the award had been drafted and would be promulgated in due course. The rules provided for advice being given to the council of the Institute as to suitable nominations for the award by means of assessors, and two assessors had been appointed, who would act in consultation with the President of the Institute to advise the council regarding nominations suitable to receive the award. The two assessors who had agreed to act were Sir Harold Carpenter and Sir William Larke, both of whom were outstanding personalities in the metallurgical world, and incidentally at the same time were honorary members of the Institute. The President added that the object of Mr. Fox's action in making this gift was to create a sort of memorial to commemorate the work that had been done in this country in the development of the centrifugal casting process. Mr. Fox considered, and rightly so, that this country had taken a leading part in the development of the centrifugal casting process as a process in the realms of foundry metallurgy, and with the object of marking the work that had been done in this country in that direction he had presented this sum of £500 to the Institute.

### Election of President

The PRESIDENT, in proposing Mr. H. Winterton (Scottish Branch) as his successor in the presidential chair, said that he did so with peculiar pleasure because during his year of office he had been closely associated with Mr. Winterton, and whilst he could claim to have been a friend of Mr. Winterton's before he was raised to the presidential chair, he was perfectly certain that his association with Mr. Winterton during his year of office had only served to increase that friendship. Mr. Winterton had been a member of the Institute for a very long time, in fact so long as to be able to possess a membership card dating back to the early days of the Institute when it was the British Foundrymen's Association, and when he believed the membership fee was about the same as a present-day driving licence. He was sure they would all agree that for consistent loyalty, energy and activity in the interests of the Institute there was no one who could beat Mr. Winterton's record.

Mr. J. Cameron (Past-President), in seconding, remarked that this was the second time the Scottish Branch had nominated an Englishman for this position. From many years friendship with Mr. Winterton, and from a knowledge of his business capacity, his generosity, his driving force and his enthusiasm, he was convinced that Mr. Winterton would prove himself an ideal President of the Institute.

Mr. Winterton was unanimously elected. In acknowledging the honour conferred upon him, he recalled that in September, 1905, he was proposed as a member of the Institute. He assured them he would do his very best to adorn the position in which they had placed him, and he sincerely hoped that in a year's time when he came to demit office, he would have the pleasure of knowing that the membership was over the two thousand mark.

### Vote of Thanks to Retiring President

Mr. Winterton proposed a hearty vote of thanks to the retiring President, which Mr. Hurst suitably acknowledged. Mr. Hurst remarked that it had been a matter of great personal pride to him to have been President of this Institute, and it was a memory which he would always treasure. He concluded with the remark that it would have been utterly impossible for him to have done any work at all but for the able support of the Secretary, Mr. Makemson, who had proved a tower of strength.

### Election of Vice-Presidents

Mr. Winterton proposed the name of Mr. C. W. Bigg, of Derby, for election as Senior Vice-President. Mr. V. C. Faulkner (Past-President), in seconding, remarked that Mr. Bigg had already presided with considerable distinction over the East Midland branch, and his period of office as Junior Vice-President of the Institute had also been successful. Mr. Bigg had joined the Institute in 1915, and surely there was never a more lusty war baby. He considered that it was only fitting they should give Mr. Bigg, as his twenty-first birthday present, the position of Senior Vice-President.

Mr. Bigg, who was unanimously elected, responded. He said that Mr. Faulkner had reminded him that he had been a member for 21 years, and he could truly say that those 21 years so far as he was concerned, had been an association productive of very much benefit and a tremendous amount of pleasure, and he was most anxious to do all he could to promote the best interests of this Institute.

On the motion of Mr. J. Cameron (Past-President), seconded by Mr. Worcester (Past-President of the West Riding of Yorkshire Branch), Mr. Joseph Hepworth, J.P., M.P., was unanimously elected Junior Vice-President. Mr. Hepworth suitably acknowledged the honour.

### Election of Auditors

On the motion of Mr. Roy Stubbs, J. & A. W. Sully & Company, Chartered Accountants, were unanimously re-elected auditors for the coming year.

### Election of Members of Council

The Secretary announced the result of the ballot for the election of five members of Council.

The following were elected:—Mr. A. Campion, Mr. J. W. Gardom, Mr. B. Hird, Mr. F. K. Neath and Mr. J. M. Primrose.

### Election of Honorary Members

The PRESIDENT proposed the election as Honorary Members of the Institute of Prof. Albert Portevin, a distinguished French metallurgist holding the Chair of Professor at the Foundry School in Paris, and also Professor at the School of Arts and Manufactures; and Dr. Percy Longmuir, one of the founding members of the Institute, having joined in 1904 and having occupied the office of President in 1910-11. MR. WINTERTON seconded, and Prof. Portevin and Dr. Longmuir were unanimously elected Honorary Members.

The PRESIDENT, in closing the proceedings, mentioned that a few days ago one of their esteemed members of Council, Mr. McClelland, celebrated his golden wedding, and on behalf of the members of the Institute he conveyed to Mr. McClelland hearty congratulations.

The PRESIDENT extended a cordial welcome to Mr. Guy and Mr. Moore, two members of the Institute from South Africa. He mentioned that Mr. Guy was President of the Engineering Employers' Federation in South Africa.

## CIVIC RECEPTION

Following the Annual General Meeting the members and their ladies repaired to the City Chambers, where they were entertained at a Civic Reception by the Lord Provost and Magistrates of the City. In the Satinwood Salon from 8 to 8.30 p.m. the guests were received and individually greeted by the Lord Provost; Mr. J. E. Hurst, the retiring President, and Mr. Harry Winterton, the President-Elect. Thereafter the company proceeded to the Banqueting Hall, where an interesting little ceremony took place.

The LORD PROVOST (Mr. John Stewart) presided, and was accompanied on the platform by

Bailies Cochrane and Jean Mann, Mr. J. E. Hurst, Mr. H. Winterton, Mr. John Craig (managing director of Colvilles, Limited) and Mr. Daniel Sharp (Convener, Conference Executive Committee).

The Lord Provost, in extending to the guests on behalf of the Corporation of Glasgow a very hearty welcome to the City, remarked that in the course of a year's work it was his duty and privilege to meet many people who were attending conferences, but in view of the fact that Glasgow was a great industrial city he could hardly conceive of a more appropriate conference that should be received by the City of Glasgow than that of the Institute of British Foundrymen. As they were all aware, Glasgow's prosperity depended very largely on the production of iron and steel, as well as shipbuilding and engineering, and he supposed there could really be no shipbuilding or engineering without the foundrymen.

Mr. Hurst, in conveying to the Corporation of Glasgow, through the Lord Provost, the thanks of the Institute for the hospitable manner in which they had been received, recalled that the last time the Conference was held in Glasgow was in the year 1925, eleven years ago, and in the official record of the proceedings on that occasion it was succinctly stated that at the Civic Reception, which took place on that occasion in the afternoon, the oratory was brief on account of the heat. (Laughter.) Mr. Hurst went on to say that Scotland was famous in our metallurgical history in so far as it related to foundry work, and that in itself was an attraction to them in coming to Glasgow and holding their Conference in this great city.

Mr. Winterton, who followed, formally proposed a hearty vote of thanks to the Lord Provost and Magistrates of the City, to which the Lord Provost suitably responded.

An enjoyable programme of vocal and orchestral music followed, while dancing was indulged in by many of the guests till 11 p.m.

## OPENING OF CONFERENCE

The first Session of the Conference opened on Wednesday morning, June 10, in the Rankine Hall of the Institution of Engineers and Shipbuilders in Scotland, Elmbank Crescent. The retiring President (MR. J. E. HURST) presided during the early part of the proceedings, and at the outset formally introduced the Lord Provost of Glasgow (Mr. John Stewart), Sir James Lithgow, Bart., M.C., D.L. (President of the Reception Committee), Col. Norman Kennedy, D.S.O. (President of the Chamber of Commerce), and Sir Arthur Huddleston, C.M.G., O.B.E., M.A. (Director of the Royal Technical College).

THE LORD PROVOST said his main business there that morning was again to extend to them a very hearty welcome to the City of Glasgow. He supposed the main purpose of the Institute and of this Conference was to discuss the matters intimately relating to the scientific and material conditions of their business. The foundry after all was the very basis on which shipbuilding and engineering rested. He supposed it would be impossible to produce a steam engine or a ship, or even some small domestic article such as a pot or pan, without the foundryman's skill. It was well known, for example, that in producing the "Queen Mary" the foundryman's business was intimately related to its construction, and that rather more than 1,000 tons of castings had to be cast before the ship could be built. They were all exceedingly glad that trade had improved materially. In Glasgow they had suffered very much indeed owing to unemployment, and, like some other districts that had more or less concentrated on the heavy industries, Glasgow had possibly had more than its share of unemployment, and he was more than delighted that the unemployment figures were going down very materially. Interpreting their feelings, he was sure they all hoped that for some years to come this country would become more prosperous, which would be of great benefit to everybody in the country. The Lord Provost concluded by expressing the hope that the visitors would all enjoy their stay in Glasgow.

Sir James Lithgow said that his duties that morning were both pleasant and light, being merely to welcome them to Glasgow on behalf of the Reception Committee, of which the Institute had so kindly asked him to take the Presidency. He expressed the hope that the arrangements that had been made for their comfort during their business session and for their entertainment during their time of recreation would be all they would like them to be. He trusted their proceedings would be useful and fruitful, and that when they left the City they would look back on their visit with feelings of satisfaction.

Col. Norman Kennedy said he considered it a distinct privilege to have been asked to come there that morning to extend on behalf of the directors and members of the Glasgow Chamber of Commerce and Manufacture a very warm welcome to the delegates. He hoped that their deliberations would be successful and profitable. He had had the opportunity of looking through their report, and, if he might say so, he would like to congratulate them on that report, and to say that he was very greatly impressed with the thorough way in which their committees and sub-committees had done their work. If the rest of their work was done in as thorough a manner, he was perfectly certain their 1936 Conference would be a huge success.

It seemed to him that in the difficult conditions in which we live to-day, the difficult world conditions, the intense competition, and very often unfair competition that trade had to suffer on account of trade barriers, the day of the individual for the present at any rate had gone. That was why he thought that technical conferences of this kind were invaluable. An individual could not kick against a trade barrier, but a conference could do something to mitigate that evil, and that was why he thought they would be able to do much good work through this conference. For the same reasons he thought that to-day the work of Chambers of Commerce was every day becoming more important. He asked them when they returned home to support their local Chamber of Commerce, if they were not doing so already.

Sir Arthur Huddleston, in extending a welcome to the delegates on behalf of the technical and scientific institutions of Glasgow, remarked that the Institute of British Foundrymen stood for progress in their industry. In these days progress was in every point associated with scientific progress, and the institutions for which he spoke were essentially concerned in scientific progress. It was all-important that there should be the closest connection between them, and therefore the institutions for which he spoke welcomed most warmly the fact that they were holding this conference in Glasgow, and he hoped they would enjoy their visit and that it would be profitable in every way.

### Presentation of the Oliver Stubbs Medal

The President intimated that the next item on the agenda was the presentation of the Oliver Stubbs medal. As they all knew, this was the highest award it was possible for the Institute to give, and it was awarded for services of outstanding merit in foundry research. This year the Committee had decided to award two medals, one to Mr. F. Hudson and the other to Mr. E. Longden. He concluded by inviting the Lord Provost to make the presentation of the medals.

The Lord Provost thereupon formally presented the medals to Mr. Hudson and Mr. Longden.

Mr. Hudson, in responding, said he was deeply appreciative of the honour they had conferred upon him in presenting him with the Oliver Stubbs medal. He could only say thank you, but in expressing his thanks he desired to couple them with the name of Glenfield & Kennedy, Limited, because if they had not given him facilities for doing this work it was possible he would not have won the medal.

Mr. Longden said he appreciated the honour that they had conferred on him. He thought he could say that the Lancashire Branch would also feel honoured by this award. He also wished to thank the "Foundry Trade Journal," which provided a further means of expressing one's thoughts.

### Sir Archibald McInnes Shaw Medal

The Lord Provost then presented the Sir Archibald McInnes Shaw Prizes to Mr. Alexander Wallace, an apprentice patternmaker, and Mr. Peter Miller, an employee of Mavor & Coulson, Limited, Glasgow.

The President announced that this year it had been decided to award the Meritorious Service Medal to Mr. James Smith, of Newcastle.

### The E. J. Fox Gold Medal

The President also announced the establishment of another medal to be known as the E. J. Fox Gold Medal. He went on to remark that one of the most outstanding developments in foundry metallurgy during the post-war years was that of the introduction and perfection of the centrifugal casting process. This had become a fully developed process which came to be regarded as ranking equally in importance with others of the great metallurgical developments. To commemorate this event, Mr. E. J. Fox, managing director of the Stanton Ironworks Company, Limited, had presented to the Institute of British Foundrymen the sum of £500 to be invested as a Trust, the revenué therefrom to be expended annually in the provision of a suitable medal to be awarded to any individual who had contributed in some outstanding way to the progress of the foundry industry with particular reference to foundry metallurgy. The active association of the President of the Institute with the development of the centrifugal casting process, was regarded by Mr. Fox as creating a fitting opportunity to make this gift to the Institute. The council of the Institute had conveyed to Mr. Fox their willingness to administer this gift, and expressed their appreciation of the honour done to them and also the implied honour to their President in entrusting the Institute with this gift. In view of the fact that the centrifugal casting process was developed largely at Stanton by Mr. E. J. Fox and brought to commercial perfection in Great Britain, the council of the Institute had decided that the Award should be known as The E. J. Fox Gold Medal, thus commemorating for all time the important part played by Mr. E. J. Fox in retaining for Great Britain the honour associated with the development of this important metallurgical process.

Mr. C. E. Williams expressed on behalf of the members of the Institute their very great appreciation of Mr. Fox's generosity.

The President proposed a vote of thanks to the Lord Provost of Glasgow, Sir James Lithgow, Sir Arthur Huddleston and Col. Norman Kennedy. Mr. Winterton seconded, and the Lord Provost suitably responded.

### Induction of New President

Mr. Hurst then formally invested Mr. Winterton with the Presidential Badge and Miniature and installed him as the Institute's thirty-third President. He remarked that the members could rest assured that Mr. Winterton would make an excellent President, and he was satisfied they would all be delighted to serve loyally under him.

### Presentation of Badges

Mr. Winterton having formally occupied the chair amid prolonged applause, his first duty was to present the Past-President's badge to Mr. Hurst. He said he felt sure they all agreed that the Institute had never had a better President than Mr. Hurst.

MR. HURST, in replying, said it had been a matter of great pride to him to have been President of this Institute. He had enjoyed his year of office very much indeed, and he wished to thank every single one of them, officers and members alike, for the loyal support and enthusiasm they had shown during his term of office.

MRS. HURST then presented to Mrs. Winterton the collarette and badge which is worn by the President's wife.

MRS. WINTERTON expressed her pleasure in receiving the collarette and her appreciation of the honour it carried with it.

The PRESIDENT then invested Mr. C. W. Bigg with the collarette of the Senior Vice-President, which MR. BIGG acknowledged.

The SECRETARY (Mr. T. Makemson) remarked that they had now had the presentation of various badges, but this year for the first time there would be an additional badge. There had now been provided a badge for the use of the Junior Vice-President, and he was afraid he was going to commence the Presidential year of the new President by disobeying the instruction. He was going to tell them by whose generosity that badge had been provided. It had been given to the Institute by the new President.

The PRESIDENT invested Mr. Joseph Hepworth, J.P., M.P., with his badge of office as Junior Vice-President.

In acknowledging the honour, MR. HEPWORTH remarked that, although he was practically only an apprentice in the work of the Institute, he was extremely proud to be the first recipient of this magnificent badge. The associations he had made since he joined the Institute had been to his advantage, and he trusted that the friendships he had made during the short time he had been associated with the organisation would long continue.

### Greetings from Overseas

The Secretary announced the receipt of greetings and good wishes for the success of the Conference from The American Foundrymen's Association; The Verein Deutscher Giessereifachleute, Berlin; l'Association Technique de Fonderie, Paris; Professors Piwowarsky and Nipper, Aachen; and Messrs. Sydney Gimson, A. Harley and Wesley Lambert, Past-Presidents.

### Welcome to Foreign Delegates

The President, on behalf of the Institute, extended a hearty welcome to those visitors who had come from overseas, including several from Germany, America and South Africa.

Mr. Winterton then delivered his Presidential address.

## PRESIDENTIAL ADDRESS

Mr. Hurst and Gentlemen,—

An interval of eleven years has elapsed since my old friend, Mr. John Cameron, had the pleasure of extending to the members of this association a hearty welcome to Scotland. Though my welcome to you may perhaps not be so characteristically Scottish, yet I can assure you that it is none the less hearty, and I esteem very sincerely the honour you have done me in placing me at the head of the Institute as its President and thus affording me the opportunity of greeting you on this visit to the land of my adoption. We are growing accustomed nowadays to hear of the trend southward of trade and population, and although in some measure there may be a certain amount of ground for that assumption, it must not be forgotten that there is an almost continuous interchange with the North of both trade and people. This is all to the good, I think, and tends to bind the two countries closer and closer together, not only from the national standpoint, but also from the point of view of trade.

Since the inception of the Institute, which, as you are all aware, was founded in 1904 as the

British Foundrymen's Association, many changes have taken place, and much good work has been done on the lines laid down by the originators, whose avowed intention was to form an association having for its object the advancement from both practical and technical outlooks of the foundry industry, and a general co-operation amongst all branches of the trade for education, enlightenment and information on the widest possible basis.

How wide that basis has been and how generously the ideas of the founders have been interpreted my presence in the chair to-day bears ample testimony, and I am quite certain that all the sister trades which are indissolubly linked with the actual process of founding fully appreciate the implied honour which the parent has bestowed upon its offspring.

There are, however, still vast realms open for further enterprise in the direction of development, and year by year, as our knowledge increases, it seems that we are only at the beginning of our task, which becomes more onerous and responsible as our Institute advances in age.

In looking into various references by my predecessors in office to the work which lay before the Institute, I note that at the last conference in Scotland the President at that time remarked that there was a vast field for improvement in method, in organisation, and in research. Last year Mr. Hurst said that remarkable as had been the increase in knowledge during the past quarter of a century, it must not be supposed that all had been discovered or that finality had been reached. In many directions we were only on the gateway of knowledge, and through each doorway which had now been opened, the earnest student saw long corridors ahead. Truly prophetic words these, and I think that since these remarks were made, not only our own Institute, but many other allied associations, have been marching steadily onwards to the acquirement of that knowledge which will eventually make for success in many directions, and the opening out of still more avenues of research which must lead to the complete knowledge and thorough mastery of the industry both from the technical and practical point of view.

## Educational Work

It must be very gratifying to the older and more experienced members of the Institute to realise that definite efforts are being made for the instruction of the younger members of the industry, and the steps taken in this direction by the establishment of special classes with distinctive courses at Glasgow, Birmingham, and Sheffield, should tend to prove that the efforts of the Institute and its younger yet still more learned offspring, the British Cast Iron Research Association, will have an appreciable effect upon the industry in the years to come. It is also pleasing to note that incentives to the encouragement of further technical and theoretical study and endeavour are not lacking so far as the Institute itself is concerned. The Oliver Stubbs medal, the Buchanan medal, the Surtees Memorial prizes, the Meritorious Service medal, all serve to foster interest in the work of the Institute and last year the establishment of the Edward Williams Lecture, delivered as it was by one of the pre-eminent industrial leaders of the day, marked an epoch which cannot fail to leave its mark upon the history of the Institute. This year we are to have the privilege of listening to Professor Mellanby, who will deliver the second lecture of the series.

Most of the members will have heard by this time, too, that, thanks to the generosity of Mr. E. J. Fox, managing director of Stanton Ironworks Company, a special gold medal is to be presented each year to the person adjudged to have been the inventor or introducer of some outstanding advance in foundry practice or to the person who shall be credited with such work or aid to the foundry trade as to contribute in the most marked degree to the advancement of the science generally. With these inducements, if indeed such were needed, it is easy to visualise rapid strides in the art and science of metal founding generally far in advance of those of former years, thorough and all embracing though these seem to have been.

While we are discussing the progress of the foundry trade in these times, it is very interesting to look back to the days when matters were not so advanced, when cast iron was in its infancy, and the methods of production crude and unreliable. The ordinary man in the street of popular renown is accustomed to regard Tubal Cain as the earliest artificer in iron and brass, and let it go at that. The manner of instruction by this earliest recorded leader of technical training and the method of handing down the instruction from generation to generation is lightly passed over, and information regarding the development of the industry is sparse and for the most part unauthentic. That some magnificent work in iron, brass and copper was done centuries ago cannot be disputed, and it would seem from relics which have been discovered from time to time, that the iron age followed that of copper and bronze, though undoubtedly the manufacture of the two latter demanded much greater metallurgical skill and knowledge than did the first named.

### Early Scottish Ironfounding

So far as the English development of the ironfounding industry is concerned there seems to be plenty of information available, but such is not the case with regard to the Scottish trade, the records of which up to a point are vague and uninformative. It would seem that here is a promising opening for a man of letters and leisure. In the Middle ages it would appear that the Scots were satisfied, in order to obtain their supplies of iron, whether in the form of spears or plough-shares, to depend upon raids upon their more industrial and industrious neighbours in the North of England, and this desire for acquisition may possibly account for many of the forays which history records as having been made into the land beyond the Tweed and Solway.

It was not till the eighteenth century was well advanced that it became known that ironstone was abundant in Scotland. Up to that time the raw material had been imported from the Continent and from England and smelted with the aid of charcoal, the supply of which was becoming scarce. There was, however, no combination of interests, such as we know to-day, to lead to the working of the ironstone. As far west as Loch Fyne, where it was possible to import ore by water from the Furness district of England, iron was produced on a small scale, and, if I mistake not, the location of this industry of ancient days is marked by the appellation of Furnace given to a small village south of Inverary, but certainly exhibiting to-day no signs whatever of having once been a centre of iron smelting. Other small centres are mentioned as having contributed to the meagre output of those times, and it is certain that iron ore was to be had in Aberdeenshire, though there is no record of its having been exploited. But as recently as 1875, so Cadell records in his "Story of the Forth" there was to be seen at Taynuilt, near Oban, the largest and most important of the old Highland ironworks. This was established in 1753, and took the place of a furnace started by an Irish company at Glen Kinglass which is said to have been commenced in 1730, and relics of which can still be seen lying promiscuously in the neighbourhood.

About the year 1760 a great revolution took place in connection with the iron trade in Scotland, and from that date records are more authentic. Dr. Roebuck, the son of a Sheffield cutlery manufacturer, who had been engaged in the manufacture of sulphuric acid at Preston Pans, conceived the idea, together with Mr. Samuel Garbett, of Birmingham, and Mr. William Cadell, of Haddingtonshire, of establishing works for the manufacture of iron in

Scotland. After much cogitation and what at that time must have been considered an enormous amount of travel, it was decided that a site in close proximity to plentiful supplies of ironstone, coal, limestone and water would prove the most successful, and it was under these conditions that the works at Carron, near Falkirk, which have now attained to such huge dimensions and world-wide renown, were launched.

One can conceive with what trepidation these hardy pioneers of the cast iron trade of Scotland entered upon their task. Of local skilled labour there was none; charcoal was the only means of providing the necessary heat, and it was realised that soon the forests would be depleted; coal certainly was in use, but no forced blast was available; transport was slow and unreliable, and in the light of later investigations it would seem that the small company of enthusiasts commenced on an impossible task. By degrees, however—and progress must have been slow—workers more or less skilled were imported from the south, and then in 1762 Dr. Roebuck discovered the utility of coke as a fuel.

Perhaps the most drastic reformation was the introduction at Carron by John Smeaton, a Leeds man, and the builder of an Eddystone lighthouse, of an apparatus for the production of the powerful blast required for the smelting of iron ore. From this point it may be said that many of the troubles of the pioneers were over. Local labour was beginning to become more enlightened, and in this connection it is somewhat amusing and very instructive to note that while it was found absolutely necessary, if progress were to be made at all, to employ Englishmen, great care was taken to import as few as possible so as to ensure that a larger proportion of Scots helpers should be engaged and thus hasten the time when the whole of the work could be carried out by Scots.

I might carry you step by step along the road of progress in the iron trade of Scotland to the present time, but space forbids. I must, however, not omit to mention two other developments which had a marked effect upon the industry. These were the introduction of black band ironstone by Mushet, who was a bookkeeper in the Clyde Iron Works, and the adoption by Neilson of the hot blast. The use of the steam engine, introduced by James Watt, also helped considerably, but it is curious to note that it was at first used not to drive the engine developing the blast, but to pump the water back from below the water wheel into the reservoir. The black band ironstone was known for some years before it was recognised as a useful article of commerce, and it was not until 1825 that the first experiments proved its value. Still the foundry trade in Scotland did not make great strides till long after Queen Victoria came to the throne. Certainly the output of iron increased considerably and small plants were being erected in various parts of the country.

Then came the reaction after the Crimean war, and from that period development in all directions was rapid and progressive. The various public authorities became alive to the necessity of reasonable housing for the people, sanitation took a prominent place in the public eye, and education generally improved in all directions. The Clyde valley, helped by its waterway, which was being developed into a harbour for the largest known ships of that period, became transformed into a vast hive of industry, in which the iron trade took pre-eminence. Blast furnaces and heavy foundries sprang up, and were kept busy not only by the requirements of the shipbuilders, but also by the demands of the various authorities whose schemes of drainage and water supply were developing year by year. At one time four large foundries were principally engaged in the production of water pipes from 1 ft. to 2 ft. in diameter, cast by the vertical system in huge circular pits, and when the local demand subsided large quantities were exported to Canada and other places abroad. But new methods of manufacture succeeded the old, the

English competition became keener, our cousins abroad laid down their own foundries, and the export trade from Scotland gradually weakened till about the year 1926 the last of the old pipe foundries closed down, and the site, which once carried huge workshops and stately offices, is now bare and silent, every brick and stone having been removed.

### A Flourishing Industry

But the engineering and light castings foundries have continued to flourish and Falkirk and district still holds its own among the manufacturers of light castings and sanitary ware, though other towns such as Kirkintilloch, Barrhead and Glasgow itself turn out an enormous quantity of builders' ware. Edinburgh too now has its foundries, all of which may be classed as successful in their particular line, and various other centres throughout the Lowlands vie with the Clyde valley in its production of iron, for from time to time ore has been discovered in various new fields. Throughout the northern part of Scotland the development of machinery and plant of various descriptions has demanded the establishment of foundries and in most of the important cities the industry is progressing strongly on the most modern lines. Perhaps one of the most noticeable features of recent years has been the readiness of older firms to adopt mechanised principles, and many of the foundries established last century and even those who ranked amongst the very earliest have not hesitated to take that step in their desire to keep abreast of the times.

One important feature which has presented itself to me in my wanderings has been the ubiquity of the Scot, and particularly the Scottish moulder. Go where one will, into almost any foundry in any part of the world, one is almost sure to hear the well-known Doric accent, and I know of towns in England and Canada and Australia, where the Scottish accent is as pronounced as in the Gallowgate and that by men and women who have never visited the land of their forbears. What would be the feelings of Dr. Roebuck, who first brought English moulders to Scotland, if he could revisit the scenes of his early labours and find events so topsy-turvy is a matter of surmise?

Changed, too, are the methods generally adopted by the leading foundries throughout the land—and by this I mean Great Britain—from the days when Samuel Smiles' attempt to obtain permission to visit the Carron works was met with the somewhat ungracious reply, "Na, na, it canna be allooed. We canna be fashed wi strangers here." In these days, it seems, the more important the undertaking, the less likely is it to endeavour to surround itself with unreasoning insularity, and the fact that during this conference so many well-known firms have extended their hospitality to our members, proves that the onward march of time has begun to break down the old prejudices and barriers, and firms, irrespective of personal gain, are centring their attention on the higher attributes of trade and endeavouring hand in hand, as far as is reasonably compatible with commonsense, to reach the highest summit of excellence that it is possible to attain.

May I conclude my remarks upon a close personal appeal addressed to the heads of all foundries and allied trades in the British Isles. This Institute was established in 1904 and became a Royal Chartered Society sixteen years later. Many hundreds of foundrymen have passed through its membership books, and to-day there are 1,892 members, an increase over last year of 112. But this is not enough. The work of the Institute is valuable not only to the members, but to employers generally, to say nothing of the general public, who cannot fail to benefit in the long run by the research and practical labours of the Institute. The work is of an international character, as you are probably aware, and I therefore confidently recommend every member to endeavour during the coming years to induce friends to join our ranks. A goodly number of members visited the International Exhibition at Brussels last September and were made welcome, along with representatives of nearly a score of other countries, by the Belgian Association, whose President was honoured by the King of the Belgians by the presentation of the Albert medal in recognition of the services of the Association to the country. We have a representative list of subscribing firms but we could do with many more. Admitting the value of the work done, and the appreciation of that work on many occasions expressed by other associations both at home and abroad, let me impress upon you all the necessity for increased support financially, and most of all for a largely increased membership of all grades.

Gentlemen, again I thank you for the honour you have conferred upon me. I am aware of the fact that I follow many experienced and energetic Presidents, none more energetic perhaps than my immediate predecessor, and certainly none more cheerfully popular. But I will do my best to merit your trust and to carry out my duties to the best of my ability, and I confidently appeal to you all to accord me during my year of office that cordial support which has ever marked the labours of those who have preceded me in the presidential chair.

### Vote of Thanks to the President

Mr. Hurst, in proposing a vote of thanks to the President for his address, made special reference to Mr. Winterton's admirable historical study of the origin of ironfounding in Scotland. He mentioned as a point of interest that perhaps the earliest attempt centrifugally to cast pipes was made in Scotland by Andrew Shanks, an ancestor of the present firm of Shanks & Company, Limited, which was still in existence. Somewhere about the year 1870 Andrew Shanks made and actually cast by the centrifugal process spigot and socket pipes, and that was probably the first attempt made to apply the centrifugal process to the casting of iron pipes. Mr. Hurst went on to say that it had struck him that the study of the history of the development of ironfounding, as distinct from the history of ironmaking, was a most fascinating one, and he had often wondered why this Institute had not taken on itself to organise some sort of collective attempt to study the history of ironfounding in their various districts.

The vote of thanks was accorded with acclamation and the President briefly replied.

The following Papers were then read and discussed:—

"The Phenomena of Capillarity in the Foundry," by Prof. A. Portevin and Dr. Paul Bastien. (French Exchange Paper.)

"The Manufacture of Intricate Thin-Walled Steel Castings," by Dr. R. Hunter and J. McArthur.

"Composition and its Effects upon the Properties of Mould and Core Sand Mixtures at Elevated Temperatures," by F. Hudson.

During the morning the ladies participated in a motor drive to Largs, and on their return they joined the members at lunch at the Grosvenor Restaurant.

Parties of members visited the following works in the course of the afternoon:—

> Glenfield & Kennedy, Limited, Kilmarnock; John Lang & Sons, Limited, Johnstone; The Singer Manufacturing Company, Limited, Clydebank; Babcock & Wilcox, Limited, Renfrew; Harland & Wolff, Limited, Clyde Foundry, Govan.

## ANNUAL BANQUET AND DANCE

The annual banquet, followed by entertainment and dancing, was held in the Grosvenor Restaurant, Gordon Street.

The President (Mr. H. Winterton) presided over a distinguished gathering, which included Sir James Lithgow, Bt., M.C., D.L. (President of the Reception Committee), Sir Arthur Huddleston, C.M.G., O.B.E., M.A. (Director of the Royal Technical College, Glasgow), Col.

Norman Kennedy, D.S.O. (President of the Glasgow Chamber of Commerce), Mr. John Craig, C.B.E., D.L., J.P. (Chairman of Colvilles, Limited), Mr. A. McKinstry, M.Sc., M.I.M.E. (managing director, Babcock & Wilcox, Limited), Prof. Percy Hillhouse, M.I.N.A. (President of the Institution of Engineers and Shipbuilders in Scotland), Prof. Mellanby, D.Sc., M.I.Mech.E. (Royal Technical College), Mr. R. M. Allardyce, M.A. (Director of Education, Glasgow), Lieut.-Col. Macfarlane, D.S.O., Bailie Hector McNeill (Deputy-Chairman of Glasgow Corporation), Mr. J. E. Hurst (Immediate Past-President), Mr. C. W. Bigg (Senior Vice-President), Mr. Joseph Hepworth, J.P., M.P. (Junior Vice-President), Mr. Daniel Sharpe (President of the Scottish Branch), Mr. A. McCance, D.Sc. (President of the West of Scotland Iron and Steel Institute), Mr. J. B. Lang (John Lang & Sons, Limited, Johnstone), and Mr. P. H. Wilson (Stanton Ironworks Company, Limited).

### The Toasts

The usual loyal toasts having been proposed by the President and duly honoured,

Mr. Joseph Hepworth (Junior Vice-President) proposed "The City and Corporation of Glasgow." He said that their city and their country had reared men who had excelled in science, in literature, and even in politics, but last, though by no means least, was that great feat, the building of the "Queen Mary," an achievement of which any city or any country had every reason to be proud.

He supposed that the city of Glasgow, like every other city, had been passing through very critical times in recent years, and at this juncture he would like to strike a note of optimism and say quite frankly that, if we could only settle the international difficulties that we had been faced with in recent years, he ventured to suggest that not only their city, but all the cities in this great Empire of ours, would come in for a new era of prosperity, and he sincerely hoped that that day would not be long delayed.

## Glasgow's Industrial Development

Bailie Hector McNeill (Deputy-Chairman of Glasgow Corporation), in responding to the toast, conveyed the good wishes of the Lord Provost, whom he had just left in the City Chambers welcoming the Automobile Engineers, who were also holding their annual conference within the city at this time.

He was convinced, speaking as one who had served his time in the Clydeside engineering shops, and speaking from what he had learned during his apprenticeship and the number of years he had worked as a journeyman, that they still had the leaders of industry and they still had the workmen who were able to show to the world at large that, so far as shipbuilding and the allied trades were concerned, they still were top dog in the world, and they as a Corporation had their responsibilities in facing the problem of providing the industrialists of their city and country with a healthy, virile, competent race of men and women to carry on the work.

## The Foundry Industry of Scotland

Mr. C. W. Bigg (Senior Vice-President), in proposing the toast of "Scottish Trade and Commerce," said that the foundry itself could be reckoned among the most important of Scottish trades. Among Scotland's oldest industries was that in which they were all proud to be engaged. Before Scotland achieved fame in shipbuilding, she had won some renown in the science and art of founding. A satisfactory source of castings supply was pre-eminently necessary to shipbuilding and engineering, and unless the foundry industry of Scotland had proved equal to every demand made upon it, the fame of Scotland in shipbuilding, engineering and many other industries would not be what it was at the present day. Southerners were apt to judge Scotland mainly by exports. It was a fact that one of the main exports of Scotland was men. The development of Scotland's trade and commerce had been such as to command for her a prominent place in the export markets of the world. Unfortunately, these markets were not open to her to the same extent as formerly, and it had been found that this had a marked effect on the home position. The formation of such bodies as The Scottish National Development Council and The Scottish Economic Committee showed a spirit of co-operation which was certain to redound to the welfare of the country. That development could not be real unless it was justified by the existence somewhere of a market for its products. World conditions to-day were such as to convince us of the increasing importance of our home market, and when one visited such a hive of industry as Clydeside with its teeming population one could not fail to appreciate the tremendous potentialities as a market of such a community, and he suggested that Scotland's problem, and indeed the problem of us all, lay in visualising the progress and conditions necessary to materialise the potentialities of such communities as markets, and ever-increasing markets, for the goods which our ever-increasing industries would produce.

Mr. Archibald McKinstry (managing director, Babcock & Wilcox, Limited), in replying to the toast, remarked that his life had been spent in engineering, and he had been struck by the important part that founding had played in that great industry. He thought that one of the chief exports of Scotland was Scotsmen. It had been his privilege to wander much about the world, and he had met Scotsmen in every country he had visited, occupying, as many of them seemed to do, the most important positions in the various countries. The people of the British Isles could not support themselves on internal trade; we must make ourselves efficient for catering for the markets of the world, however difficult they might be at the moment. In the case of his own concern, they were paying in Scotland almost one million pounds' worth of wages per annum, and that was produced by a business which was made up of something like 65 per cent. of export trade. It was quite impossible to give employment to the people who needed employment in Scotland unless particular attention was paid to the requirements of the export trade. At the present moment there was enormous difficulty in dealing with that trade.

After detailing some of the difficulties experienced at the moment by British firms in securing orders from abroad, Mr. McKinstry said that although there was a comparative boom at the moment he did not think he ought to sit down without striking a note of warning. The present boom could only be continued if particular emphasis was placed on the desirability of being able to enter other markets than our home market. Do not let us be unduly optimistic, but on the other hand do not let us be unduly cast down by the difficulties. He was perfectly satisfied that the courage, the ability, the resource and the ingenuity of Scotland and Scotsmen could hold its own against any competition, and that the wave of prosperity which was starting now would not die down in the very near future.

### Foreign Policy and Its Bearing on Industry

The next toast, which was proposed by Sir James Lithgow (President of the Reception Committee), was "The Institute of British Foundrymen." Sir James said that Mr. Hepworth had referred to the difficulties in foreign countries. He (the speaker) was reminded that for a number of years now he had attended a conference at Geneva in the month of June as representing the British employers. This year for various reasons he was not attending that conference. Personally he was not one of those who scoffed at the League of Nations. He appreciated that our foreign policy had a definite bearing on the prosperity of the industries in which they were all engaged. He had spent very much time and very much thought in endeavouring to restrain the labour side of the organisation from that enthusiasm which, unfortunately, had brought the political side into the tragic disrepute that it now found itself in, where its authority had been very much lost. Neither did he condemn the efforts which had been made by successive British Governments to give a lead to the world in the matter of disarmament. After all, if Britain wished to continue to claim the leadership of the world in moral as well as material things, it surely was fit that our Government should make an effort to bring these peaceful methods about. Clearly, however, these efforts had failed. We had reached the end of the chapter so far as efforts of that sort were concerned, and we must regretfully look around for some other method by which we could continue that leadership.

Referring particularly to the foundry industry in its relation to the manufacture of arms, Sir James remarked that their business could be developed only when every phase was developed, and there was no more technical section than that connected with these works. He believed that they were entering upon a period when they would have an opportunity in every section to develop, and not only give employment but work up a reserve of capital strength, which was necessary if any industry was going to take advantage of the work of an Institute of this kind. It was no use carrying out technical research and making discoveries if the money and the men were not available to give effect to these discoveries when they were made, and therefore it seemed to him that this was a most appropriate time for their Institute to come to Glasgow and consider the problem, conscious, as he believed they were, of the fact that they were entering upon some real reward and return for all the brain and research work in which the members of this Institute were engaged. It was in that sense at least that he asked them to be upstanding and to drink the toast of "The Institute of British Foundrymen."

## THE PRESIDENT'S REPLY

The PRESIDENT, in acknowledging the toast, alluded to the work that the Institute had done since its institution in 1904, and called attention to the cosmopolitan character of the meeting that night. During the last thirty odd years since the Institute was established he thought he might claim that they had made very considerable progress. The old rule of thumb had been practically eradicated, and to-day they found that the foundry problems which obsessed them from day to day in every foundry in the country were being tackled from a different point of view altogether from that of their forebears. He was satisfied that in his own particular branch of the trade thirty years ago the establishment of a laboratory would have been laughed out of court. To-day, on the other hand, they relied on what the men in their laboratories said, and they knew perfectly well that if they acted counter to the reports of these men they were asking for trouble. He was quite sure that his friends who were directly interested in foundry work were of the same opinion. At their meeting that forenoon at Elmbank Crescent they had a battle royal between the practical side and the theoretical side. Sitting in the chair, it was very difficult for him to say which side won, but he was sure his practical friends would forgive him if he said that he was inclined to side with the theoretical men. He was convinced that eventually the practical man would have to say that the theoretical man was the man who gave him the lead, and eventually he would have to follow. He felt that to-day they were at the parting of the ways, the parting from the old way which, unfortunately, they had experienced for so long a period, the period of depression. Personally he was not inclined to think that that depressed period would last very much longer. We were certainly on the upgrade, we were certainly beginning to see the light, and he sincerely trusted that in a very short time industry not only in Scotland but throughout the British Isles, would once more take its full part in the trade of the world, and that this great Empire would be able to show the whole world that we did not intend to be relegated to a back seat.

### Scientific and Technical Institutions

In proposing the toast of "Scientific and Technical Institutions," Professor Percy Hillhouse (President of the Institution of Engineers and Shipbuilders in Scotland) said that without such technical and scientific institutions the engineering industry would be in a very poor way. Somebody had said that night that a great many of these experiments were of no use, but scientists went ahead and made experiments, sometimes without knowing exactly what they were aiming at, but they got results, and often out of those results something very useful turned up. In the old days the rule of thumb was their main lead, experience was supposed to be of more value than theory, but nowadays technical and scientific institutions were in this country existing in great numbers. There was no science or industry but what had got its own technical institution, and these institutions did a great deal of good.

In calling upon Sir Arthur Huddleston to reply, the President conveyed the hearty thanks of the Institute to the Directors of the Royal Technical College for the assistance they had given to the Institute and the founding industry in general.

Sir Arthur Huddleston (Director of the Royal Technical College), in responding to the toast, said the Technical College had always endeavoured to maintain a really close connection between teaching and research, as carried out in the College and in industry in all its phases. That connection began even before the College opened. After a brief outline of the origin of the Royal Technical College, Sir Arthur concluded by assuring them that the aim of the

College had always been, and would continue to be, the maintenance of the closest possible connection with industry.

### The Scottish Branch

The last toast, " The Scottish Branch of the Institute of British Foundrymen," was proposed in a few fitting words by Mr. J. E. Hurst, the Immediate Past-President of the Institute.

Mr. Daniel Sharpe (President of the Scottish Branch) suitably replied. On behalf of the Scottish Branch he assured them that they were delighted with the large number of members of the Institute attending the conference in Glasgow. He concluded with a brief outline of the activities of the Scottish Branch, and made reference to the very able work of the Scottish Secretary, Mr. John Bell, who had been responsible for the preparation and carrying out of all the arrangements, assisted very ably by Mr. A. Campion.

The President said he desired to add his meed of praise and thankfulness to Mr. Bell and Mr. A. Campion, a Scotsman and an Englishman, for their collaboration in the preparation of the programme. He was sure they were all agreed that once more England and Scotland had combined to make this function a complete success.

The President thereafter presented a beautiful silver tea service to Mrs. Hurst, the wife of the Immediate Past-President, as a little memento on behalf of the leading officials of the Institute of their appreciation of her services to them during her husband's year of office.

Mrs. Hurst suitably replied.

At intervals during the evening instrumental music was provided by Mr. Frank Merton and his orchestra, who also provided music for the dancing, which continued till 1 a.m. Vocal selections were rendered during the evening by Miss Jean Dawson, Mr. Elliot Dobie and Mr. J. C. Dorsie.

## THURSDAY, JUNE 11

On Thursday, June 11, the delegates and their lady friends paid a visit to Edinburgh, the Capital of Scotland. Travelling from Glasgow by special train, the party on arrival in the Capital found a fleet of motor buses awaiting them. Here the ladies embarked on a sight-seeing expedition to the Forth Bridge, followed by a tour of the city, while the men drove to the Heriot-Watt College, where a Symposium of Papers on Cast Iron was discussed.

The following Papers were presented by their respective authors and discussed jointly.

" A Study of the Influence of Manganese and Molybdenum Additions to Cast Iron," by J. E. Hurst, Ex-President.

" The Influence of Wall Thickness on the Mechanical Properties of Cast Iron," by Dr. H. Jungbluth. (German Exchange Paper.)

" The Fracture of Pig-Iron," by Dr. A. L. Norbury and E. Morgan, British Cast Iron Research Association.

" The Production of Pressure Castings," by H. H. Judson. (American Exchange Paper.)

At the conclusion of the Conference the delegates drove to the Caledonian (L.M.S.) Hotel, Princes Street, where luncheon was served. Mr. A. D. Mackenzie, Chairman of the Edinburgh section of the Scottish Branch, presided, and after luncheon formally welcomed the visitors to Edinburgh. BAILIE STEEL, on behalf of the Town Council of the City of Edinburgh, also extended to the visitors a right royal welcome, and the PRESIDENT (Mr. H. Winterton), in acknowledging, remarked that he was not surprised to learn that the machinery for operating the rudder of the " Queen Mary " had been made in Edinburgh.

After luncheon the members and their ladies were conveyed by bus to Edinburgh Castle, where a most enjoyable hour was spent in inspecting the congeries of ancient buildings which go to make up this hoary old castle which has played such a prominent part in the history of Scotland. The impressive Scottish National Shrine was also visited.

### Civic Reception

The company thereafter proceeded to the City Chambers, where they were entertained at a civic reception by the Lord Provost, Magistrates and Council of the City of Edinburgh. In the unavoidable absence of the Lord Provost (Mr. Louis S. Gumley), the visitors were received and individually greeted by Bailie Aldridge, the senior Magistrate of the City, who was accompanied by most of the other Magistrates in their scarlet robes of office.

The President (Mr. H. Winterton) briefly acknowledged the welcome extended by Bailie Aldridge.

The reception was followed by a programme of instrumental music provided by the Monica-Orr Trio, while light refreshments were served to the visitors.

The company afterwards drove back to Princes Street Station, where they entrained for Glasgow, which was reached about 7.20 p.m.

### Edward Williams Lecture

On Thursday evening, June 11, the second Edward Williams lecture was delivered in the Rankine Hall of the Institution of Engineers and Shipbuilders in Scotland, Elmbank Crescent, Glasgow, by Prof. A. L. Mellanby, D.Sc., M.I.Mech.E., Royal Technical College, Glasgow, his subject being " Cast Iron and the Engineer."

The President (Mr. H. Winterton), who presided, at the outset formally presented the Meritorious Service Medal to Mr. James Smith, South Shields. In paying a tribute to Mr. Smith's valuable services to the Institute, he mentioned that Mr. James Smith was a very old personal friend of his.

Mr. Smith, in acknowledging the gift, said he found great difficulty in expressing his feelings that night on receiving such an honour as had just been conferred upon him by the Awards Committee. It was entirely unexpected. He did not know what it was for yet, whether it was for being a good boy or a bad boy. He recalled that thirty years ago when the first convention was held at Glasgow there were no branches in existence, but as time went on branches were formed in the different parts of the country, and the Institute of British Foundrymen had progressed ever since. He admitted that at one time he became a bit discouraged. He went on to outline the history of the Newcastle Branch, the membership of which, after a period of vigorous growth, began to decline, but during the past two years a determined effort had been made to bring the branch back to its former vigour, with such success that close on 60 new members had been installed during that period.

Prof. Mellanby then delivered his lecture. (See page 64.)

### Vote of Thanks

The PRESIDENT, in thanking Prof. Mellanby for his lecture, remarked that all practical men amongst them would agree that, at any rate on the theoretical side, those who were studying the various points did not give themselves any unnecessary trouble in going most thoroughly into all the various problems that the practical man placed before them. He concluded by congratulating Prof. Mellanby on the fact that the University of Glasgow was just about to confer upon him the honour of Doctor of Laws.

MR. F. J. COOK proposed a hearty vote of thanks to Prof. Mellanby for his admirable lecture.

MR. DANIEL SHARPE, in seconding the vote of thanks, characterised the lecture as a pleasure to the old members of the Institute and an inspiration to the young.

The vote of thanks was enthusiastically accorded, and Prof. Mellanby briefly responded.

The PRESIDENT, in closing the proceedings, conveyed the hearty thanks of the Institute to the Council of the Institution of Engineers and Shipbuilders in Scotland for the use of the Rankine Hall during the Conference.

## FRIDAY, JUNE 12

The concluding day of the Conference was reserved for an excursion down the Clyde on the newest of the Clyde steamers—the " Marchioness of Graham." After leaving the industrial part of the river the vessel passed through the Kyles of Bute, and visits were paid to Loch Fyne, the north of Arran, Loch Goil and Loch Long. The party landed at Gourock and returned to Glasgow by special train.

Before the termination of the voyage, the final meeting of the Conference took place on the covered deck of " The Marchioness of Graham." MR. D. SHARPE, President of the Scottish Branch, on behalf of the Branch expressed the hope that all the visitors had enjoyed their visit to Scotland as much as the members of the Scottish Branch had enjoyed the pleasure of entertaining them; he hoped they would all carry away happy memories of Scotland and of the Conference. He expressed his thanks to his fellow members of the Executive Committee, particularly to Mr. John Bell, the Secretary of the Conference, who had carried out most of the very heavy work of organising the arrangements.

MR. H. WINTERTON, President of the Institute, expressed the thanks of the Institute to the Scottish Branch, to the Reception Committee, to the Executive Committee, and particularly to Mr. John Bell, the Conference Secretary, and Mr. A. Campion, for the most successful arrangements which had been made for the Conference. Everyone present had had a very happy time, and fully appreciated all that had been done on their behalf. He called for three hearty cheers for Mr. Bell and Mr. Campion.

Mr. John Bell, who was received with musical honours, in reply paid a tribute to his colleagues in the Scottish Branch, to the Executive Committee, to the stewards, to his colleague Mr. Campion, and also to the forbearance of Mrs. Bell. If the work of the Scottish Branch had pleased those who had participated in the Conference, then the Scottish Branch was well repaid for all that it had done.

Bailie Mrs. Mann, of the Corporation of Glasgow, representing the Lord Provost of Glasgow, tendered the regrets of the Lord Provost at his inability to be present, and his good wishes for a happy termination to a successful Conference. The Corporation of Glasgow had passed a special resolution authorising fine weather for the day, and as was the case with all resolutions of that Corporation, it had been honoured to the letter! Scotsmen were sometimes accused of being boastful of the beauties of their country, but those who had been present on that day would surely agree that they had something to boast about.

Mr. C. W. Bigg, Senior Vice-President, associated himself with the remarks of the President, and issued an invitation to all members of the Institute and their ladies to take part in the Conference in Derby in 1937.

## THE SECOND EDWARD WILLIAMS LECTURE

### CAST IRON AND THE ENGINEER

**By Professor A. L. Mellanby, D.Sc., M.I.Mech.E.,**

The lecturer's first introduction to the members of the Institute of British Foundrymen arose from an investigation with which he was charged, dealing with the qualities of cast iron suitable for Diesel engines. It occurred to him that some account of these early researches might be of interest, and that by recalling past experiments and investigations, which have now been largely forgotten, listeners might be able to form some mental picture of the difficulties which lay in the path of those British engineers who first took up the manufacture of large marine Diesel engines. It also appeared that, in view of the interest shown by Mr. Williams in the metallurgy of bygone days, these historical reminiscences might not be out of place in a lecture offered as a tribute of general admiration for so popular a member of the Institute.

It was in June, 1917, that a small deputation from the British Marine Oil Engine Manufacturers' Association called at the College and discussed with the then Director, Dr. Stockdale, and the lecturer the possibility of carrying out a programme of research upon cast iron in the College laboratories. It was finally arranged that the work would be under the lecturer's general supervision and that in the first instance there should be made (1) a collection of available trustworthy data upon cast iron and (2) an examination, analysis and testing of specimens which, with their history, would be furnished by members of the Association.

### Previous Work

*Growth of Cast Iron.*—The lecturer would have hesitated to undertake this work but for the fact that he had been promised the co-operation of his colleague Prof. Campion, whose name and work must be known to all foundrymen. Whatever success attended this investigation was largely due to him, and it is pleasing to have this opportunity of acknowledging the whole-hearted manner in which he carried out his share of the programme.

It was recognised that difficulties were likely to arise with the cast iron used for Diesel-engine cylinders and pistons from its growth after repeated heatings and coolings, and it may be of interest to learn of the information relating to this phenomenon that was then available.

Although the possibility of growth had been noted and communicated to the Royal Society by

Beddoes in 1791, it was not brought before the general engineering public until 1904. In that year, A. E. Outerbridge, Junior, read a Paper upon "The Mobility of Molecules of Cast Iron" before the American Institution of Mining Engineers. There he showed that a square cast iron test bar 1 in. by 1 in. section and $14\frac{3}{16}$ ins. long, after being heated to 800 deg. C. and cooled to atmospheric temperature 27 times, increased both in sectional area and length until it assumed dimensions of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ ins. in section and a length of $16\frac{1}{2}$ ins.

Further investigations were made by Carpenter and Rugan, who presented their results in a Paper read before the Iron and Steel Institute in 1909. They confirmed the observations of Outerbridge by taking a bar of grey cast iron and heating it 99 times to temperatures varying from 850 to 950 deg. C. After the heatings, the bar had increased 37 per cent. in volume. For further investigation of the effect of the composition of the iron upon its growth they prepared a series of test bars of cast iron free from graphite with proportions of carbon varying from 4.03 per cent. to 0.15 per cent. Their results show that the bar with 4.03 per cent. carbon after heating 90 times to an average temperature of 900 deg. C. increased in volume by 6.9 per cent. and the bar with 0.15 per cent. carbon after 39 heatings to the same temperature had a very slight diminution of volume.

A further series of tests with bars of approximately constant total carbon content but with proportions of silicon ranging from 1 to 6 per cent. showed that the growth was roughly proportionate to the silicon content.

In another Paper presented by Carpenter to the Iron and Steel Institute in 1911, the effect of heating upon bars with an approximately constant carbon content of 2.4 per cent., but with manganese varying from 0.51 per cent. to 1.6 per cent., showed that, with the 0.51 per cent. manganese bar, 152 heatings produced an increase in volume of 7.49 per cent.; with 0.935 per cent.

manganese, 151 heatings produced an increase in volume of 3.1 per cent., and with 1.6 per cent. manganese, 151 heatings resulted in no change of volume.

In the discussion of the Paper by Carpenter and Rugan results were given by Stead of experiments he had made for the purpose of determining the manner in which the growth of cast iron takes place, and he described the effect of heating, between 600 and 800 deg. C., for about 10,000 hrs., a plate of grey cast iron. In this

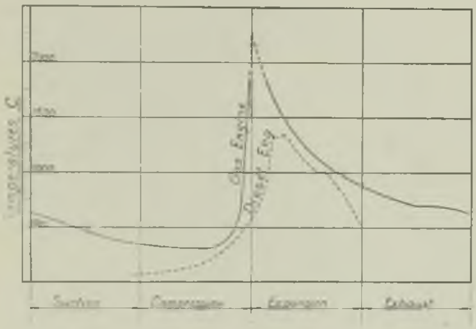


Fig. 1.—Temperature Curves Relating the Performances of Gas and Diesel Engines.

case the specific gravity of the metal fell from 7.09 to 6.14.

It will be noted that Carpenter and Rugan and Stead dealt only with the effects of temperatures above 600 deg. C., but it was well known to steam engineers that growth occurred at much lower temperatures. In a Paper given to the American Society of Mechanical Engineers by I. A. Hollis in 1909, some experiences with superheated steam at about 500 deg. Fah. were given from which it was found (1) that fittings exposed separately to superheated steam at temperatures of about 500 deg. Fah. showed permanent increase in dimensions and (2) tensile tests from fittings which failed in service after such treatment indicated a permanent loss of strength.

There were also the experiments of Meyer, Cary, Longmuir and Hatfield to show that the high-temperature annealing of cast iron resulted in the appreciable diminution of both bending and tensile strength.

### Working Temperatures in Cylinders of Internal-Combustion Engines

It was clear from these records that, before investigating more closely the properties of cast irons, some information was required about the actual temperatures to which the metal would be subjected under working conditions. At that time published figures dealing with the temperatures in Diesel engine cylinders were not known, but there were records from gas engines which it was hoped would give some guidance. Personal experiments upon a gas engine fitted with thermometer pockets in the cylinder liner showed that the highest temperature of the metal did not exceed 120 deg. C.

Information on this point was also found in a Paper by Hopkinson on "Heat Flow and Temperature Distribution in the Gas Engine," published in the Proceedings of the Institution of Civil Engineers. Here it is recorded that the highest temperature of the water-cooled parts, with boiling jacket water, was 200 deg. C. The maximum observed temperature of the piston (air cooled) was 480 deg. C., but under normal working conditions it was only 340 deg. C.

In another Paper by Coker and Scoble on the "Cyclical Changes of Temperature in a Gas Engine Cylinder," published also in the Proceedings of the Institution of Civil Engineers, the temperature fluctuations as well as the mean temperatures were recorded. The highest temperature at the end of the barrel was 109 deg. C. and the temperature fluctuation of the metal surface was not more than 10 deg. C. The maximum temperature of the piston was 340 deg. C. with a range of 80 deg. C. Under normal conditions the explosion temperature of the gas was between 1,830 and 1,950 deg. C., but under exceptional conditions it rose to 2,250 deg. C.

### Diesel- and Gas-Engine Temperatures

These results indicated that, with an ample supply of water to the jackets, the liner tem-

FIG. 2.—MICROGRAPH OF BADLY-WORN CYLINDER LINER. × 110. UNETCHED.

perature should never become very high, and it did not appear impossible to obtain a suitable mixture of cast iron, with good machining qualities, that would give satisfactory service.

The question naturally arose whether the average temperature of the gases during a cycle was higher in the gas engine than in the Diesel engine. Some information on this point may be obtained from Fig. 1, which shows, on a base of crank angles, the gas temperatures during a working cycle for each of these types of engine. The gas engine diagram is taken from the Paper by Coker and Scoble, and the temperatures in this example were, for the greater part, actually measured. The temperatures for the Diesel cycle were taken from the experimental engine in the Royal Technical College, but these were estimated from the indicator cards. The Diesel engine was working at about the full-rated load with a mean effective pressure of 92.4 lbs. per sq. in. The gas engine was working at its maximum load and the explosion pressure and temperature developed were much above the average.

In the absence of actually measured wall temperatures in the Diesel engine, it seemed reasonable to conclude that the liner temperatures would be lower than the gas engine temperatures already quoted. It was not so certain, however, that the piston temperatures in the Diesel engine would be lower than those in the gas engine. Although the maximum temperature of the combustion products of the Diesel engine is the lower, it seemed possible that the burning oil and air impinging directly upon the piston might be particularly effective in raising its temperature.

### Wear of Cylinder Liners

For information upon the wear of cylinder liners industry was largely indebted to a Paper by Hurst, entitled "Cast Iron: With Special Reference to Engine Cylinders." This Paper was presented to the Manchester Association of Engineers, 1916. The author indicated that examination of the worn surfaces of gas engine liners discloses the fact that the whole surface is covered with small pits. Although these pits are often considered to be the holes from which the coarse plates of free graphite have been detached, he states that microscopical examination shows that the holes are the result of detachment of whole grains of any of the constituents. Attention was also drawn to the fact that the harder constituents are invariably found to be standing in relief, and in a micro-photograph the hard phosphide eutectic is to be seen.

FIG. 3.—POOR-QUALITY CYLINDER LINER METAL. × 110. ETCHED.

He also considered the phenomenon of surface flow and discussed the formation of the layer of hard material found on the surface of a gas engine cylinder liner after a seizure. Some attention was given to the Brinell hardness test which the author considered to be of very little use as an indication of the wearing properties of cast iron. He suggested that an iron with the highest inter-crystalline cohesion, otherwise the highest tensile strength, will possess the greatest resistance to surface disintegration and consequently to wear.

Hurst also dealt with the effect of machining on the resulting liner surface and stated that it was fortunate that the accuracy necessary in cylinder and liner dimensions required very careful machining. The question of growth of cast iron was also treated and, in discussing an example of a cracked Diesel piston top, he stated that the cracking was mainly due to the high phosphorus content. The author concluded by recommending the employment of low percentage silicon, the elimination so far as possible of the phosphorus, and the introduction of chromium. In view of the many loose statements prevalent at the present time upon wear in automobile engine cylinders, the careful study of this Paper, although published 20 years ago, is seriously recommended.

Further information upon cylinder-liner wear and piston seizure was also found in an article contributed to the "Petroleum World" by Smith and Primrose. These writers considered that the wear in a cylinder of which they gave particulars was due to the formation of an abrasive substance between the piston ring and the liner. They attributed the abrasive substance to the oxidation and growth of the cast iron of the piston rings under the high working temperature.

### Examination of Samples Taken from Engines in Service

This section deals with the examination of a few of the samples sent for examination by different members of the British Marine Oil Engine Manufacturers' Association. The majority of these samples were taken from engines which had not proved altogether satisfactory in service, and it was hoped that examination would reveal the reasons for the troubles that had been encountered and that recommendation might be possible for the improvement of later castings.

The first sample to be considered was one taken from a cylinder liner which had worn

FIG. 4.—CRACKED-LINER METAL AFTER 100 HOURS' WORK. × 110. ETCHED.

badly in practice. The sample was not sufficiently large to provide tensile specimens, but a Brinell test gave a hardness number of 170.

The micrograph given in Fig. 2 shows how the large flakes of graphite cut up the material and how the phosphide eutectic is in excessive amount and badly segregated. The structure is obviously indicative of a material with a low resistance to abrasion.

The second sample was from a liner prepared from a mixture said to be specially recommended for internal-combustion engines. Tests showed it to have a tensile strength of about 12 tons per sq. in. and a Brinell hardness of 170. The micrograph (Fig. 3) shows graphite flakes of medium size but rather continuous in parts in a matrix of pearlite and a little free cementite. To be specially noted are the large and isolated patches of phosphide eutectic. The phosphorus percentage was 1.34, and the claim for its suitability for internal-combustion engines could scarcely be upheld.

The third example was taken from an engine liner which had cracked after running for about 100 hrs. It had a Brinell hardness number of 176 and a phosphorus content amounting to 1.07 per cent. The micrograph, Fig. 4, shows graphite in medium sized flakes in a pearlite matrix. The phosphide eutectic is present in excessive quantity in large and isolated patches.

The examples quoted are only a small section of those sent in for examination, but they may be taken as fairly representative of the cast irons that were at that time being used in marine Diesel engine practice. In the lecturer's report it was pointed out that the phosphorus content did not appear to have received from the engineer or the founder the attention it deserved, as, in the majority of samples submitted, the phosphorus content generally exceeded 1 per cent. The examination showed beyond doubt that the amount, manner of existence, and distribution of the phosphorus or its compounds had a very important influence upon the strength, wearing and growing properties of the iron.

Generally speaking it might be claimed that the examination of the specimens showed that (1) there was no recognised standard of composition or strength and (2) the failures described had been due, largely if not entirely, to the use of unsuitable metal containing too much and badly distributed graphite and phosphorus. In one or two cases, where iron of a fairly suitable composition had been used, want of control in the founding rendered it unsuitable for Diesel engine purposes. The fact that permanency of size and form and the retention of strength at high temperatures depended largely upon the stability of the carbides did not appear to be recognised so fully as was desirable.

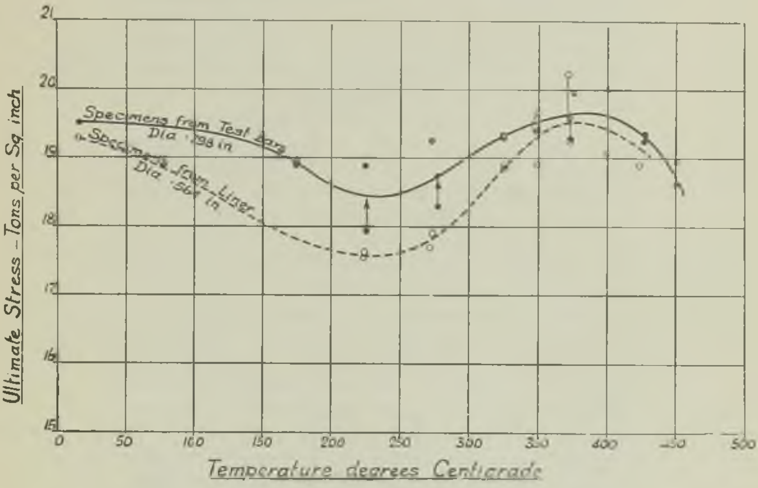


FIG. 5.—STRENGTH OF TEST BARS AND LINER MATERIAL AT HIGH TEMPERATURE.

**Programme of New Work**

As a result of the experience gained by the examinations first described, it was suggested that experiments be carried out upon an iron of approximately the following composition:—

| | | |
|---|---|---|
| T.C | ... ... | 3 per cent. |
| C.C | ... ... | 0.6 to 0.7 per cent. |
| Si | ... ... | 1.5 per cent. |
| Mn | ... ... | 1.0 to 1.5 per cent. |
| S | ... ... | 0.08 per cent. max. |
| P | ... ... | 0.50 per cent. max. |

Some difficulty was experienced at first in finding a foundry willing to work to specification and with sufficient interest in the experiments to ensure that instructions would be properly followed. At that time the writer was introduced to the late Mr. Mayer—a Past-President of the Institute—of Hardie & Gordon, Dumbarton, who undertook to do the casting work and give all the personal assistance that was possible. It would have been difficult to find anyone better suited for the supervision of the foundry work or one who showed greater interest in the investigation. The help and advice he gave are here gratefully acknowledged.

In the early stages of this investigation, test pieces only, of metal made to the above specification, were used, and these were examined very completely in the laboratory. The properties to which it appeared necessary to devote the most attention were those of (1) strength at high temperatures; (2) growth after repeated heatings and coolings and (3) resistance to wear.

The first experiments were made to determine the tensile strength of the specimens at different temperatures. For this purpose the bars were placed in an electric furnace, mounted in the testing machines, and raised to the required temperature. Loading did not commence until the specimen had been subjected to the desired temperature for about 1 hr. 20 min. These tests showed that the tensile strength diminished as the temperature rose, until at some point between 390 and 480 deg. Fah. it had its minimum value. With further increase of temperature the tensile strength rose until at about 750 deg. Fah. its value was higher than that at atmospheric temperature. This indication of a minimum strength at an intermediate temperature was quite unexpected and it was decided to investigate this point more closely in future experimental work.

In all published work upon growth of cast iron after repeated heating and cooling, the results had been confined to those cases where the temperature had been raised to about 1,600 deg. Fah. (870 deg. C.). It was felt, however, that the changes might be quite different for a lower range of temperature and a maximum of 900 deg. Fah. was selected for these tests. A large number of small specimens, ¾ in. diameter and 2 in. long, was prepared, and each piece carefully measured before placing it in the furnace.

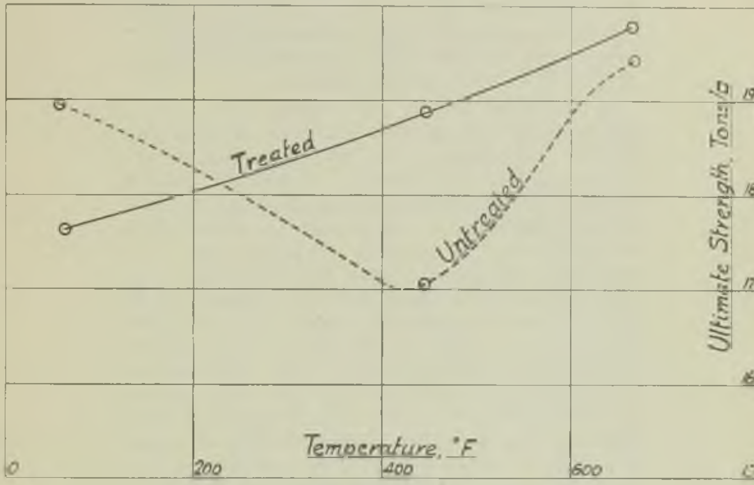


FIG. 6.—RELATIVE STRENGTH OF IRONS AFTER SOAKING AT 750 DEG. FAH.

As a general rule the heating was started at about 9 a.m. and the current remained on until 6 p.m. At this time it was cut off, and the samples remained all night in the furnace so that they would have cooled down and be ready for measurement the next morning. The measured changes after 40 heatings and coolings were so slight as to be negligible, and it appeared that under such conditions cast iron of the composition given above was not liable to growth. So far as external appearance was concerned, no appreciable change appeared to have taken place in the metal.

## Experiments with Liner Castings

From the experimental work just detailed it was considered that work was proceeding on the right lines and that an iron had been produced with a reasonable tensile strength at atmospheric temperature, and one that did not fall off to any appreciable extent in strength when the temperature was raised to values supposed to occur in Diesel engine practice. The resistance to growth was also satisfactory and microscopical examination showed that the repeated heating and cooling had no ill effect upon the structure.

It was therefore felt that castings of an actual liner might be made and that the effect of size and, in consequence, the rate of cooling of the casting, might be noted. Especially was it desired to know whether the good properties that appeared to be possessed by test specimens could be reproduced in castings of larger size. To determine this point a small liner of normal proportions was cast along with a number of both attached and separate test bars. Very detailed investigations were made upon the various samples thus provided, and some idea of the relative strengths at high temperatures of the test bars and of the liner may be obtained from Fig. 5. Here will also be noticed that minimum strength is associated with a temperature of about 250 deg. C. (480 deg. Fah.) and the unexpected rise of strength with temperature until a maximum is attained at 400 deg. C. (750 deg. Fah.). It will also be seen that, even from samples cut from the liner, a tensile strength of over 19 tons per sq. in. was obtained.

At this stage it was considered that the cast iron composition recommended had every appearance of being likely to prove satisfactory for Diesel engine liners and pistons. In order to give it a more thorough trial it was decided to cast a liner and piston that might be used in the College engine and to test them under running conditions as severe as possible. At the same time sufficient test bars were to be cast so that the phenomena of growth, strength at high temperatures and resistance to wear might be investigated in the more complete fashion to which the previous experience had shown the way.

The work was again entrusted to Messrs. Hardie & Gordon, who worked up the metal to the required composition in an air furnace, from which it was cast into small pigs ready for

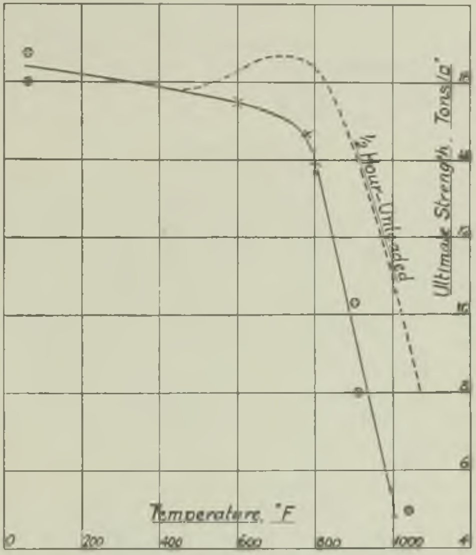


Fig. 7.—Influence of Prolonged Soaking on Strength of Loaded Bars.

recharging. It had been intended to make the castings from an air furnace remelt of this material, but at the time the moulds were completed the furnace was out of action and the parts were, therefore, cast from a cupola melt.

As mentioned previously, the early experiments had shown that cast iron had a minimum tensile strength value at 450 deg. Fah. and a maximum at about 750 deg. Fah., the strength at the latter temperature actually exceeding that at normal temperature. It was proposed by Dr.

Andrew, who had succeeded Prof. Campion in the Chair of Metallurgy, that a soaking of the material at a temperature associated with the maximum strength might favourably alter the strength at other temperatures. Tests were made to investigate this point and the results are shown in Fig. 6. The full-line curve marked "treated" shows that the effect of the heat treatment has been to increase the strength at all useful temperatures; in addition, the minimum strength characteristic at 450 deg. Fah. has entirely disappeared.

### Ageing Effect

In the tests already described, the temperature at which the specimen was broken had been maintained for only about half an hour before pulling. It was felt that a longer heating period was desirable, and a series of tests was therefore instituted where the specimen was maintained for 24 hrs. at the selected temperature. These tests showed that, at a temperature of about 800 deg. Fah., a very serious reduction of strength followed from the longer period of heating. It appeared that this change in characteristics could only be accounted for by some ageing influence which had not time to make itself prominent in the half-hour period tests.

It seemed probable that any ageing effect which had a prominent influence on the strength of the material could only arise from a change in the crystal structure. Such change might be influenced by the stress on the material during the heating process; further, it appeared probable that an increase in the duration of the heating beyond the 24 hrs. might well lead to lower strength values. For these reasons it became necessary to consider tests involving very long heating periods, while in addition the material would be held under stress during the whole of the test. A special machine was therefore designed and constructed where the load was applied through a large coil spring which could be strained through a hand wheel and screw. The results are shown by the full line in

Fig. 7, where, in some cases, the heating period extended to 115 hrs. The dotted curve represents the strength of the material with the heating period restricted to half an hour. The marked differences between the two curves show that tests of the half-hour heating periods are very misleading and serve no useful purpose. It is interesting to note the resemblance between those curves for cast iron and those now so commonly presented for steel specimens tested for the determination of the " creep " stress limit.

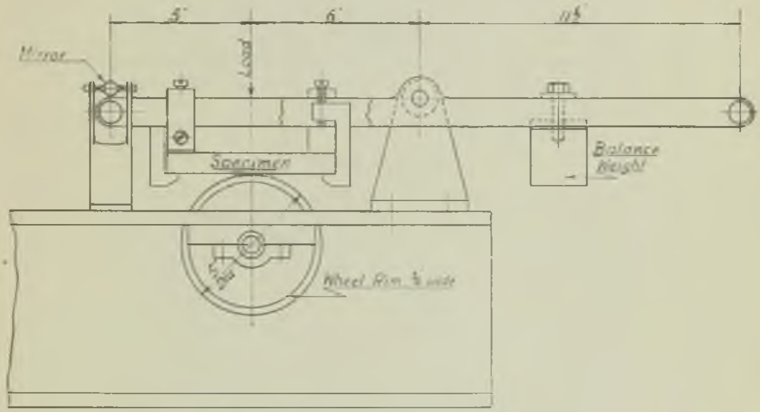


Fig. 8. -Machine for Determining the Wear-Resisting Properties of Iron.

### Wear Tests

Reference has been made previously to the tests for wear, and it may be interesting to describe the machine used for this purpose. A general view of the apparatus is shown in Fig. 8, from which it will be seen that the specimen under test is attached to a balanced lever and is rubbed by the rim of a rotating wheel situated below. A definite weight, fastened to the lever, gives any desired pressure between the two rubbing surfaces. It was hoped that this apparatus might be arranged to give simultaneous indications of the wearing properties of cylinder-liner samples and of piston rings. For this purpose the wheel was arranged to take different rims and several castings of piston ring quality were obtained for this purpose. This hope was not realised, as it was found that however much the fixed sample was worn away, the diameter of the revolving wheel remained constant. Some difficulty was experienced at first in obtaining consistent results until it was noted that the moisture content of the atmosphere had a disturbing effect. By transferring the machine to a heated room all difficulties were removed. A comparison of the results of wear tests made from the new liner and the one it replaced is shown in Fig. 9. The superiority of the new material is at once evident.

### Growth Tests

For this investigation it was first necessary to fix upon a soaking temperature which would be representative of oil-engine conditions. As will be seen later, experiments on the College engine showed that a temperature of 970 deg. Fah. (521 deg. C.) covers all normal running loads. In large engines with water-cooled pistons this temperature is well above the highest attained by the piston in any but exceptional circumstances.

In the early experiments specimens 2 in. long and $\frac{3}{4}$ in. dia. were used, but experience showed that it would be better to increase the length of the specimen to 6 in. and to determine the change of length in a measuring machine The daily heating of the specimen occupied 6 hrs., overnight it cooled in the furnace and in the morning it was brought to standard temperature by placing it for an hour in the case containing the measuring machine. The results from repeated heatings of the new liner sample are shown in Fig. 10, and it will be accepted that the figures shown are very satisfactory. There are also shown the readings taken from a sample cut from the lower end of the old liner. The use of a trunk piston on this engine makes it unlikely that the specimen was subjected to more than a very moderate temperature during its working life, and it may be taken as representative of the material in the condition in which it left the foundry. In the early heatings this material grew rapidly, but after the fifth heating it suddenly changed to a much more moderate rate of growth.

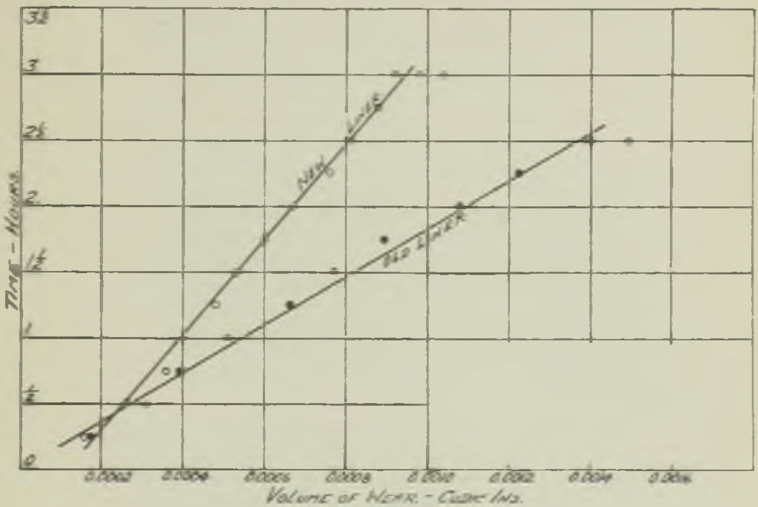


FIG. 9.—COMPARATIVE RESULTS OBTAINED FROM WEAR-TESTING OLD AND NEW LINERS.

From this brief outline, it will, it is hoped, be accepted that the lecturer and his colleagues had to a large extent accomplished one object of the research. A liner and piston had been produced, the material of which maintained its strength at all temperatures likely to be reached in oil-engine practice, it showed excellent wearing qualities and its growth was negligible. The liner and piston have now been working in the College engine for over 15 years, and during part of that period they have been running under conditions much more severe than any that occur in normal practice. No trouble has been experienced and when last measured the liner wear was negligible.

### Diesel Engine Temperatures

This lecture has been devoted chiefly to the problems associated with the qualities of cast iron required for oil-engine pistons and cylinders. Reference, however, has been made to temperature effect, and it may therefore interest members to learn what are the actual temperatures to which the piston is subjected during its working cycle. The curves shown in Fig. 11 illustrate how the piston temperature varies from centre to circumference with different loads. The curves also show the influence of the outlet temperature of the jacket water. The temperatures given are those at the lower surface of the piston and from further experimental work upon the temperature gradient through the metal, it is estimated that the maximum piston temperature at full load (100 lbs. sq. in. m.e.p.) would be about 850 deg. Fah. At an overload represented by a mean effective pressure of 125 lbs. per sq. in. the temperature would be increased to about 950 deg. Fah.

The lecturer already has referred to the assistance given in this work by Prof. Campion. He must also gratefully acknowledge the advice and help of Prof. Desch and Prof. Andrew, both of whom held the position of Professor of Metallurgy while the work was proceeding. Especially has he to be thankful for the assistance of Dr. John S. Brown, who devoted himself so wholeheartedly to the mechanical part of the research programme.

The account of this early work is now at an end, and it is hoped that it has awakened some interest in the difficulties that had to be overcome by the manufacturers of the early marine oil engines. To the younger generation it may appear ridiculous that there should have been any real problem and they may wonder why so much experimental work was necessary before liner and piston cracking changed from common occurrences to far-away memories.

But it is thought that with the arrival of any

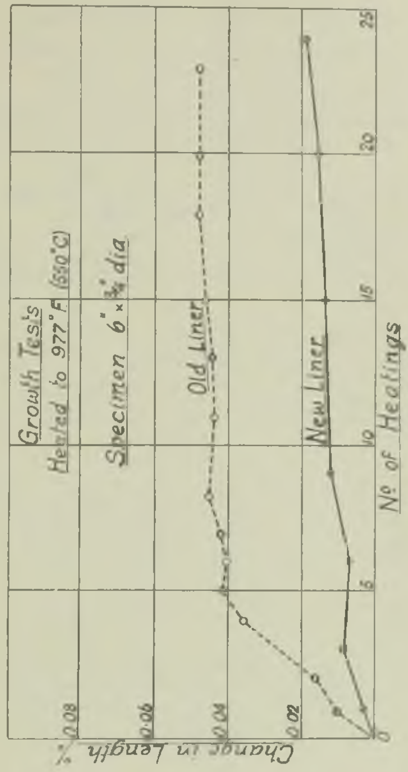


Fig. 10.—Growth-Test Results on Old and New Liners.

other new set of engineering conditions, problems of a type similar to those which were encountered will again arise, and experimental research will still be necessary for their solution.

At the present time there is available for assistance in the foundryman's day-to-day difficulties,

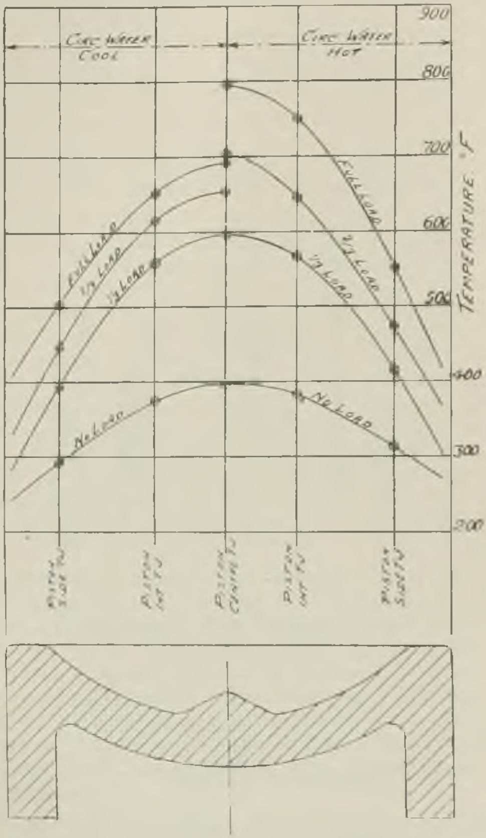


**Fig. 11.—Showing how Piston Temperatures Vary from Centre to Circumference with Different Loads.**

the staff and equipment of the British Cast Iron Research Association.

It is gratifying that the membership of the

Association is so large and that so much advantage is taken of the facilities it offers. To the lecturer the study of the annual reports is one of ever-increasing interest. When he learns of the tremendous advances that have taken place in recent years, largely due to the work of Mr. Pearce and his able staff, he feels proud that for a period he was privileged to work along with some of the members of the Institute in the same field.

# PAPERS PRESENTED AT THE GLASGOW CONFERENCE

## CAPILLARITY AS A FACTOR IN FOUNDRY PRACTICE

By Professor Albert M. Portevin, Ing. and Dr.h.c. (Honorary Member), and Dr. Paul G. Bastien, Ing. A and M.

[*French Exchange Paper*]

### What is Surface Tension?

Capillarity is a property to which very little attention has been paid hitherto in foundry practice, at least not from an exact and objective point of view. Very little information is available concerning the relationships which may connect this property to the phenomena actually encountered in foundry practice.

In foundry practice its importance chiefly appears in the formation of blow-holes during the solidification of castings, in the penetration of the molten metal into the sand of the moulds or "searching," which sometimes occurs, and also in the important complex property known as "life." Surface tension also plays an important part in the action of the slags, fluxes, and so forth employed in the foundry.

In the following considerations it is not proposed to deal either with the formation of blowholes or with the action of fluxes, because that would necessitate a discussion of all the very involved problems of the evolution of gases and the chemical action of the external atmosphere on molten metals. The Paper will be confined to a discussion of the function of surface tension in the phenomena of "life" and "searching."

### I.—Principles Underlying the Methods of Determining the Surface Tension of Molten Metals

The scarcity of precise data regarding the value of the surface tension of molten metals and the discrepancies existing between the figures given by different authors are chiefly due to: (1) the difficulty of measuring the surface tension exactly; and (2) the disturbances caused by changes in the surface of the molten metal. The following points will therefore be discussed briefly :—

(A) *Principles Underlying the Methods of Determining the Surface Tension.*[1 2 3]

(*a*) *Capillary Height Method.*—In this method a vertical capillary tube is immersed in the molten metal, and the difference in height between the metal in the capillary tube and the metal outside is measured. The method has hitherto been employed for metals by measuring the depression $h$ in capillary tubes of graphite by electrical contact means or by radiography, the following formula being employed :—

$$A = \frac{h \times r \times \rho \times g}{2 \times \cos \alpha}$$

where $r$ is the radius of the capillary tube,
$\rho$ the density of the molten metal, and
$\alpha$ the angle of contact.

Smith[3] has determined the surface tension of a certain number of metals by this method, on the assumption that the angle of contact was equal to 180 deg. He found :—

| | | | |
|---|---|---|---|
| Sb | A = 274 dynes/cm. | Al | A = 520 dynes/cm. |
| Bi | 346 ,, | Zn | 707.5 ,, |
| Pb | 424.5 ,, | Ag | 858 ,, |
| Hg | 447 ,, | Au | 1,018 ,, |
| Sn | 480 ,, | Cu | 1,178 ,, |

Libmann[4] also employed a modification of this method for studying the surface tension of copper and silver.

(*b*) *Method Employing the Detachment of Discs.*—In this method the force necessary to detach a disc from contact with the free surface of the liquid is measured. As far as the authors are aware, this method has not been employed for metals.

(*c*) *Weight of Drop Method.*—Tate in 1864 showed that if a vertical, sharp-edged tube is supplied with liquid, the weight of the drop is proportional to the weight of liquid which would be raised by surface tension in a tube of the same diameter.

Quincke[5, 6] employed this method for determining the surface tension of molten metals by heating the ends of rings or wires to melting point and ascertaining the weight of the drops which formed and fell. He thus found that

| | | | |
|---|---|---|---|
| $a^2 = \frac{2A}{d} =$ | $4.3$ | for | Se |
| | $4.3 \times 2$ | ,, | Hg, Pb, Ag, Bi, Sb |
| | $4.3 \times 3$ | ,, | Au |
| | $4.3 \times 4$ | ,, | Pt, Cd, Sn |
| (where $d$ is | $4.3 \times 6$ | ,, | Pd, Zn, Fe |
| the density) | $4.3 \times 12$ | ,, | Na |
| | $4.3 \times 20$ | ,, | K. |

Matuyama[7] has also employed this method for determining the surface tension of antimony-cadmium, antimony-zinc, and antimony-lead alloys by measuring the weight of a drop falling from the orifice of a capillary tube and calculating the surface tension by Lohnstein's formula :—

$$P = 2\pi r . A . f\left(\frac{r}{A}\right)$$

where P is the weight of the drop,
$r$ the radius of the base of the drop,
A the surface tension,
$f\left(\frac{r}{A}\right)$ a function of $\frac{r}{A}$.

(*d*) *Large Drop or Bubble Method.*—A large drop is placed on a horizontal plane surface. Assuming that the curvature of the intersection of the drop by a plane normal to the surface at a point, and hence normal to the meridian plane of the surface passing through that point, is negligible compared with that of the meridian section at the point considered (see Fig. 1), it appears that :—

$$A = \frac{h^2 . d . g}{2}.$$

By employing this method, it is also possible to determine the characteristics of a drop formed by a liquid in a second liquid, provided that *d* is replaced by the differences in the densities of the two liquids. As will be shown later, use has been made of this property to determine the surface tension of aluminium in cryolite.[8]

Finally, in the case of a single liquid, it is possible to blow a bubble of air or inert gas in the liquid below a horizontal plane surface, and thus determine the surface tension of the liquid relatively to the gas. The authors have employed this method for determining the surface tension of unoxidised aluminium using a large bubble of argon.[8]

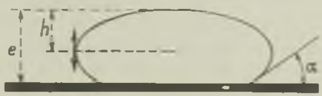


FIG. 1.—LARGE DROP.

The properties of large drops were utilised by Siedentopf[9] for determining the surface tensions of Cd, Sn, Pb, Hg, Bi and Sn-Bi alloys, and also by Herzfeld[10] for Ni, Co and Fe.

(*e*) *Method Employing the Measurement of the Pressure Necessary to Force a Bubble or Drop Out of the End of a Capillary Tube.*—The pressure necessary to force a bubble of an inert gas through the end of a sharp-edged capillary tube immersed in a liquid is connected with the surface tension of that liquid by the following relationship, which was first deduced by Cantor and subsequently modified by Feustel :—

$$A = \frac{p.r}{2}\left(1 - \frac{2}{3}\frac{d.r}{p} - \frac{d^2.r^2}{p^2}\right)$$

where $p$ is the pressure,
$r$ is the radius of the capillary and
$d$ is the density of the liquid.

Sauerwald and Drath[11] utilised this method for determining the surface tension of a large number of molten metals and alloys (Hg, Sn, Pb, Bi, Sb, Cu and Cu-Sb, Cu-Sn, Bi-Sn and Bi-Pb alloys).

Jaeger[12] and, later, Sauerwald[13] also employed the method for studying the surface tension of molten salts and slags.

Finally, Hogness[14] introduced a modification of the method by measuring the pressure necessary to cause a drop of a liquid to issue from the upper end of a vertical capillary tube, and in this way determined the surface tensions of Hg, Sn, Cd, Pb, Bi and Zn.

(*f*) *Other Methods.*—Mention should be made of the method of capillary waves employed by Grunmach[15] for determining the surface tension of molten metals (Pb), and the method employing the oscillations of a spherical drop, which are, however, of secondary interest.

To summarise, a certain number of experimental methods are available, and of these, the method utilising the properties of capillary tubes has been employed most. On the other hand, upon examining the results published by the various authors, it is found that the metals which have been most studied are low melting-point metals or are inoxidisable, and that on the whole the results are not very concordant. There are practically no data available for those metals which readily undergo changes when in the molten state, and with regard to aluminium in particular, it is scarcely possible to mention any investigations other than those carried out by Smith,[3] which will be discussed later.

## Influence of the Cleanness of the Liquid on the Surface Tension

In the case of substances which are liquid at ordinary temperature, such as water and mercury, the exact measurement of the surface tension necessitates the use of absolutely clean substances, since according to the principle enumerated by Marangoni any accumulation of impurities on a portion of the surface diminishes the tension in that portion. Various methods of cleaning contaminated surfaces have been proposed for water and mercury.

In the case of molten metals, their surface tension may be disturbed either by the presence of impurities dissolved in the metal or by the formation of films due to reaction with the surrounding atmosphere.

Smith[16] gives an example of the first possibility in connection with the cupellation of silver. As the lead oxide is absorbed by the porous cupel, the silver tends to run together in the form of a bead under the action of its surface tension. If the silver contains a certain proportion of an element of low surface tension, such as tellurium, the metal spreads and disappears in the pores of the cupel instead of running together to form a bead.

A classical example of the second category is afforded by aluminium which cannot be melted, even in atmospheres where the partial pressure of oxygen is very low, without becoming covered with an elastic film of alumina.

Similarly, Vance White,[17] investigating the surface tension of lead alloys in an oxidising atmosphere, has shown in the case of a Linotype alloy containing an addition of 0.2 per cent. of zinc, that its tension may vary from 455 dynes/cm. in a reducing atmosphere to 1,198 dynes/cm. in the same atmosphere containing 50 per cent. of air. It follows from the foregoing that the measurement of the surface tension of molten metals should be carried out in such a manner as to avoid the formation of surface films by reaction with the surrounding atmosphere.

## Relations between the Surface Tension of Molten Metals and their Atomic Characteristics

In this field, among the oldest known relationships, mention should be made of that given by Eötvös[18] :—

$$A.V^{\frac{2}{3}} = k.(t_0 - t)$$

where A is the surface tension,
V the molecular volume,
$t$ the temperature,
$t_0$ a temperature in the vicinity of the critical temperature, and
$k$ a constant, independent of the liquid (of the order of 2.27),

and that derived from the preceding relationship by Ramsay and Shields[19] :

$$A.V^{\frac{2}{3}} = k.(\theta - t - d)$$

where $\theta$ is the critical temperature,
$d$ a correction term in the vicinity of 6 ($k$ being of the order of 2.12).

In the course of his researches on the surface tension of metals, Smith[3] discovered that the surface tensions are periodic functions of the atomic weights.

When the curve of the reciprocals of the surface tensions $\frac{1}{A}$ for the different metals is plotted side by side with Lothar Meyer's curve showing the periodic rise and fall of the atomic volumes with increasing atomic weights, there is to be seen a general resemblance which is accentuated if the atomic volumes raised to the $\frac{2}{3}$ rd power are plotted as ordinates instead of the atomic volumes.

More recently, Sugden[20] has proposed the following relationship :

$$P = \frac{M.A^{\frac{1}{4}}}{D - d}$$

where M is the molecular volume,
D the density of the liquid and
$d$ the density of the saturated vapour.

Sugden has termed the parameter P the *parachor*. The parachor has been determined for a certain number of metals. Later, use will be made by the authors of the calculated value of the parachor for aluminium, which is :

$$P_{Al} = 39.$$

## Investigation of the Surface Properties of Oxidised and Unoxidised Aluminium[8]

The formation of a solid or liquid film of alumina by spontaneous or induced oxidation is of considerable practical importance on account of the chemical and mechanical properties of the film and its properties as an electrical insulator. This fact gives rise to disadvantageous consequences (difficulties in making contact between electrical conductors, difficulties in casting, etc.) or, on the other hand, useful results (protection against corrosion and oxidation, insulation of electrical windings, etc.). Although qualitative data at least are available regarding the thickness, porosity, insulating properties and the chemical resistance of this film, yet there are no such data available regarding the strength and the influence which the film exerts on the surface tension of the molten metal, although such data would be of prime importance both from the point of view of the protective action of the alumina and the casting properties of the aluminium.

The following is divided into two parts :—

(II*a*) Determination of the strength of the film of alumina.

(II*b*) Determination of the surface tension of oxidised and unoxidised aluminium.

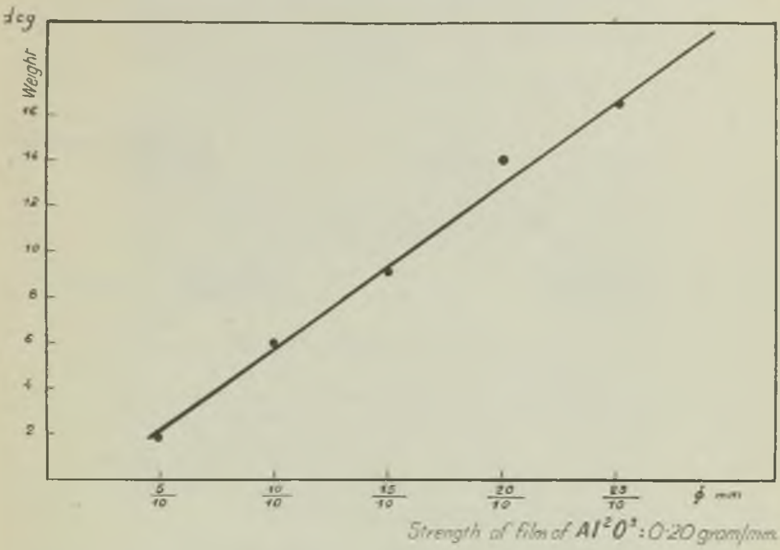


FIG. 2.—VARIATION OF THE STRENGTH OF AN ALUMINIUM TUBE WITH THE DIAMETER OF THE ALUMINIUM WIRE.

### (II*a*) Determination of the Strength of the Film of Alumina[8]

The method used was to determine the force required to rupture an aluminium wire melted in its sheath of alumina. Two different modifications of this method were employed :—

(*a*) *Wire Suspended by One End.*—An aluminium wire is suspended vertically by its upper end and a source of heat—for instance, the flame of a bunsen burner—is passed in a uniform manner upwardly along the wire, which melts over a certain lenght but retains its original shape, due to the tube of alumina acting as a sheath. This tube breaks at the instant the weight of metal which it is supporting exceeds the strength of the envelope of alumina. Knowing the diameter of the wire and the load supported by the tube of alumina, this load being determined by weighing the portion of wire which drops off, it is a simple matter to find the strength of the oxide film per unit length.

$$k.ds = \pi.r^2.d.g.ds$$

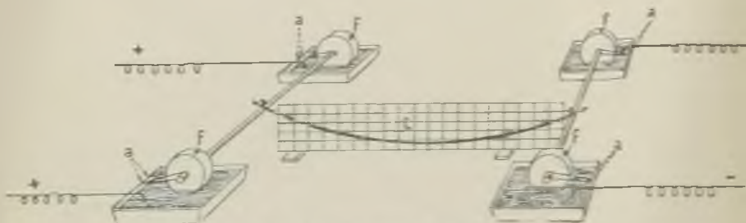

FIG. 3.—EXPERIMENTAL LAY-OUT.

Experiments were made on wires of 0·5 mm., 1 mm., 2 mm. and 2·5 mm. in diameter. Fig. 2 shows the variation of the load supported by the annular film of alumina with the diameter of the film. From these experiments it is deduced that the mean strength of the film of alumina is :

$$R_1 = 0{\cdot}20 \text{ gram/mm.} = 1{,}960 \text{ dynes/cm.}$$

(*b*) *Wire Suspended by Both Ends.*—An aluminium wire is suspended by both ends, employing a device which allows it to assume freely its position of equilibrium in a vertical plane. An electric current is passed through the wire to heat it by Joule effect, and when it is melted in its sheath of alumina it assumes the form of a catenary. Knowing the span of this catenary and its sag at the instant of rupture, it is possible to calculate the force supported by the tube of alumina at the point of its rupture.

### Experimental Apparatus

As shown in Fig. 3, the aluminium wire was fixed at each end to the centre of a rod connecting two cylindrical sheet-metal floats *f* placed respectively in two dishes filled with mercury. To prevent the floats from rubbing against the sides of the dishes when pulled by the weight of the aluminium wire, the rods connecting the pairs of floats *f* were held in position by wire loops *a*, which, however, allowed them to rotate freely about their axis of rotation without appreciable friction.

The dishes of mercury also served for the connection of the leads carrying the current for fusing the aluminium wire. As the wire becomes hotter, it expands, melts and assumes the shape of a catenary, the sag of which can be measured by means of a squared board *t* set up vertically just behind the wire. The fusion of the aluminium wire is ascertained by moving the latter carefully by means of a magnet. By gradually increasing the span of the catenary, a moment is reached when it breaks at one of its ends.

### Calculation of the Load Supported by the Tube of Alumina at the Point of Rupture

Considering a perfectly flexible wire suspended at two points in the same horizontal plane, an element of wire of length $ds$ weighs

where $r$ is the radius of the wire,
$d$ is the density of the aluminium,
$g$ is the acceleration due to gravity.

If T is the tension of the wire at the point $(x, y)$, there are the following equations for equilibrium :—

$$d\left(T\frac{dy}{ds}\right) = \pi.r^2.d.g.ds$$

$$d\left(T\frac{dx}{ds}\right) = 0$$

which gives by integration :

$$y = \frac{a}{2}\left(e^{\frac{x}{a}} + e^{-\frac{x}{a}}\right) \text{ (catenary)} \qquad (1)$$

$$T = k.a.\frac{ds}{dx} = k.\frac{a}{2}.\left(e^{\frac{x}{a}} + e^{-\frac{x}{a}}\right) = k.y \qquad (2)$$

$a$ being an integration constant.

The equation (1) is obtained by referring the catenary to its *axis of symmetry* and to its *base.* The general equation of the equilibrium curve is :

$$y - y_0 = \frac{a}{2} \cdot \left(e^{\frac{x - x_0}{a}} + e^{-\frac{x - x_0}{a}}\right)$$

Taking as the point of origin one of the ends of the catenary and defining the latter by its length and the distance between the supports, let

$l$ = the length of the arc of the catenary,
$\alpha$ = the distance between the points of attachment.

The catenary passes through A and through B ; therefore :

$$- y_0 = \frac{a}{2}\left(e^{-\frac{x_0}{a}} + e^{\frac{x_0}{a}}\right)$$

$$- y_0 = \frac{a}{2}\left(e^{\frac{\alpha - x_0}{a}} + e^{-\frac{\alpha - x_0}{a}}\right)$$

Furthermore, the length of the catenary is given by*

$$l = a\left(e^{\frac{\alpha}{2a}} + e^{-\frac{\alpha}{2a}}\right)$$

If we put

$$\frac{\alpha}{2a} = u, \text{ we may write : } \frac{l}{\alpha} = \frac{e^u + e^{-u}}{2u}$$

which can be developed into an entire series in the following manner :—

$$\frac{l}{\alpha} = 1 + \frac{u^2}{1.2.3} + \frac{u^4}{5\,!} + \ldots + \frac{u^{2n}}{(2n+1)\,!} \ldots$$

whence, by limiting the development to its third term :

$$\frac{u^4}{5\,!} + \frac{u^2}{3\,!} + \left(1 - \frac{l}{\alpha}\right) = 0.$$

By means of this fourth-power equation it is possible to calculate $u = \frac{\alpha}{2a}$, and consequently $a$.

---

* The authors have refrained from giving here the intermediate steps in the calculation. The reader interested in the question is invited to refer to P. Appel : " Traité de Mécanique rationnelle." Vol. I, p. 198 (Gauthier Villars et Cie, 1926 edition).

Knowing $u$, it is easy to calculate $a$, $x_0$, $y_0$, and hence the tension of the catenary at the point of maximum load, that is to say, at A or at B.

A certain number of experiments were made on wires of 0.5 and 1 mm. in diameter. One of these experiments, for example, carried out on wire of 0.5 mm. in diameter, gave :—

$l_0$ (initial length of the catenary at the temperature of the surroundings) = 39.5 cm.

$l$ (length of the catenary at the melting point of the aluminium) = 40.2 cm.

$a$ (distance between the points of suspension) = 38 cm.

$f$ (sag of the catenary at the moment of its rupture) = 7.3 cm. ;

thus, the value of the strength of the film of alumina per millimetre of length was

$$T = 0.24 \text{ gr./mm.}$$

The mean of the results obtained by the catenary method gives

$$T_{mean} = 0.20 \text{ gr./mm.}$$

a value in agreement with that given by the vertical wire method.

Measurements of the thickness of the film of alumina[21] were made by the method given by H. Sutton by reducing the aluminium in a current of dry chlorine at a high temperature and weighing the residual alumina. The experiments gave for the mean thickness of this film of alumina formed by heating about 1 min. at about 700 deg. C. :

$$e_{mean} = 10^{-5} \text{ cm.} = 0.01\,\mu$$

which gives

$$R_2 = 2 \text{ kg./mm.}^2$$

for the tensile strength of the alumina.

It will thus be appreciated that this mechanical strength is much greater than that which could have been expected according to the results obtained on crystallised alumina.[22]

### (IIb) Determination of the Surface Tension of Oxidised and Unoxidised Molten Aluminium[8]

In this investigation it was proposed to determine the surface tension of aluminium free from any oxidation and to compare the value obtained with that obtained with aluminium covered with its film of alumina.

(*a*) *Surface Tension of Aluminium covered with a Resilient Film of Alumina.*—If large drops of aluminium are made in the air, they are immediately covered with a film of alumina. By determining the elements of large drops thus formed and solidified, the following mean values are found :

$$e = 12 \text{ mm.}$$
$$h = 8.5 \text{ mm.}$$

which gives

$$A = \frac{1}{2} \times \overline{0.85}^2 \times 2.38 \times 981 = 840 \text{ dynes/cm.}$$

(*b*) *Surface Tension of Aluminium Free from Oxidation.*—Owing to the very low tension of dissociation of alumina, it is extremely difficult to measure the real surface tension of unoxidised aluminium. This explains the scarcity of information regarding the surface tension of aluminium and the doubtful character of the values which have been given.

For these determinations two methods based on the properties of large drops were used.

(*a*) *Formation of a Bubble of Argon in the Interior of the Molten Aluminium*

*Method.*—Aluminium of 99.5 per cent. purity is melted in a moderately deep graphite crucible (Fig. 4). A bubble of pure and dry argon is injected into the metal by means of a bent tube below a horizontal plane P consisting of a thin steel plate having a slight downwardly directed concavity. A large bubble of argon is thus produced under the plane P, and the elements of the bubble may be measured by sawing the aluminium ingot, after solidification, along a meridian plane.

The first experiments were disturbed by pipe formation on the solidification of the metal. In order to obtain, after solidification, a bubble which is not deformed and is of the correct measurements, care must be taken to employ a device P of low thermal inertia (this being effected by using a thin steel plate) and immersed to a sufficient depth in the bath of aluminium for the bubble to form below the region of pipe formation of the ingot. This method gave us as a mean :

$$A = 300 \text{ dynes/cm.}$$

($\beta$) *Investigation of the Equilibrium Aluminium-Cryolite-Air*

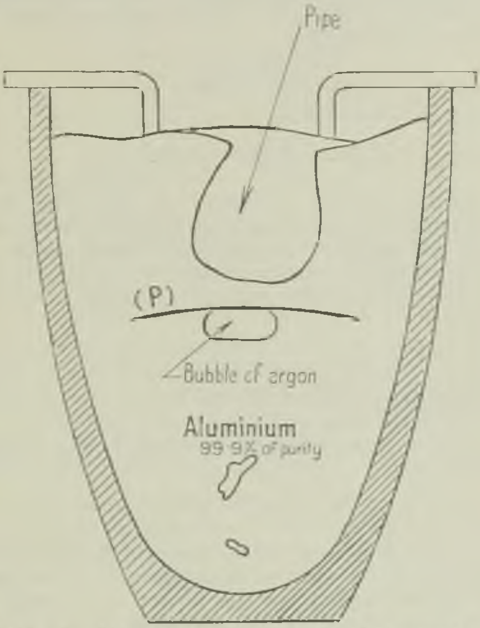


FIG. 1.—BUBBLE OF ARGON IN ALUMINIUM.

Preliminary measurements were made with a view to determining the surface tension $A_1$ of aluminium in cryolite and $A_2$ of cryolite in air, making use of the properties of large drops.

*Surface Tension of Aluminium in Cryolite*

It is an easy matter to produce large drops of aluminium in molten cryolite without the formation of a film of alumina on the surface of the liquid metal, since the cryolite dissolves the alumina. After the whole has solidified, the elements of the drop are determined on a meridian section of the ingot. We found :

$$e = 28.5 \text{ mm.}$$
$$h = 19.0 \text{ mm.}$$

Taking for the densities of aluminium[23] and cryolite[24] at 975 deg. C., the temperature of solidification of the cryolite,

$$d_{Al} = 2.295$$
$$d_{cryolite} = 2.20$$

it is deduced therefrom :

$$A_1 = \frac{1}{2} \times \overline{1.90}^2 \times (2.295 - 2.20) \times 981 = 170 \text{ dynes/cm.}$$

*Surface Tension of Cryolite in Air.*—This was determined by injecting dry air through a bent tube into molten cryolite so as to form a bubble under a horizontal plane constituted by a steel plate having a slight downwardly directed concavity. It was found :

$$e = 7 \text{ mm.}$$
$$h = 4.8 \text{ mm.}$$

Taking as densities at 975 deg. C. :

$d_{cryolite} = 2.20$

$d_{air}$ = negligible compared to $d_{cryolite}$

it is found :

$$A_2 = \frac{1}{2} \times \overline{0.48}^2 \times 2.20 \times 981 = 250 \text{ dynes/cm.}$$

*Surface Tension of Aluminium in Air.*—It is now proposed to consider the *hypothetical case** of a lens of cryolite floating on the surface of a bath of unoxidised aluminium (Fig. 5). Let M and N be two points situated on the same vertical line, the former being placed on the surface of separation cryolite-air and the latter on the surface of separation aluminium-cryolite. Let

$p$ be the pressure in the air and } in the proximity
$p_2$ the pressure in the cryolite } of M
$p_1$ the pressure in the cryolite } in the proximity
$p'$ the pressure in the aluminium } of N.

* Such an experiment could not be made actually, because the exposed surface of the aluminium would oxidise at once on contact with the air.

Applying the laws of hydrostatics, we may write :

(1) $p' = p + y_1.D.g$ where $\left.\begin{matrix}\text{D is the density of the aluminium,}\\ d \text{ is the density of the cryolite.}\end{matrix}\right.$

(2) $p_1 = p_2 + (y_1 + y_2).d.g$

Since the lens of cryolite is in equilibrium, it may be supposed to be solidified and may be considered

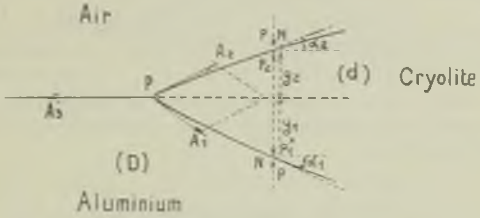


FIG. 5.—EQUILIBRIUM OF ALUMINIUM-CRYOLITE-AIR.

$ds_1$ : element of arc computed on P.N.
$ds_2$ : element of arc computed on P.M.

as a float in equilibrium on the surface of the molten aluminium. The external forces applied to it are gravity, the thrust of the displaced metal, and finally, the forces of surface tension, which latter forces form a system in equilibrium at each point of contact of the three media. We thus have :

$$y_1.(D-d) = y_2.d.$$

From the combination of the equations (1), (2) and (3), we deduce :

$$p_2 - p = p_1 - p'$$

or :

$$(4) \qquad \frac{A_2}{R_2} = \frac{A_1}{R_1}$$

$A_2$, $R_2$ and $A_1$, $R_1$ being respectively the surface tensions and the radii of curvature in the meridian plane of the lens at M and N.

The notations of Fig. 5 give :

$$R_2 = \frac{ds_2}{da_2} = \frac{dy_2}{\sin a_2.da_2}$$

$$R_1 = \frac{ds_1}{da_1} = \frac{dy_1}{\sin a_1.da_1}$$

which allows one to write (4) as follows :—

$$(5)\ A_2.\frac{\sin \alpha_2.d\alpha_2}{dy_2} = A_1.\frac{\sin \alpha_1.d\alpha_1}{dy_1}$$

Since the equation (3) when differentiated gives :

$$dy_1.(D\text{-}d) = dy_2.d,$$

(5) may be written :

$$A_2.d.\sin \alpha_2.d\alpha_2 = A_1.(D\text{-}d).\sin \alpha_1.d\alpha_1$$

which by integration becomes :

$A_2.d.\cos \alpha_2 = A_1.(D\text{-}d).\cos \alpha_1 + C \qquad C = \text{constant}.$

The lens of cryolite is a solid of revolution by reasons of symmetry, and on the vertical line of its poles we have :

$A_2.d = A_1.(D\text{-}d) + C$ or $C = (A_2 + A_1).d - A_1.D$

Let us consider the point P on the line of contact of the three media aluminium, cryolite, air. At P we have simultaneously :

$$\frac{\sin \alpha_1}{A_1} = \frac{\sin \alpha_2}{A_2} = \frac{\sin(\alpha_1 + \alpha_2)}{A_3} \quad \ldots \quad \ldots \quad \ldots (6)$$

$$A_2.d.\cos \alpha_2 - A_1.(D\text{-}d).\cos \alpha_1 = (A_2 + A_1)d - A_1.D \ (7)$$

a system of three equations which enable us to calculate $\alpha_1$, $\alpha_2$ and $A_3$, knowing $A_1$ and $A_2$.

*Application to the System Aluminium-Cryolite-Air.*—

$$\text{Putting} \left\{ \begin{array}{l} \cos \alpha_2 = x \\ \cos \alpha_1 = y \end{array} \right.$$

the first relationship (6) and the equation (7) are written :

$$\left\{ \begin{array}{l} A_2^2.x^2 - A_1^2.y^2 = A_2^2 - A_1^2 \\ A_2.d.x - A_1(D\text{-}d).y = A_2.d\text{-}A_1.(D\text{-}d) \end{array} \right.$$

or :

$$A_2.d(x - 1) - A_1.(D\text{-}d).(y - 1) = 0 \quad (8)$$

$$A_2^2.(x^2 - 1) - A_1^2.(y^2 - 1 = 0) \quad \ldots \quad (9)$$

The solutions of the problem are thus furnished by points of intersection of the straight line of equation (8) with the hyperbola of equation (9), this straight line and hyperbola already having in common the point $x = 1$, $y = 1$.

In the case of the equilibrium with which we are now dealing,

$$A_1 = 170\ ;\ A_2 = 250\ ;\ d = 2.20\ ;\ D = 2.29.$$

Consequently, the equation of the straight line (8) becomes

$$550x - 15.3y - 535.7 = 0$$

which is the equation of a straight line having a very large angular coefficient, situated as indicated in

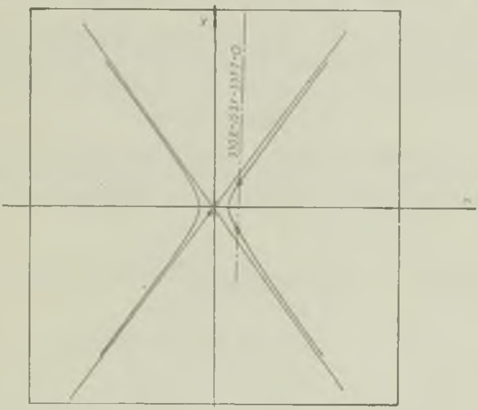

FIG. 6.

Fig. 6, and consequently intersecting the hyperbola such that :

$$/x/\approx 1,\ /y/\approx 1$$

or

$$a_1 = a_2 = \epsilon,$$

$\epsilon$ being a very small value.

*Interpretation.*—The result $a_1 = a_2 = \epsilon$ shows that the lens of cryolite is extremely thin (Fig. 7) and that, consequently, we have substantially :

$$\vec{A}_3 = \vec{A}_1 + \vec{A}_2 = 170 + 250 = 420 \text{ dynes/cm.}$$

This value, moreover, constitutes an upper limit of the surface tension of unoxidised aluminium, since if the angle between the tensions $A_1$ and $A_2$ is not zero, their resultant is such that

$$\vec{A}_3 < \vec{A}_1 + \vec{A}_2$$

It follows from these experiments that the surface tension of oxidised aluminium (840 dynes/cm.) is twice as great as that of unoxidised aluminium, which lies between 300 and 420 dynes/cm. This emphasises the importance of the films of alumina and explains the difficulties met with in aluminium foundry practice.

Smith[3] in an investigation to which reference has already been made determined the tension of aluminium by the capillary-tube method, and found :

$$A = 520 \text{ dynes/cm.}$$

which may be explained by the fact that he took precautions to avoid the oxidation of the aluminium either by passing a steady current of illuminating gas

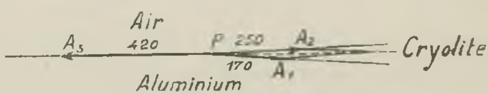


FIG. 7.—EQUILIBRIUM ALUMINIUM-CRYOLITE-AIR.

through his furnace or by allowing wood charcoal to float on the surface of the metal—methods which are insufficient to prevent completely the oxidation of the aluminium.

If $300 < A_{Al} < 420$ dynes/cm., it follows that the *parachor* of this metal (see above) is of the order of :

$$P = 46$$

a value which agrees satisfactorily with the calculated value :

$$P_{calc.} = 39.$$

In conclusion, it should be pointed out that the equilibrium alumina-cryolite-air is impossible, since

$$840 > 170 + 250$$

which explains why cryolite spreads instantly on the oxidised surface of baths of aluminium.

### III.—Influence of the Surface Tension on "Life"

Most of the authors who have considered "life" have seen *a priori*, which, moreover, appeared logical, a preponderant influence of two well-defined physical properties, the surface tension and fluidity. Actually, personal experiments have shown that these two physical factors are of only secondary importance, at least provided the metal is not altered chemically and that, on the contrary, the phenomena of solidification are of primary importance.

The authors have, in fact, shown that :—

(1) *For pure metals*[25, 26] the "life," measured by the length $\Lambda$ attained by a horizontal flat spiral, is expressed by :

$$\Lambda = A_0 d \frac{c(\Theta - F) + L}{F - \theta}$$

where $\Theta$ is the pouring temperature,
$\theta$ is the temperature of the mould,
F is the temperature of solidification of the metal,
$c$ is the specific heat } of the metal.
L is the latent heat of fusion } of the metal.
$d$ is the density } of the metal.
$A_0$ is a constant

It follows that the "life" of pure metals is the resultant of complex factors, amongst which the calorific properties (F, L, $c$) play a part of primary importance.

(2) *For alloys*[27 28 29 26] the following laws have been established :—

(*a*) "Life" varies inversely with the solidification range and exhibits a relative maximum when fusion is congruent (pure metals, eutectics, definite compounds) and a minimum for saturated solid solutions. In this solidification range the first stage (crystals not in contact) has the greatest effect.

(*b*) "Life" depends upon the faces of solidification and is relatively much greater when the liquid gives rise to convex crystals (definite compounds) than when it gives dendrites (solid solutions approximating to pure metals). This is connected with the part played by the first stage of solidification. This shows once again the primary importance of the factors of solidification and crystallisation in the castability of alloys.

Furthermore, after reflection, it is not possible to see clearly what relationships there may be between the surface tension, a factor pertaining to the liquid state, and the equilibrium diagram, which, on the contrary, defines the phenomena occurring when the solid phase appears. The surface tension could only be influenced by the constitution as defined by the diagram if such constitution persisted in the liquid phase in the form of undissociated compounds, which, moreover, does take place in certain cases.

If the surface tension only plays a secondary part in the " life " as defined by the length of flow of the metal before solidification in a spiral of appreciable section, this is no longer the case when the metal has to penetrate passages of small cross-section.

Consider, in fact, a tank supplying liquid under a head to a horizontal passage (Fig. 8), and suppose that the liquid does not wet the passage. The liquid has entered the passage, and by hypothesis the whole is in equilibrium. Let

$p_0$, $p_1$, $p_2$, $p'_2$ be the pressures at the points marked in Fig. 8,
$a$, the angle of contact of the liquid in the passage,
$d$, the density of the liquid,
$r$, the radius of the capillary tube.

We have :

$$p'_2 = p_2 \qquad p_0 = p_1 \qquad p_2 = p_0 + h.d.g$$

$$p'_2 - p_0 = \frac{2A}{R} = \frac{2A \cos a}{r}$$

whence,

$$h.d.g. = \frac{2A \cos a}{r}$$

$h.d.g$ is the head above which the liquid can enter and flow through the passage. In other words, in the phenomena of " life " the effect of the surface tension is to diminish the metallostatic head by the quantity $\frac{2A \cos \alpha}{r}$, which, although negligible in the case of passages of normal dimensions, becomes very appreciable when the metal has to pass through fine orifices.

Considering the case of mercury and a capillary tube of glass :

$A=418$ dynes/cm., $\alpha \cong 45°$,* $d=13.6$ c.g.s. ; $g=981$ whence

$$h = \frac{0.044}{r}$$

Consequently, if

$$r = \frac{1}{100} \text{ mm.},$$

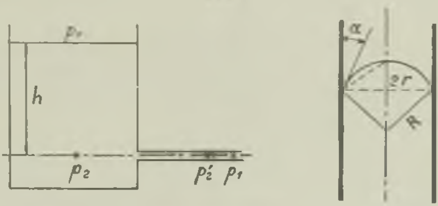


FIG. 8.—TANK SUPPLYING LIQUID UNDER PRESSURE TO A HORIZONTAL PASSAGE.

a head of 44 cm. of mercury will be required to cause the metal to enter the capillary.

It will thus be appreciated that the surface tension may play an important part in the accurate casting of parts comprising fine details, such as, for instance, the characters employed in Linotype printing.

### "Searching" and Capillarity

"Searching" is the penetration of the metal into the wall of the mould or cores. It is met with chiefly in the case of cores in copper founding. This penetration takes place :—

(*a*) Through the pores of the sand if the walls

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* The values indicated for $\alpha$ by the various authors are somewhat discordant. The authors have adopted a mean value which also corresponds to that given by Gay-Lussac.

have not been coated with a protective dressing. in which case the penetration depends upon the *permeability* of the sand (varying with the sand, its moisture content and ramming density). The result is a metallic sponge or scab, which adheres to the casting and, at the least, appears in the form of incrustations of sand on the surface of the casting.

(*b*) Through fissures in the dressing, if the walls have been coated with a protective dressing. The production of these fissures depends upon the thermal properties of the sand (expansibility, conductivity, specific heat), its preparation (moisture, dryness, shrinking) and the method of applying the dressing and its nature. The result is the formation of thin metallic projections or partitions terminating in the above-mentioned scab.

In all cases, the penetration of the metal into the pores and fissures depends upon the "life," the pressure and capillarity on account of the fineness of the cavities.

Ignoring the factors which depend upon the mould, the casting and the dressing, and confining our attention to the phenomena which depend upon the metal, viz., "life" and capillarity, these involve the following factors :—

(1) *For the "Life."*—The pouring temperatnre ; the nature of the metal or alloy ; the temperature of the mould (in this case of the walls, and consequently the rate of heating of these walls).

This last factor depends not only upon the nature of the walls of the mould (especially the moisture content and the thermal properties of the sand), but also upon the weight and shape of the casting and the situation of the wall relatively to it. In particular, there is a very distinct difference between the mould and cores, since the mould surrounds the casting and has a greater mean radius of curvature than the core, which is surrounded by the molten metal. Thus, "searching" is to be considered, above all, in connection with the cores, and depends upon their diameter *d* and the thickness *e* of the metal, as shown in Fig. 9.*

In particular, when the temperature of the sand attains the temperature $\Theta$ of the metal, the fluidity is involved. This is the limit case of castability.

(2) *For the Capillarity.*—In addition to all the factors previously discussed, the phenomena of capillarity involve the thickness $\epsilon$ of the cavities, pores of the sand or fissures of the dressing, the

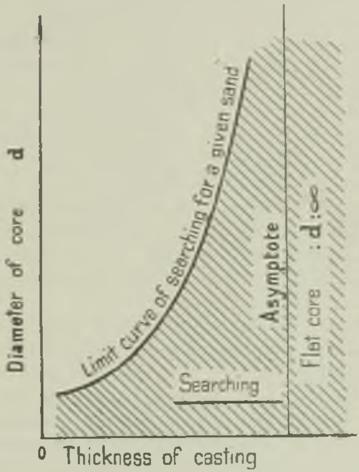


Fig. 9.—Relationship between Limit of Searching, Thickness of Casting and Core Diameter.

surface tension of the molten metal and the wetting of the walls by the metal, which depend upon the *state of the surfaces* of the metal and walls.

In the case of a liquid which does not wet the walls (which is the general case of molten metals in

* In experiments on bronze bushes, A. Miroux (Bull. A.T.F., October 1928, p. 295) confirmed that "searching" took place when the diameter of the core and the thickness of the bush exceeded certain values (15 mm. and 12.5 mm. for the experimental conditions selected), all the other factors remaining constant, and he plotted the corresponding curves.

refractory moulds), we have shown that the influence of the surface tension appears in the form of an additional pressure equal to $\frac{2A \cos \alpha}{r}$, which is necessary to cause the molten metal to penetrate a horizontal capillary conduit of diameter $2r$.

If, on the contrary, the liquid wets the walls, it is drawn into the capillary passage, and if the latter is horizontal, the liquid will flow through indefinitely.

The cavities in sand moulds are necessarily irregular and comprise successive enlargements and constrictions, and hence the phenomena of capillarity are complicated by these variations in diameter. It is, indeed, well known that the resistance to the movement of drops of liquid in capillary tubes possessing successive constrictions and enlargements differs considerably, according to whether or not the liquid wets the walls, and if the liquid does wet the walls, according to whether or not air bubbles are included in the liquid. In fact, in the last-mentioned case the resistance is considerable for the introduction of air and is very slight for the penetration of the liquid.

Hence, there are two very distinct cases, depending on whether or not the molten metal wets the walls. Thus, as shown in Fig. 10, a drop of liquid on the horizontal surface of the solid assumes the shape I or II, according to the circumstances, and the *angle of contact* $\alpha$ or the liquid angle formed by the tangent to the edge of the drop and the solid surface is given by:

$$\cos \alpha = \frac{T_{AS} - T_{LS}}{T_{AL}},$$

$T_{AS}$, $T_{LS}$, $T_{AL}$ being the three measurable or unknown surface tensions at the three surfaces of contact or separation of the air A, the solid S and the liquid metal L. This relationship, expressing the conditions for the equilibrium of the three tensions, leads to the statement that:

when $\cos \alpha < 0$, $\alpha$ obtuse, the liquid does not wet;
,, $\cos \alpha > 0$, acute, the liquid wets.

In the special case when $\cos \alpha = 1$, $\alpha = 0$, the liquid spreads indefinitely in the form of a film over the solid and wets the solid perfectly.

Since the angle of contact depends solely upon the nature of the liquid and of the solid, it is constant irrespective of the inclination of the surface, and for a vertical wall the surface of the liquid at the point of contact is *convex if the liquid does not wet and concave if the liquid wets.*

This, however, is much more a mathematical mode of expression rather than an explanation which would enable one to foresee whether or not the liquid will wet, because even if one does not always know $T_{AL}$ and $T_{LS}$, one is ignorant of the value and significance of $T_{AS}$.

In everyday language, this means that when the liquid-solid attraction prevails, the liquid wets. When, on the other hand, the mutual attraction of the particles (atoms, ions, molecules) of the liquid prevails, the liquid does not wet.

The attraction of the particles or the cohesion manifests itself in liquid in the " internal pressure " and in solids in the " intrinsic pressure " or hardness. These magnitudes are, indeed, related to the surface tension (T. W. Richards, Traube, Sydney Smith), which, according to T. W. Richards, is likewise related to the chemical affinity.

Liquids are more soluble in one another the more nearly alike are their respective internal pressures, and investigations on the intermiscibility of organic liquids, and also of solid solutions of metals, have shown the importance of the ratios of the atomic volumes and the concentrations of valency electrons. The atomic characteristics and valencies thus play a fundamental part in intermiscibility and internal pressure.

Thus, in the case of ionic valencies, the internal pressures are greater the more strongly polar are the molecules and the greater are the forces of affinity. Strongly polar compounds do not dissolve in water which is a polar liquid, but the molecules retain a sufficient affinity for those of water to be readily wetted. At the same time, there is an increase in the hardness and a rise in the melting point. Thus, in the increasing order of internal pressures and affinity, wetting precedes solution or combination.

On the other hand, the solid-liquid attraction manifests itself not only by the crystalline orientation of the electrolytic deposit on the crystals of the supporting metal, *when nothing alters the perfect contact*, but also by the molecular orientation of the liquid, which, in a manner, proceeds towards the pre-ordained state, that is to say, the crystallised state. Thus, oils which wet metals exhibit at the contact an oriented molecular layer or film, the consideration of which is of fundamental importance from the point of view of lubrication.

In this connection, it is likewise opportune to recall the formation of mono- or bimolecular layers of fatty substances on metal surfaces. These phenomena have been investigated by J. J. Trillat by means of electronic diagrams which show the formation and propagation of films of grease on metal surfaces, unless extremely minute precautions are taken in preserving them.

It thus appears possible, by considering the atomic magnitudes and affinities which control miscibility, the ability to combine and the molecular orientation, to shed some light on the phenomena of wetting related to them, and considerable importance is to be attached to the physical or chemical surface changes.

To return to the subject now under discussion, if a molten metal in contact with a mould of silicious sand is studied, there is complete insolubility between the liquid with metallic affinities and the solid silica with energy affinities of co-valency. There is therefore no wetting, but if there is oxidation of the surface of the metal by the formation of a film of oxide, even very thin, it is necessary to distinguish :—

(*a*) Oxides which, although they readily form silicates that are insoluble in the molten metals, possess a metallic character, such as oxides of iron, nickel, cobalt and copper, and which consequently possess a certain solubility in the metal. In this case, wetting may take place.

(*b*) Oxides of polyvalent metals, such as alumina, which, like silica, possess atomic valency bonds and are insoluble in the metal, form on the surface a film whose strength and influence on the surface tension have been discussed in the foregoing.

This film opposes wetting, and hence "searching," and for that reason, even relatively small additions of aluminium may be made in order to modify considerably the surface property of molten alloys. Such films also exert their influence during the re-melting of scrap.

NOTE.—Another defect in casting which is connected to these phenomena is the formation of

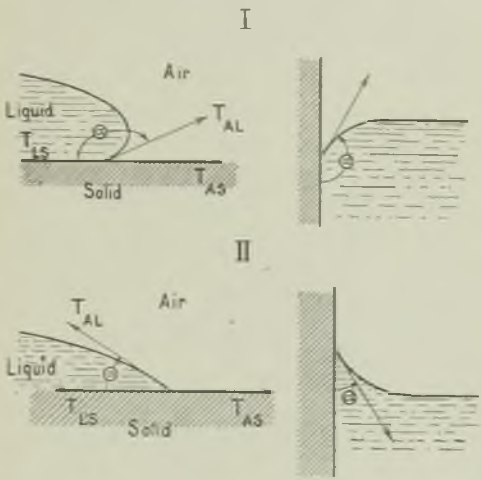


FIG. 10.—INFLUENCE OF WETTING ON CAPILLARITY.

"chilled drops" produced by the spurting of the molten metal cast into the mould from the top. These drops may adhere to the walls and afterwards may not be incorporated in the metal when the level of the molten metal reaches them. This adhesion and incorporation are dependent upon the same factors as those which have been discussed in the foregoing.

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## DISCUSSION

Mr. V. C. Faulkner (Past-President), who was asked by the President, in the absence of the authors, to put the points of the Paper before the conference, explained that it had been exceedingly difficult to translate the Paper into English. Actually in the translation the word " searching " had been coined. The translator, to whom he desired to pay a compliment, had adopted that expression, being cognisant that the authors were speaking of the property of a metal which caused the erosion of the mould and consequently the scabbing of the casting. He would be very glad, personally, if members could find a better word than " searching." He felt that this was the kind of Paper that needed a serious amount of study, and he invited the more practical members to examine it carefully. He thought that some of the conclusions that the authors had drawn were quite capable of being interpreted by the ordinary man in charge of the shops.

Mr. Ben Hird confessed that he had not had an opportunity of really seriously studying the Paper, but he was pleased that someone had taken up this matter of capillary attraction in the foundry. He had not sufficient scientific knowledge to discuss the matter on the lines that the authors had laid down, but from a practical point of view it was a matter that he had had in mind for a considerable time. As a foundryman he was sure that the study of the way in which metal filled a mould by a rolling action was very important, and it would be very wise for them firmly to fix this matter in their minds when studying some of their foundry problems. Personally, he felt such a study was well going to repay further research, both from the practical point of view and from the more academic standpoint.

### The Word "Searching"

Dr. J. W. Donaldson said he had not had time to study the Paper in detail, but he could see that the authors had carried out a very important investigation on the surface properties of metals and of oxidised and unoxidised aluminium in particular. He was interested in what was said with regard to wetting and "searching," as he had carried out experiments on the frictional properties of oils and had found that wetting and adsorption by oils of a metal surface was an important factor in lubrication. He would suggest that the term "adsorption" as adopted by Longmuir for the penetration of the molecules of a metal surface by the molecules of an oil might be used in place of the term "searching," as there was a certain similarity between the two phenomena. Wetting and adsorption of metallic surfaces by oils gave the best conditions for satisfactory lubrication, whereas wetting and adsorption, or "searching," by the surface films of molten metals had a deleterious effect on mould surfaces. The production, therefore, of surface films which had non-wetting properties was important, and the authors had shown that such films resulted with small additions of aluminium. The investigation as carried out by the authors was of a highly scientific nature, and the fact that it added to the knowledge of the physical properties of metals was of value, as all such physical data were of ultimate use and advantage to the practical foundryman, and he therefore considered the members of the Institute should be grateful to the authors for their contribution.

In a written communication Mr. Faulkner pointed out that the French word for adsorption was the same as English. The word used in the French text was "abreuvage."

# CAPILLARITY AS A FACTOR IN FOUNDRY PRACTICE*

**By Professor A. M. Portevin and Dr. P. Bastien**

## Authors' Reply

The authors readily admit that the subject dealt with is rather entering the sphere of physics, had it not been envisaged in its entirety from the point of view of its rôle in foundry practice. It is precisely for this reason that they thought it useful to explain this in order that they should not be misunderstood by foundrymen. This particular study of the rôle of the skin of aluminium has involved experiments and mathematical developments which to some people would appear superfluous and unnecessary in a general examination. It is necessary to remember the final part played by capillarity in " life " and " searching " (*abreuvage*). This latter phenomenon caused difficulty in translation and in understanding, as was pointed out by those taking part in the discussion. On this occasion the words " wetting " (*mouillage*), " adsorption " and " searching " (*abreuvage*) were mentioned, and they must not be confounded.

*Wetting* is the property of adherence in a liquid and a solid, which makes the liquid spread itself over the surface of a solid, which it finally covers—a glass, really clean and well degreased, or a metal in the same condition, is wetted by water, alcohol and by oil, but not by mercury; greasy glass is not wetted by water, etc.

*Adsorption* is the property associated with a solid capable of inducing at its surface an increase of concentration of a dissolved body or of a gas and of retaining them; thus the tissues

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* See page 88

adsorb certain materials, such as charcoal adsorbing gas; this property is exhibited in a high degree by animal black. In foundry sands the clayey matter adsorbs colouring matter, and this property is utilised in sand testing. The adsorption of a dissolved body by a solid implies wetting of the solid by dissolution, but wetting does not necessarily involve adsorption. Wetting relates to the solvent and adsorption the dissolved body. This is exactly what Mr. Faulkner pointed out when he said that this phenomenon was designated by the same word in English and French, and was obviously distinct from "*abreuvage*"—searching.

*Abreuvage* (searching) is the name given by foundrymen to a phenomenon leading to a castings defect (scabbing); the liquid metal penetrates into the pores of the mould, much as water into a sponge, with the result that the casting joins itself with a mixture of sand and metal corresponding to the portion of the mould which has been searched by the metal. For this to happen it is necessary for the metal to wet the mould.

This elaboration has seemed necessary to the authors in order to prevent confusion of thought, and they thank those who took part in the discussion, and hope that this reply will be satisfactory.

# THE MANUFACTURE OF INTRICATE THIN-WALLED STEEL CASTINGS

By R. Hunter, B.Sc., Ph.D., and J. McArther (Member)

While in recent years considerable progress has been made in the production, with consistency, of sound steel castings, the improvement is nowhere more marked than in those castings which may be referred to by the title of this Paper. The term "thin-walled" has, of course, to be regarded as purely relative, as naturally it is not possible to produce large castings with as thin sections as small ones. Consequently, the range covered by this Paper extends from the production of small castings weighing a few pounds, and having portions

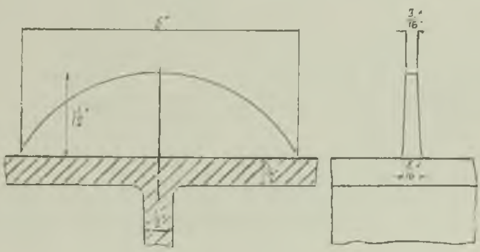


Fig. 1.—Small Tearing Bracket.

only $\frac{1}{8}$ in. thick, to considerably heavier castings weighing up to approximately 38 cwts. and with a thickness of up to $\frac{1}{2}$ in.

The examples selected for detailed description are chosen as representing as wide a range of applications as possible, and at the same time serve to illustrate the many difficulties encountered and the precautions to be observed to ensure the production of sound castings. The castings chosen have all been made in sufficient quantities, in the manner described, to prove conclusively the soundness of the procedure adopted, although it is not claimed that no alternative method of manufacture is available.

In many applications for steel castings, weight is at a premium, and consequently the designer has been compelled to reduce sections to the minimum thickness to give the requisite strength, or to the minimum section acceptable by the steel founder. The latter alternative appears to be

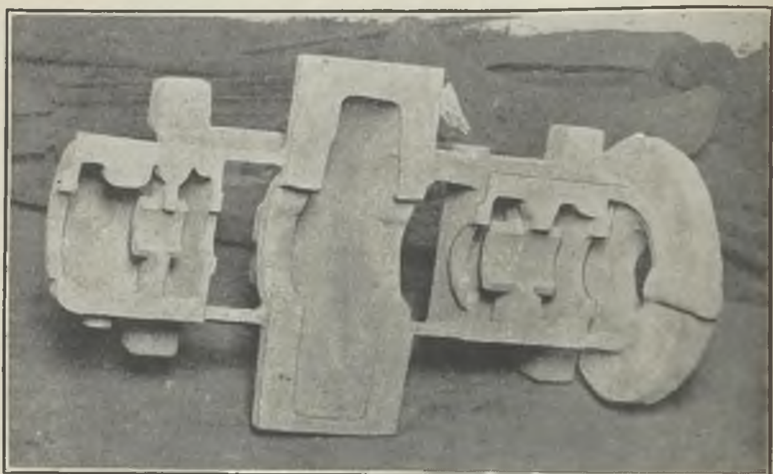


FIG. 2.—HORIZONTAL PUMP FRAMING.

the limiting factor in many cases, as the designer can often, by using the lightest possible section in conjunction with suitable stiffening webs, provide a structure possessing the maximum strength and rigidity for a given weight. In several of the castings described this type of design will be observed, while in others the problem is the complete covering of a very large area with thin metal, as exemplified by the combined oil engine bedplate and end casing described.

While many of the difficulties experienced in the production of thin-walled castings are naturally common to other designs, some of these troubles become intensified owing to the geometry of the thin-walled type. It is therefore proposed to deal with these aspects, with particular reference to thin-walled castings, under a number of headings.

### Maintenance of Size

It is not surprising that the accuracy of dimensions frequently causes trouble with this

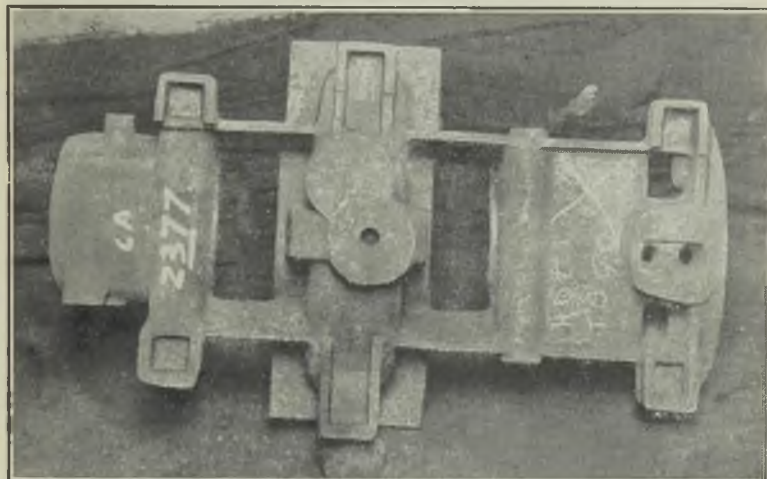



Fig. 3.—Horizontal Turbine-Pump Frame.

type of casting. In castings of normal proportions it is sometimes possible, if difficulty be anticipated in maintaining size, to add an extra machining allowance to compensate for any minor irregularities. This procedure is seldom possible with the castings described in this Paper, as it is essential that, besides leaving an adequate machining allowance, the distance between the centre lines of the various journal pads, etc., must be accurately maintained, in order to ensure uniform loading conditions in service.

Whilst a contraction allowance of about $\frac{3}{16}$ in. per ft. is generally found to be satisfactory for steel castings of normal design, thin-walled castings, on the other hand, have as a rule to be made with a smaller allowance than this. The allowance used in some of the castings described

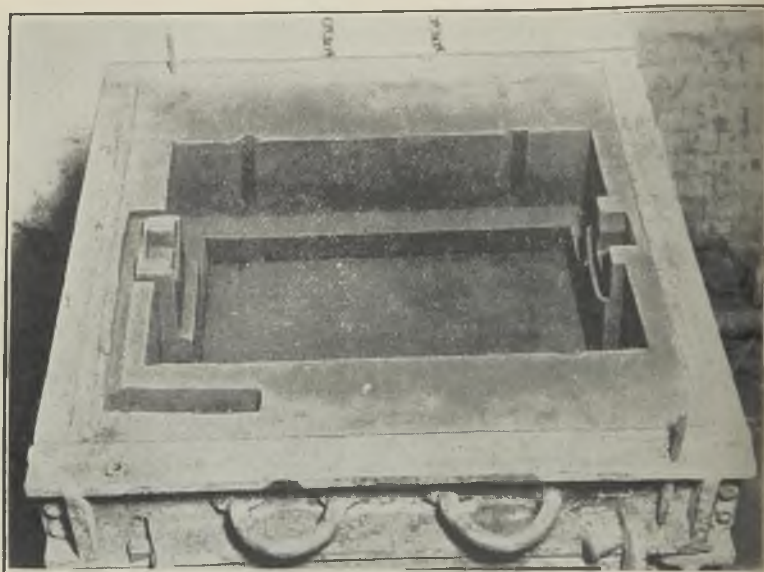


FIG. 4.—DRAG HALF MOULD FOR TURBINE-PUMP CASING.

is down to $\frac{3}{32}$ in. per ft. in the horizontal direction. The actual value employed depends on the design of the casting and sometimes, in fact, may vary in different parts of the same casting. These remarks apply to the contraction in the horizontal direction, but it is found that the normal allowance of $\frac{3}{16}$ in. per ft. in the vertical direction gives satisfactory results in practically all cases.

While it is essential to use the correct contraction allowance for each design of casting, sometimes trouble is experienced owing to different castings from the same pattern being found not to have contracted by the same amount. The possible causes of this difference

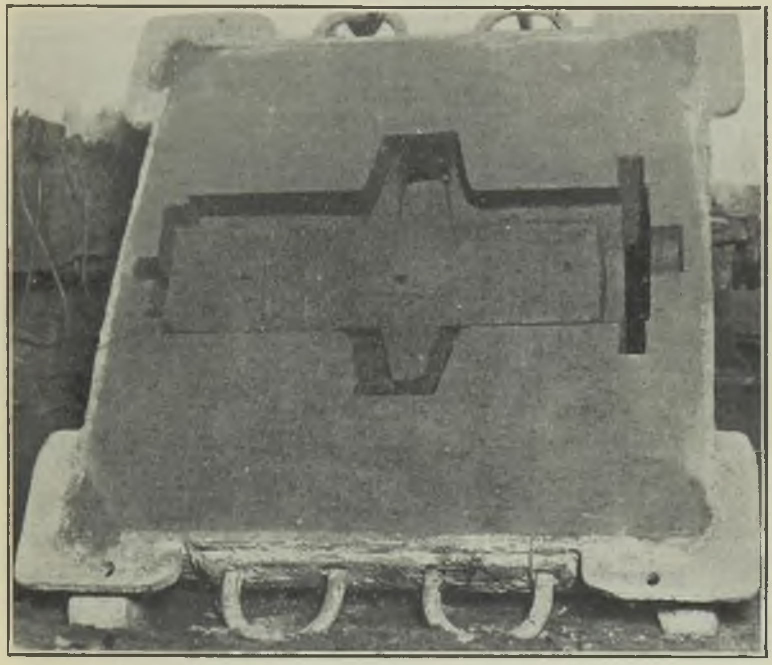


FIG. 5.—COPE OF MOULD FOR TURBINE-PUMP FRAMING.

in behaviour in such cases are many, but the principal variables may be regarded as: Resistance to crushing of mould and cores; temperatures of metal and mould; rate of pouring; composition of steel, etc. At present, in spite of improved technique, it cannot be claimed that absolute uniformity of all these factors can be rigidly maintained. Every effort is made to do so, but it is found that additional precautions have to be taken.

With thin-walled castings provision is always made to shatter readily the main cores and any parts of the mould which tend to impede the free contraction of the casting. This is done at a

Fig. 6.—Main Core in position in half mould shown in Fig. 4.

certain standardised time, determined by experience, after completion of pouring. The actual time depends on the design of the casting; the heavier the casting the greater the lapse of time. This procedure is, of course, also adopted to minimise the possibility of hot tears, and while it may also be useful for this purpose if it is done in time, the authors find it to be always of very great assistance in ensuring uniformity of contraction.

**Prevention of Hot Tears**

This problem might well constitute the subject of a Paper by itself, and the authors can only afford here to touch briefly on this subject and indicate the various means adopted to pre-

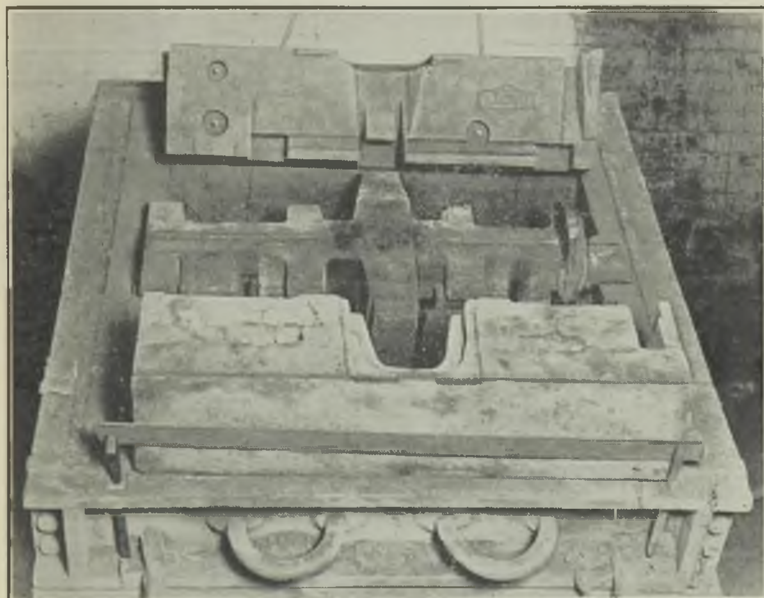


FIG. 7.—TWO CORES FORMING SIDES OF CASTING ARE SHOWN REMOVED FROM MOULD.

vent the occurrence of hot tears in the particular type of castings described. Hot tears are liable to occur in steel castings due to their relatively high contraction on cooling. If this contraction be unduly impeded by the mould or cores then rupture occurs, owing to the low tensile strength of the steel at elevated temperatures. While the composition of the steel and the process of steelmaking influence the amount of contraction, these factors at present cannot be controlled to eliminate the danger of hot tears.

The light sections in a casting, everything else being equal, naturally cool more quickly than the heavy ones, and consequently during the cooling process are generally stronger than the latter, despite their smaller cross-sectional area.

FIG. 8.—MAIN CENTRAL CORE FOR TURBINE-PUMP FRAMING.

The result of this is that hot tears tend to occur at what are generally termed "hot spots" in the casting. In thin-walled castings, where the metal is maintained as uniform in thickness as is possible, these "hot spots" are generally situated at the junction of the various webs with the main body. If the cooling conditions are so regulated that the casting is cooled uniformly, then the weakness caused by "hot spots" would be absent, and the hot-tearing tendency greatly decreased. The use of suitable external chills to hasten the cooling at the desired points may achieve this ideal condition. It is not possible, however, to enunciate any definite rules to govern the weight of chill to be employed, but there are, nevertheless, certain precautions to be observed in their use.

The edges of chills should never be left square,

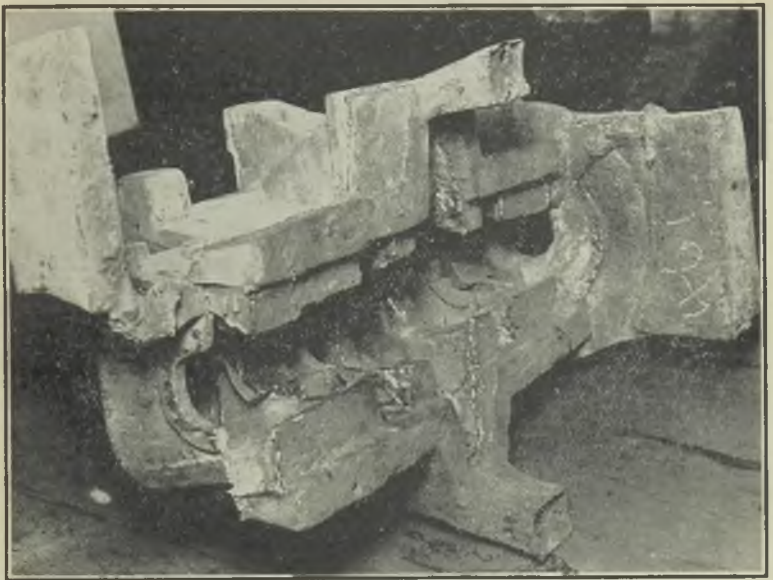


FIG. 9.—SHOWING POSITION AND SIZE OF THE VARIOUS FEEDING HEADS.

but should be rounded with a generous radius. If this precaution be not adopted, trouble may be experienced due to surface cracks appearing on the casting at the edge of the chill. It is also important that the chill be carefully cleaned before use, and it is also found advantageous to coat it with aluminium paint prior to drying the mould.

With thin-walled castings, however, chills should be used with discrimination, since, naturally, they must add to the difficulty of running a casting whose thickness probably has been controlled by this factor. If chills appear to offer the best means of overcoming the tearing tendency, then their use is justified, but they should be made as light as possible. It is also advisable that light chills be securely tied back to the mould to prevent their possible distortion by the metal. For thin-walled castings, the authors prefer whenever possible to use suitable flat-headed nails as a mild chilling influence to assist in making the cooling conditions as uniform as possible.

Rather than add difficulties to the running of the castings by the use of chills, the strength at the hot spots can often be adequately increased by the judicious placing of brackets. The type of bracket found to be suitable for thin-walled castings is as indicated in Fig. 1. No definite rule can be given for the number of brackets necessary, as the requirements depend so much on the design of the casting. One decided advantage of brackets is that they assist the running of the casting, particularly where the design is such that the metal rises slowly in the mould. For this reason also they are sometimes made to extend the whole length of the casting.

As will be appreciated, these precautions are necessary, because it is not practicable to make the mould and cores with a negligible degree of resistance to the contracting casting. It is naturally better practice to reduce this resistance to a minimum, rather than use devices in an attempt to overcome the deficiencies. In the description of the manufacture of the various castings, details are given of the different methods found to be of service in this direction. Probably in no other phase of steel foundry practice has greater ingenuity been exercised than in the provisions made to reduce the crushing resistance of moulds and cores. In this Paper, however, no claim is made to summarise all the expediences adopted, but the castings selected for description illustrate various assemblies which have been found to be satisfactory for the different types.

In regard to cores, the underlying principle is, of course, to make them as light as possible, consistent with adequate strength and rigidity, to resist the action of the molten metal. The details as to how this may be accomplished are given later in the Paper.

It will be observed that a cast-iron grid is

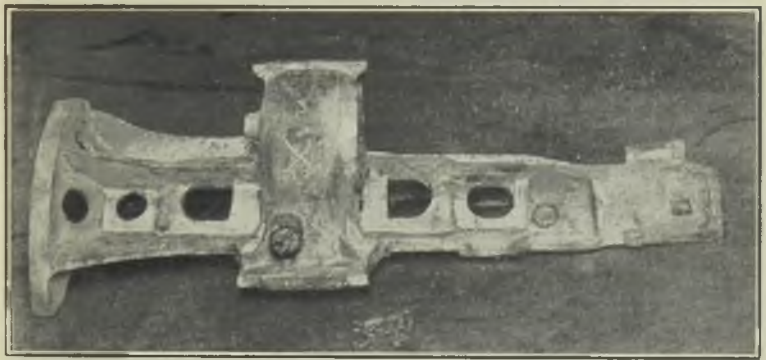


Fig. 10.—Vertical Turbine-Pump Framing.

generally employed to support the core and carry the additional reinforcements. This grid, wherever possible, should be situated in the mould outside the actual casting, and is, in fact, generally located in the core print. Consequently, the most rigid part of the core does not interfere with the free contraction of the casting.

### Gating of the Casting

It is not possible to lay down rigid rules governing the gating of thin-walled steel castings, as each design must be considered on its merits; a common down runner is generally made to serve a number of gates, as will be observed later in the Paper. Bottom running is usually employed, but additional gates are generally added at progressively higher levels to assist the running of thin sections. Whenever the symmetry of the castings permits they are run equally from both sides. In comparison with castings of normal proportions, thin-walled castings have generally a larger number of gates and are practically never top run.

### Choice of Moulding Method

The considerations affecting the choice of the moulding position of the castings under con-

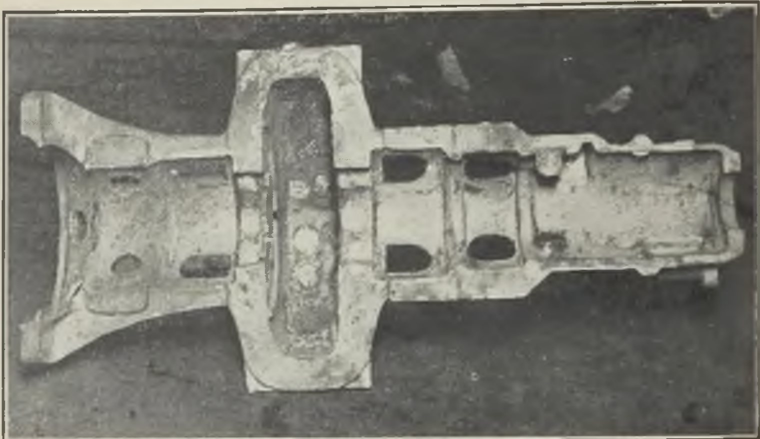


Fig. 11.—Interior Aspect of the Casting shown in Fig. 10.

sideration are essentially similar to those arising with other types. Whenever possible, it is preferable for the principal machining faces to be cast downward. So many other factors, however, affect this choice that often it is not practicable to make the casting in this manner.

Making the casting, for example, with the principal machining faces downwards may present difficulties in moulding or in the subsequent assembly of mould and cores. On the other hand, it may be quite impossible to ensure the successful running of the casting. Frequently, however, the chief problem is the feeding of these important areas, as naturally since they are at the foot of the mould, the design of the casting may interfere with the placing of suitable feeding heads. With thin-walled castings also, the maintenance of uniform thickness is of great importance and consequently the mould and cores must be so assembled and held so that they will not be distorted by the molten metal. It will be appreciated, therefore, that generally the final

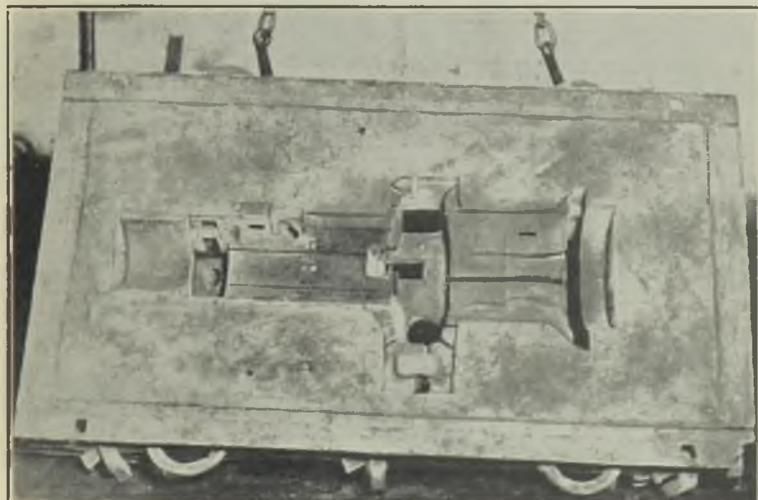


Fig. 12.—Cope half mould for Vertical Pump Framing.

decision as to the direction of moulding will be a compromise of the above factors, and that each casting must be carefully studied before deciding the most suitable method of manufacture.

### Steel Requirements

The steel used for the castings described in this Paper is made in a basic-lined electric arc furnace of 5 tons capacity. The normal steelmaking practice is followed, using two slags ensuring that the metal is particularly free from non-metallic inclusions and is thoroughly deoxidised. With thin-walled castings, naturally, the casting temperature must be carefully controlled, because it must be sufficiently high to ensure the complete running of the casting with no "cold shuts," and yet it must not be so high as to cause other equally serious troubles. It is possible with the electric furnace to obtain a very strict control of the analysis of the steel. The composition of the steel used is, however,

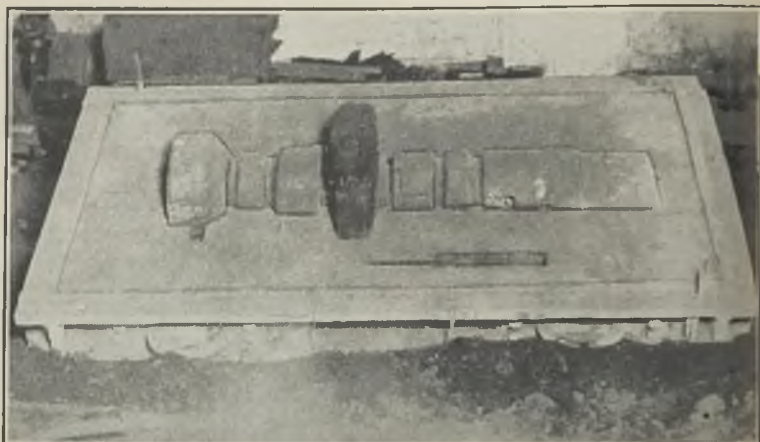


FIG. 13.—CORE ASSEMBLY ON DRAG.

quite normal and contains 0.20 to 0.25 per cent. carbon.

All castings are thoroughly annealed, and the following is a typical test in this condition:—

| | |
|---|---|
| Test No. ... ... | 462A. |
| Yield point ... ... | 18 tons per sq. in. |
| Maximum stress ... | 33 tons per sq. in. |
| Elongation ... ... | 28 per cent. |
| Bend (1 in. by $\frac{3}{4}$ in.) | 180 deg. N.F. |

### Moulding and Core Sand

Owing to the lightness of the metal, the conditions are not as severe in some respects as encountered with heavy castings. Nevertheless, strict control of the sand is just as important as in the other branches of the industry, and care taken in sand preparation is amply recompensed by the improved surface of the castings. Dry-sand moulding is used throughout the manufacture of the castings described. A naturally-bonded silica sand is used as a facing for the cores.

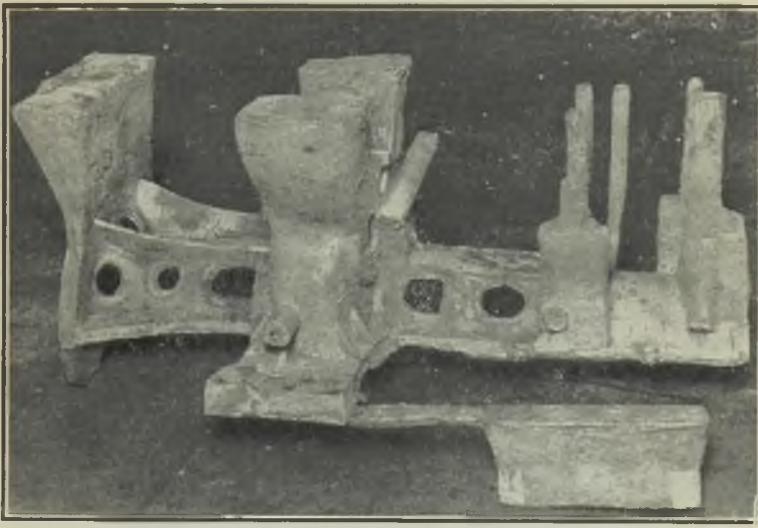


Fig. 14.—Feeding-head Arrangements for a Vertical Pump Framing.

The facing sand for the moulds consists of a milled mixture of the above natural sand and floor sand. The proportions in which these are mixed depends, of course, on the nature of the casting to be produced. To strengthen the surfaces of the mould and cores where required, these areas are liberally reinforced with sprigs. The oil-sand cores are made with a mixture of sharp silica sand and a proprietary bonding compound.

### Horizontal Turbine Pump Framing

Figs. 2 and 3 show two views of this casting. It will be observed that the designer has made every effort to lighten the casting while still maintaining its full strength and rigidity. The general thickness of the casting is $\frac{3}{8}$ in. The

FIG. 15.—TOP VIEW OF A GEAR-CASE CASTING.

journal pads are slightly heavier than this, and a fairly substantial flange forms one end of the casting.

The most important machined faces are shown in Fig. 2, comprising the bearing supports and the flange of the impeller trough. It might be considered good practice, therefore, to cast this face downwards. Experience, however, proved that it was not possible to feed adequately the journal pads and the supporting webs when this procedure was adopted. As these areas must of necessity be perfectly sound, the casting was made with the journal faces upward, in order that suitable risers could be conveniently placed. The design of the casting does not permit feeding of the flanges seen in Fig. 3 on the underside of the casting, which have conse-

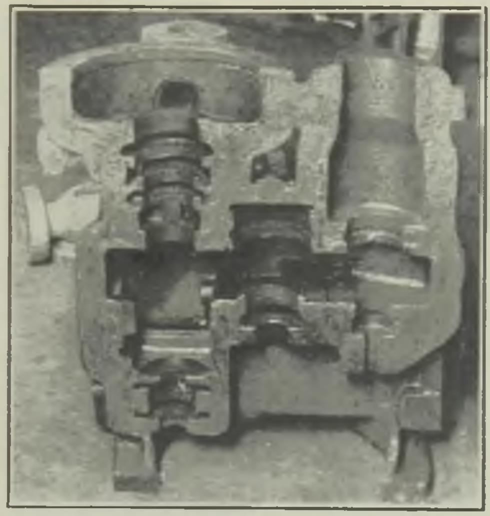


FIG. 16.—INTERNAL ASPECT OF A GEAR-CASE CASTING.

quently to be chilled to ensure soundness. A block pattern is used in the production of this framing, the mould being formed almost entirely of cores.

Figs. 4 and 5 illustrate the drag and cope respectively, after removal of the pattern. The former also shows the location of the test-bar and the method of gating. A single down-runner leads to two gates running into the top of the sides of the casting. Each of these gates at its junction with the casting is $1\frac{1}{2}$ in. deep by $\frac{3}{8}$ in. broad.

The main bottom core is shown in position in the drag in Fig. 6. This core is reinforced with a cast-iron grid located in the core print. The facing and backing sand does not exceed $1\frac{1}{2}$ in. in thickness, and the centre of the core is composed of riddled ashes. Vents from the underside of this core are registered with suit-

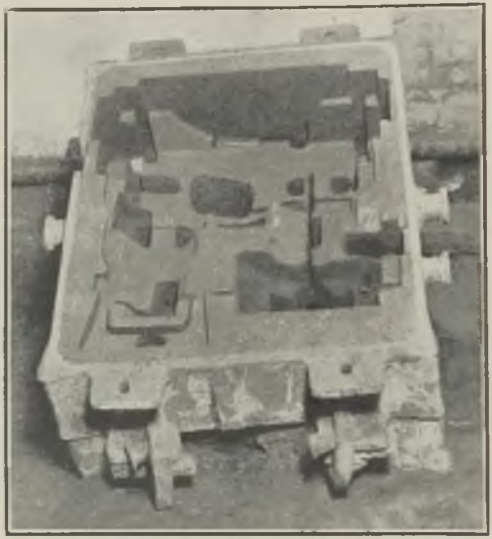


FIG. 17.—COPE HALF OF GEAR-CASE MOULD.

ably placed holes in the drag. The green core is placed in the drag and dried along with it.

The two cores forming the sides of the casting are shown removed from the mould in Fig. 7. These are constructed similarly to the main bottom core, except that naturally only the side forming the mould is finished with facing sand. The chills for the bosses on the sides of the casting are also shown, the bars being subsequently removed by machining.

The main central core is made in halves, as shown in Fig. 8. Whilst this core is also strengthened by means of a cast core-iron, it is too weak in the green state to withstand handling. It is, therefore, partially dried and the two halves then tied together with steel wire passed round their respective core-irons at three points.

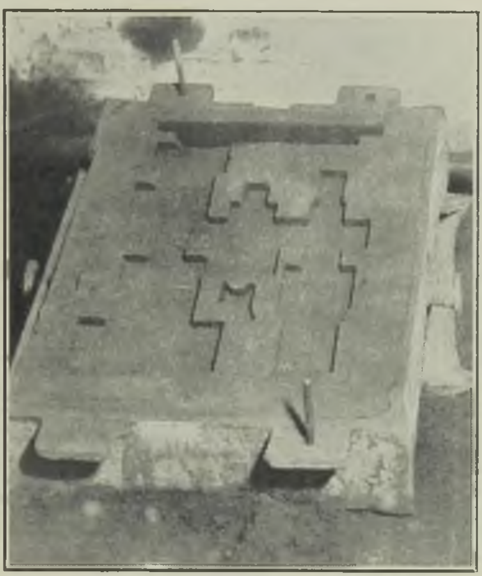


Fig. 18.—Drag half of Gear-Case Mould.

The composite core is then dried as a unit, and is seen in its position in the mould in Fig. 7. This core is made entirely of facing sand. For venting purposes numerous pricked holes are made from the vertical joining faces of the two halves to within about $\frac{1}{4}$ in. of the surface of the core. These holes are connected to a series of grooves cut in the vertical joint, and exits for the gases are provided through three vent holes passing up through the cope as shown in Fig. 5.

The various small cores constituting the numerous oil ducts and drainage passages are made in oil-sand for convenience in fettling. Fig. 9 shows, better than any written explana-

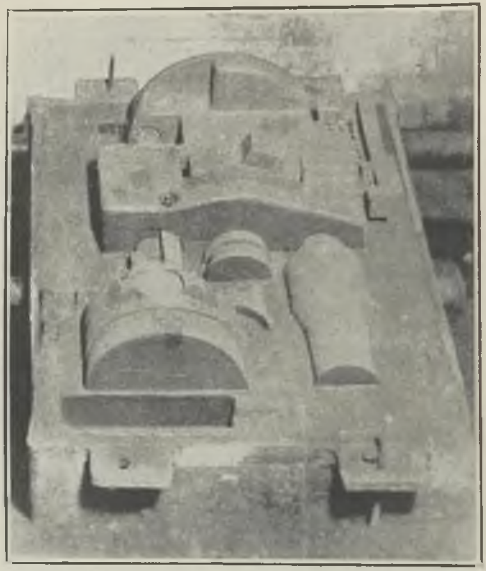


FIG. 19.—CORES ASSEMBLED IN GEAR-CASE MOULD.

tion could describe, the location and size of various feeding heads.

## Vertical Turbine Pump Framing

Figs. 10 and 11 show views of this framing. This type is supplied in castings up to about 5 ft. 6 in. long overall. The thickness of the metal in the body is only $\frac{5}{16}$ in., and the principal difficulties associated with this casting are the running of such light metal over this length, and the prevention of hot tears.

No great difficulties are presented in the moulding of this casting. Fig. 12 shows the cope, in which will be noted the numerous brackets which have been added to prevent tearing. The drag is made perfectly plain, con-

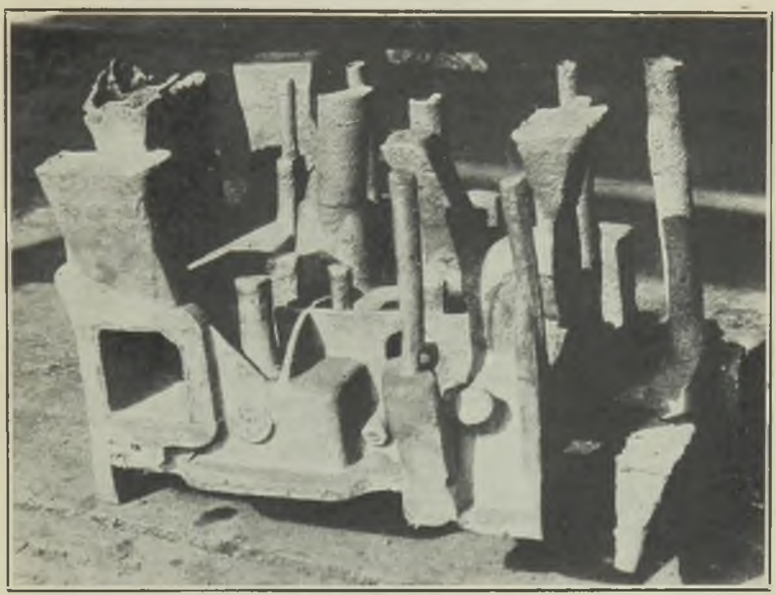


FIG. 20.—FEEDING ARRANGEMENTS FOR GEAR-CASE CASTING.

taining only the prints for the main cores. The main core assembly is shown in position on the drag in Fig. 13. For convenience in handling, this core is made in three distinct parts: first, the main central core; secondly, the saddle core for the trough, and thirdly, the large diameter core shown at the left-hand side. These cores are composed entirely of facing sand reinforced with a cast-iron grid which is situated in the core print. Venting is carried out by means of pricked holes, as previously described. The cores are assembled on the drag in the green state and dried along with the mould.

The method of gating this casting is clearly seen in Fig. 12, from which it will be observed that the down-runner is situated close to the middle of the length of the casting, and that two gates run from this into the two adjacent flanges of the trough. This casting, complete with the various feeding heads, is shown in Fig. 14.

FIG. 21.—NOZZLE SEGMENT CASTING WITH HEAD AND RUNNER.

### Gear Case

Figs. 15 and 16 show views of top and underside of this casting. The thickness of the metal in the body and webs is $\frac{3}{8}$ in. and $\frac{5}{16}$ in. respectively. It will be observed that the upper side, despite its intricate nature, does not necessitate a great deal of core work, although it certainly involves a high degree of moulding skill. The construction of the underside, however, makes the use of a considerable number of cores essential.

Figs. 17 and 18 show the cope and drag

respectively. Core prints and bottom of the main flange only are left in the drag, and the green and partially-dried cores assembled in position are shown in Fig. 19. This procedure enables any minor adjustments in the cores to be readily made, and so greatly reduces the total closing-time which would otherwise be necessary if the cores were assembled in the dried condition. Owing also to the number of cores to be assembled on the drag, a considerable amount of sealing is

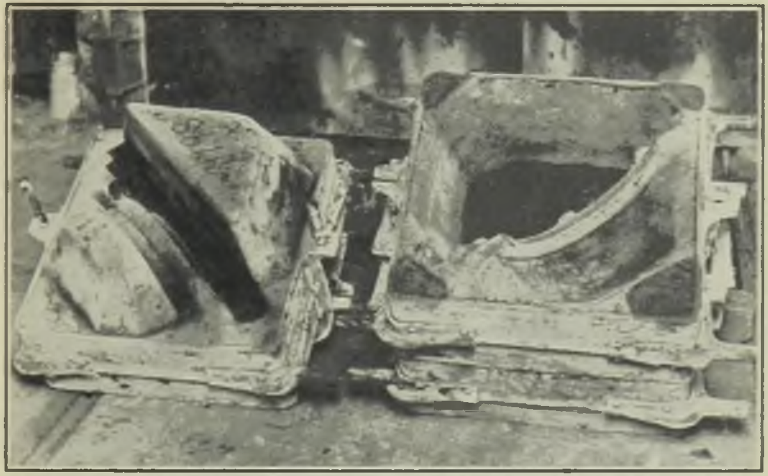


FIG. 22.—COPE AND DRAG HALF MOULDS FOR NOZZLE SEGMENTS.

necessary to avoid fins, and this procedure ensures thorough drying at all such points.

The exceedingly complicated nature of the cope will be observed in Fig. 17 and the few cores that are necessary are placed in this portion of the mould before drying. The method of running this casting will be seen in this illustration. Two gates leading from a common down runner are attached to the bottom edge of the smallest flange as shown at the bottom left-hand corner.

The cores assembled in the drag of this mould are made in several different ways. The large cores are reinforced by cast-iron grids and are made entirely of facing sand. On the heavier sections of these cores the venting is carried out by a series of pricked holes extending inwards as near to the surface of the core as possible. These holes radiate from channels cut in the underside

FIG. 23.—CORE ASSEMBLY FOR NOZZLE-SEGMENT

of the cores and provision is made for the gases to escape downwards through the drag. A number of the large cores, however, are reduced in section to about 1 in. thick in parts. It is not practicable, therefore, at such points to have pricked holes for vents, and consequently in such places the cores are wax-vented. When this procedure is adopted, of course, the cores are partially dried to allow the wax to run out before assembly on the drag. The numerous small cores are reinforced with bent wire and are either pricked for venting or wax-vented.

The principal machining-faces on this casting, it will be observed, are cast face downwards, and fortunately the shape of the casting does not make the adequate feeding of such parts difficult. The numerous and substantial nature of the feeding heads, however, will be noted in Fig. 20.

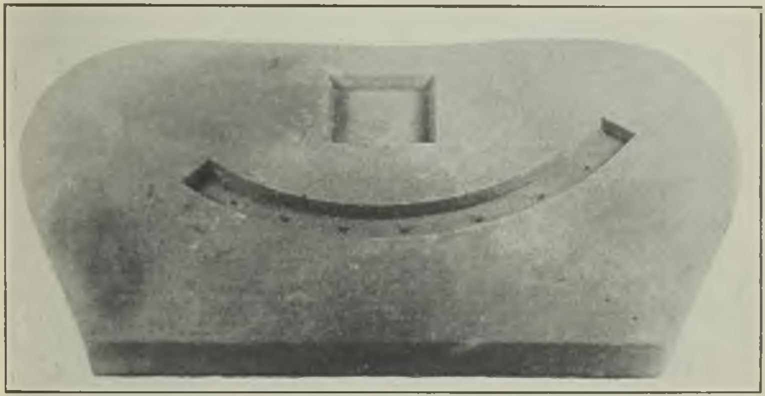


FIG. 24.—CORE FOR LOCATING WOODEN JIG FOR NOZZLE CORE ASSEMBLY.

## Nozzle Segment

Fig. 21 shows this casting complete with head and runner. The shape of the flange of the casting is as indicated. The principal difficulties in the production of this casting are the running of the extremely-thin metal of only $\frac{1}{8}$ in. in thickness, separating adjacent nozzles, and the accuracy of the location and shape of the nozzles. Fig. 22 shows the cope and drag of the mould. The core assembly in position in the drag is shown in Fig. 23. All cores are made in oil sand.

The principal reason for casting the segments on edge is that the cores suffer the minimum of distortion by the molten metal when placed this way. Accurate assembly of the cores is naturally of paramount importance. To attain this, a wooden jig is provided which is located by means of the print shown in the core in Fig. 24. The top prints of the nozzle cores are registered with suitable marks on the circumference of the jig, while the bottom prints are located in the semi-circular recess. The vents for the nozzle cores will also be observed leading from the bottom of the recess. The nozzle cores, partly assembled, will be seen in Fig. 25.

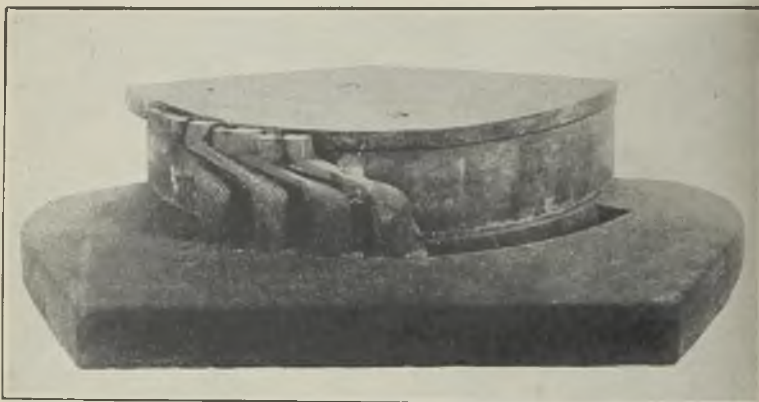


Fig. 25.—Nozzle Cores partly assembled.

**Combined Oil Engine Bedplate and End Casing**

General views of this casting are shown in Figs. 26 and 27, whilst longitudinal and transverse cross-sections are given in Fig. 28. The casting is roughly 11 ft. long by 3 ft. wide by 3 ft. deep at the sump end and weighs about 38 cwts. The thickness of the metal in the body and the webs supporting the bearings is $\frac{1}{2}$ in. which in proportion to the size of the casting is extremely light as will be appreciated from Fig. 28. The principal difficulties arising in the production of this casting are:—

(1) The successful running of such a large area of thin metal; (2) prevention of hot-tears, and (3) maintenance of size.

From a consideration of the various factors influencing the choice, it was decided to mould the casting with the bearing pads and the horizontal flange encircling the body face downwards. The pattern as placed on the drag is

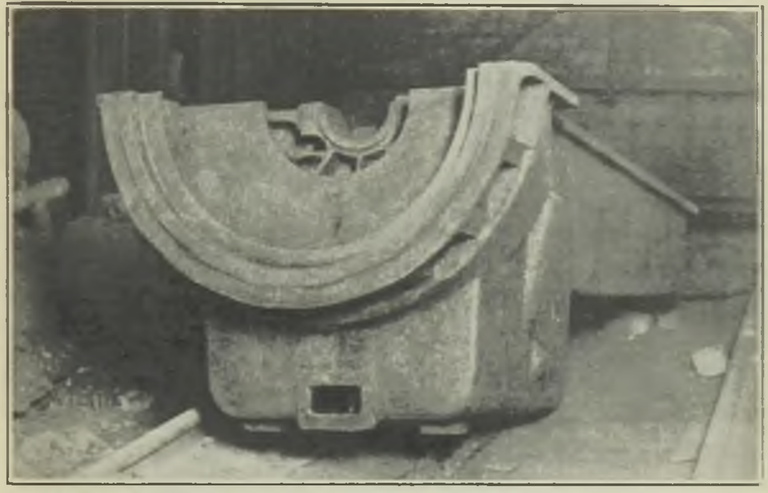


Fig. 26.—Combined Oil-Engine Bedplate and End Casing.

shown in Fig. 29, which at the same time shows the method of running and gating the casting. The numerous small heads placed where required are represented by wooden blocks.

To prevent hot-tearing, the main cores were made in such a manner that while they were sufficiently robust to withstand the action of the liquid metal, they offered little resistance to crushing by the contracting casting. Means were also provided whereby the main core irons could be readily shattered at the desired lapse of time after casting.

An illustration showing a typical core-iron assembly is seen in Fig. 30. The cast-iron grid-base into which also are cast steel wires bent to follow the external contour of the core will be noted. The long cast-iron fingers projecting from the grid add extra rigidity to the core without unduly affecting the resistance of the sand shell to crushing. At the same time, they provide a ready means of breaking up the core as a

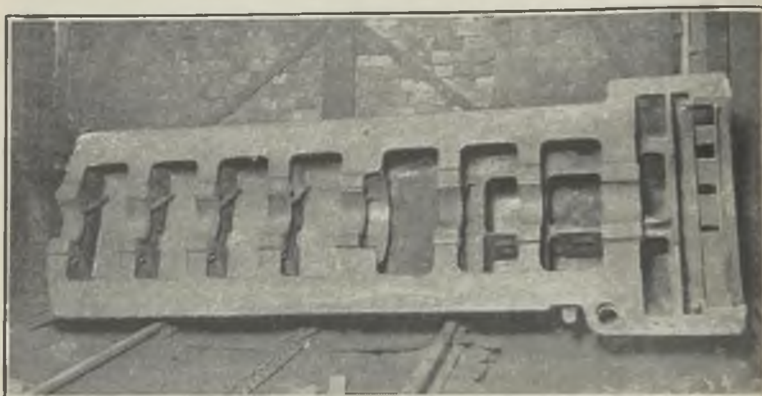
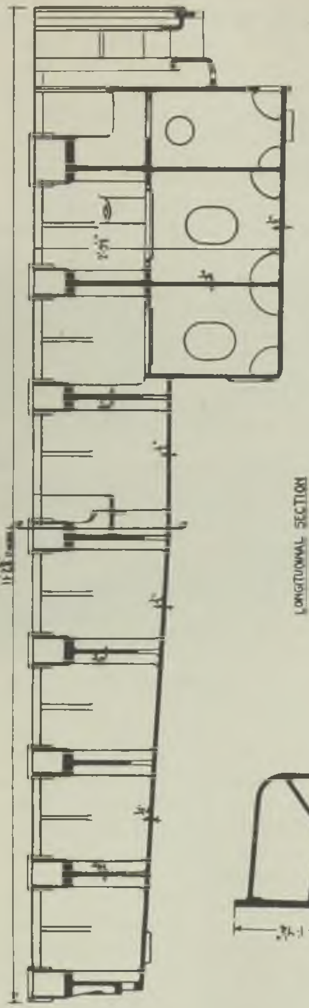


FIG. 27.—INTERNAL ASPECT OF CASTING SHOWN IN

whole when the base grid has been shattered. Fig. 31 shows a cross-section of a typical core. To facilitate manufacture, the centre is filled with clean riddled ashes which are removed after the core is dried. It will be observed that the core-iron grid is located in the core-print, and consequently does not interfere with the free contraction of the casting. The cores at the deeper sump end are similarly constructed. The top cores are, however, made separately and located by prints engaging with corresponding recesses in the lower cores.

It will be noted from the transverse sections in Fig. 28 that the bearing pads are consider-



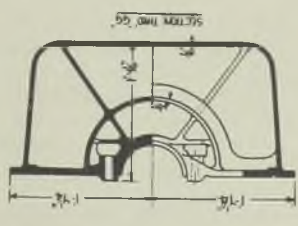



Fig. 28.—Bedplate and End Casing.

ably heavier than the walls of the casting, and consequently since it is not possible to add a feeding head at these points, external chills have to be used. The soundness of the main-bearing bolt-holes is ensured by the insertion of a mild-steel bar which is subsequently removed by machining.

### Diesel Engine Crankcase

Figs. 32 and 33 are illustrations of the eight-cylinder crankcase, while Fig. 34 is a cross-

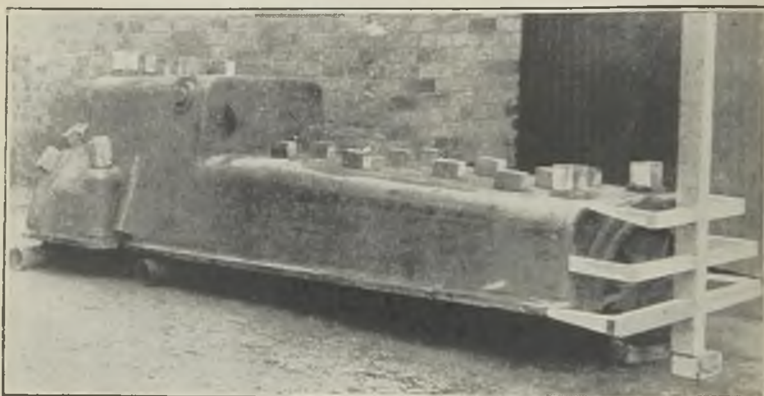


FIG. 29.—PATTERN FOR THE OIL-ENGINE BEDPLATE AS PLACED ON DRAG.

section. The main body is $\frac{3}{8}$ in. thick, while the webs are only 0.3 in. in thickness. The length is over 7 ft. and the height about 2 ft. 10 in. The extremely complicated nature of this casting will be observed, and the difficulties associated with the successful manufacture will be appreciated. The casting was moulded upright as shown in Fig. 34. A single down-runner was situated at one end, and from it three pairs of runners were connected to the side walls at the bottom, middle and top of the casting.

The main cores were made to possess the minimum resistance to crushing, and provision was made that they could be easily shattered immediately after casting. A cross-section of the

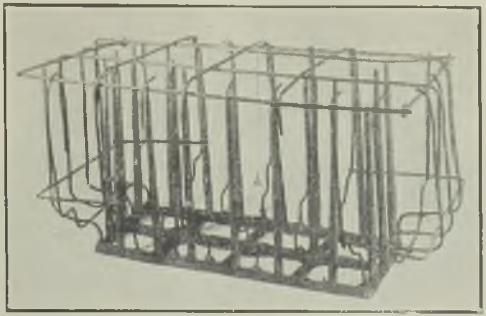


FIG. 30.—CORE-IRON ASSEMBLY.

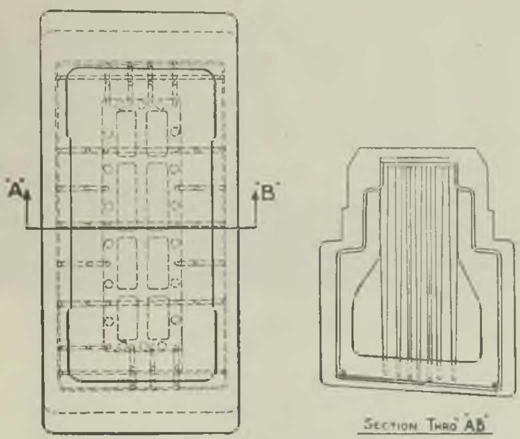



FIG. 31.—MAIN CORE FOR BEDPLATE.

main cores is illustrated in Fig. 35. The horizontal cross-section " AB " shows how the suitably-shaped wires are located by the vertical iron casting with L-shaped ends. Outside these wires is placed the wire netting which serves to reinforce the facing sand. While the thickness of the sand in these cores naturally varies from point to point, it is never more than 2 in. In making these cores, the centre is supported by riddled ashes, which are removed after the core is dried.

The shaped ends of the castings carrying the wires are butted together, as shown, so that a

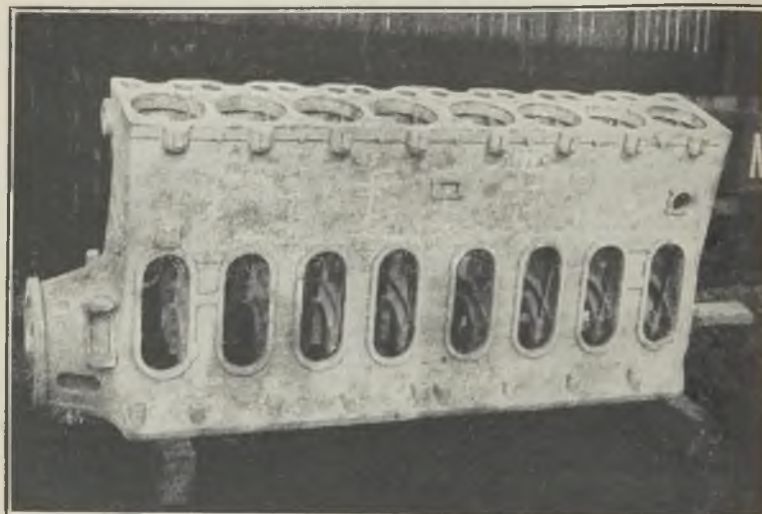


FIG. 32.—EIGHT-CYLINDER CRANKCASE CASTING.

blow delivered at the top will readily shatter both cores. The actual moulding is carried out in a perfectly straightforward manner, but provision is made that the mould can be readily shattered and disassembled in order that it will not interfere with the contraction of the casting. As soon as the casting has been poured, two men, starting at the end remote from the runner, shatter the main cores by striking the central supports at the top. As soon as this is

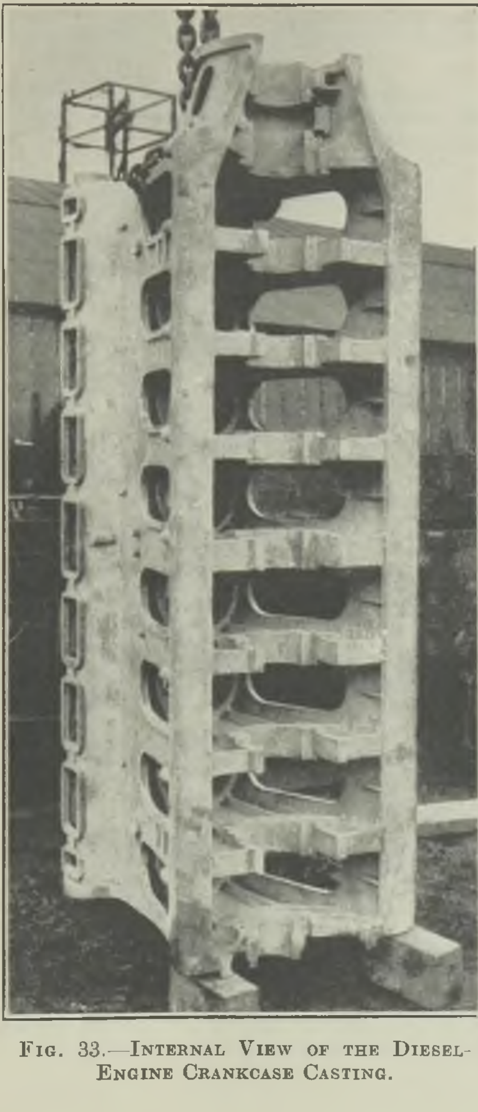


FIG. 33.—INTERNAL VIEW OF THE DIESEL-ENGINE CRANKCASE CASTING.

done, the mould is shattered and the casting released.

**Summary**

This Paper may be conveniently divided into two parts. The first section deals with the various phases of steel foundry practice, with

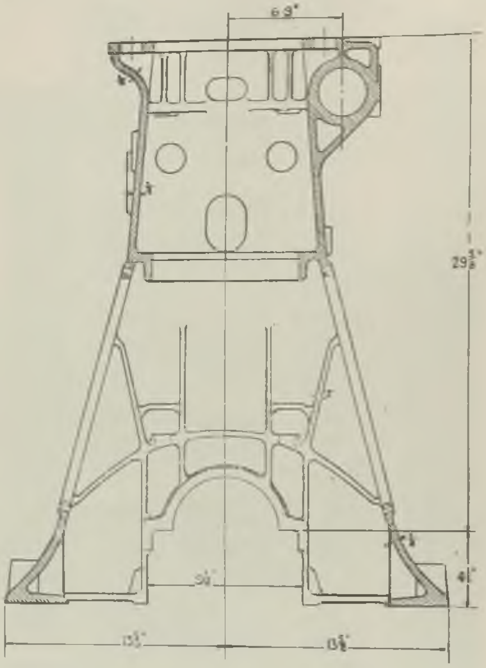
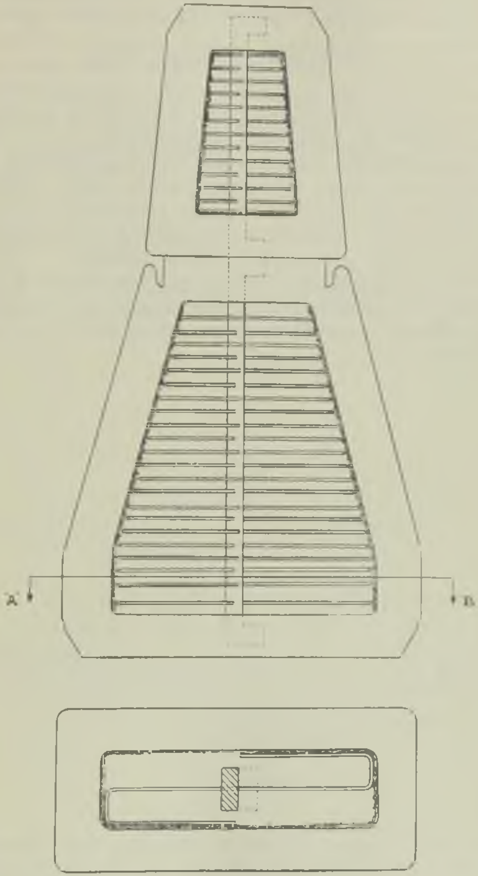


Fig. 34.—Cross-section of Diesel Engine Crankcase.

particular reference to thin walled steel castings. Each of these factors has been considered from a general standpoint, and only the underlying principals have been outlined.

The second part is devoted to the description of the actual manufacture of typical castings. The following castings are described :—

(1) Horizontal turbine pump framing.
(2) Vertical turbine pump framing.
(3) Gearcase.




SECTION THRO' AB

FIG. 35.—MAIN CORES FOR CRANKCASE.

(4) Nozzle segment.
(5) Combined bedplate and end casing.
(6) Diesel engine crankcase.

The difficulties in production peculiar to the various examples are considered, and the expediences which have proved successful in overcoming them described. While these descriptions have necessarily been brief, the underlying reasons for the adoption of the various methods have been in particular emphasised.

The authors wish to take this opportunity of expressing their gratitude to G. & J. Weir, Limited, and to The English Electric Company, Limited, for permission to publish photographs illustrating castings of their designs. They also wish to thank the various members of the staff of the Clyde Alloy Steel Company, Limited, who have assisted in the preparation of this Paper.

# COMPOSITION AND ITS EFFECT UPON THE PROPERTIES OF MOULD AND CORE-SAND MIXTURES AT ELEVATED TEMPERATURES

**By F. Hudson (Member)**

In a previous Paper* the author gave the results of an investigation into the properties of mould and core materials at elevated tempera-

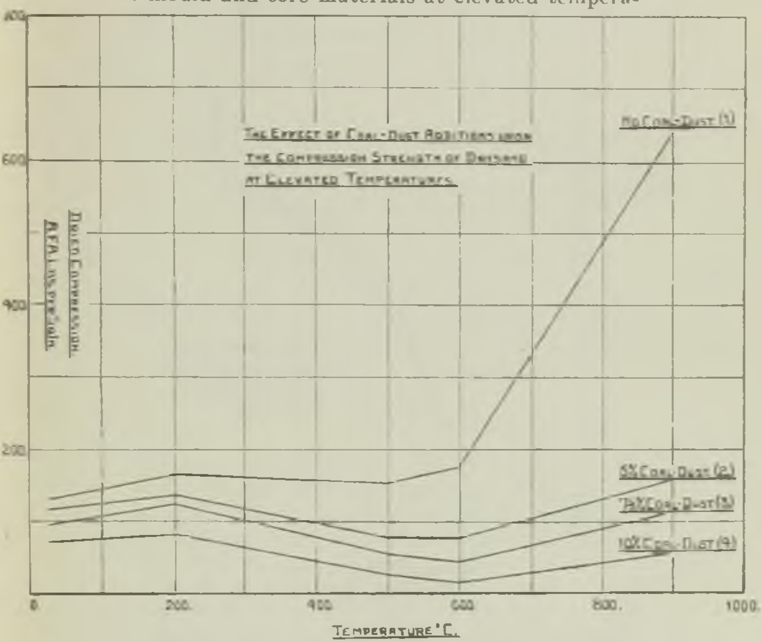



Fig. 1

tures. This Paper outlined in a general way the properties which could be expected in the above materials during and after the casting operation, and from the results obtained it was

* "Some Properties of Mould and Core Materials at Elevated Temperatures," included in this volume.

apparent that there was room for considerable improvement.

The present Paper is a continuation of the first and takes the investigation a step farther, indicating possible practical methods for controlling the properties of mould and core materials at elevated temperatures. From a study of the

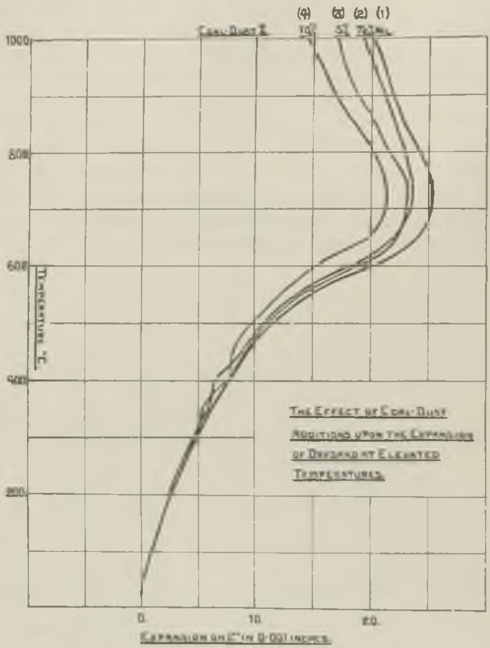



Fig. 2.

previous results obtained it is obvious that the composition of the mould or coresand mixture in service has an important bearing upon the properties at elevated temperatures as well as the foundry technique employed. The remarkable effect, for example, of coal-dust additions in reducing expansion and preventing the abnormal increase in strength consequent on heating, in conjunction with an easier fettling operation, undoubtedly warrants further investigation. It is considered that the high-temperature characteristics of most green sands are infinitely preferable to those exhibited by dry sand and loam, and there is a vital need for improved physical properties at high temperatures in these latter materials.

Very often the foundryman falls back on dry sand when he wishes to be particularly assured of good results, and whilst the characteristics of dry sand may be excellent at room temperature,

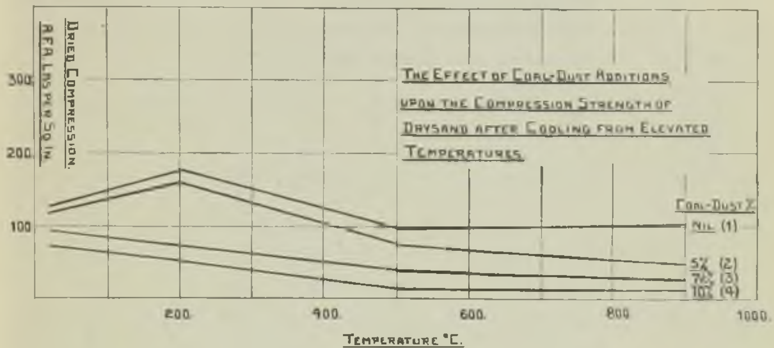



FIG. 3.

the same statement by no means applies during and after the casting operation. If the addition of coal dust is so effective for controlling the properties of green sand at elevated temperatures it is obvious that its application, or the application of carbonaceous matter in another form, might also be advantageous to dry-sand practice.

In the steelfoundry the question of the high-temperature properties of mould and core materials are of particular importance. From previous tests conducted with steelfoundry "compo," it is evident that this material is open to considerable improvement.

In this present Paper an effort has been made to indicate the effect of various additions to mould and core materials with the view of obtaining more suitable properties at elevated temperatures. An effort has been made to keep these additions within the realms of practical possibility and the Paper concludes with some remarks affecting foundry technique in relation to the main trend of the investigation. It is not pro-

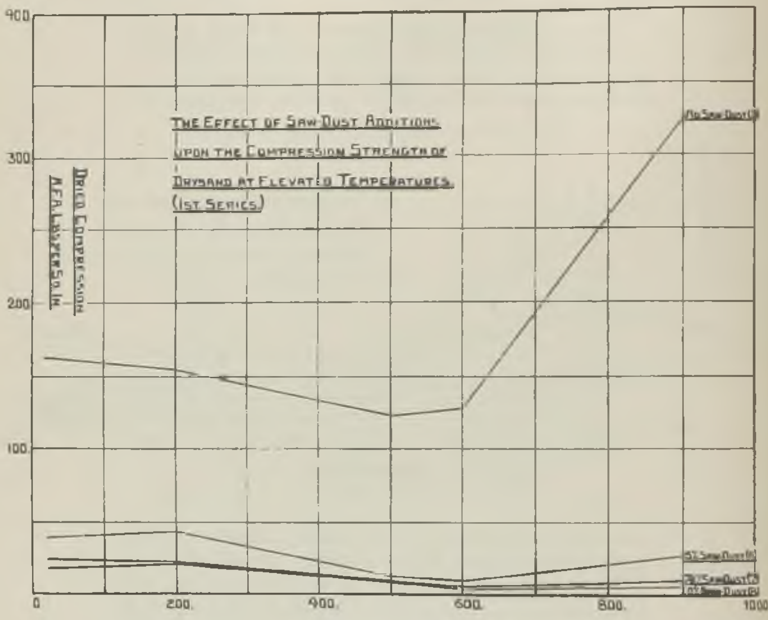



**Fig. 4.**

posed to describe the methods employed for test purposes as these are identical to those adopted for the original investigation and adequately outlined in the first Paper published. Furthermore, an effort has been made to keep to general remarks covering the trade as a whole rather than to deal with any particular branch.

In selecting the subject of the Paper it was

TABLE I.—*Effect of Coal Dust Additions upon the Properties of Dry Sand at Atmospheric Temperatures.*

| Mix. No. | Mixture composition. | App. den. | Per cent. moisture. | Compression strength. A.F.A. lbs. per sq. in. | | Permeability. A.F.A. No. | | Per cent. loss on ignition. |
|---|---|---|---|---|---|---|---|---|
| | | | | Green. | Dried. | Green. | Dried. | |
| 1. | 30 per cent. reclaimed oil-sand cores, 69.25 per cent. dry-sand floor sand, 0.75 per cent. bentonite, no coal dust. (Milled 5-10 mins.) .. .. | 1.69 | 8.0 | 4.6 | 128.5 | 61.5 | 87.0 | 4.77 |
| 2. | As above, plus 5 per cent. coal dust .. | 1.61 | 7.8 | 5.9 | 116.5 | 60.0 | 81.0 | 8.90 |
| 3. | As above, plus 7½ per cent. coal dust .. | 1.57 | 7.9 | 5.5 | 94.4 | 58.0 | 78.0 | 9.61 |
| 4. | As above, plus 10 per cent. coal dust .. | 1.52 | 7.5 | 5.3 | 73.6 | 44.0 | 59.0 | 12.62 |

felt that matter of fundamental nature was indicated, and obviously the effect of composition is a proper starting point. The question of density of ramming is not covered in the Paper, as this aspect is quite secondary. Furthermore, the author considers that any work on ramming control should be done by foundries for them-

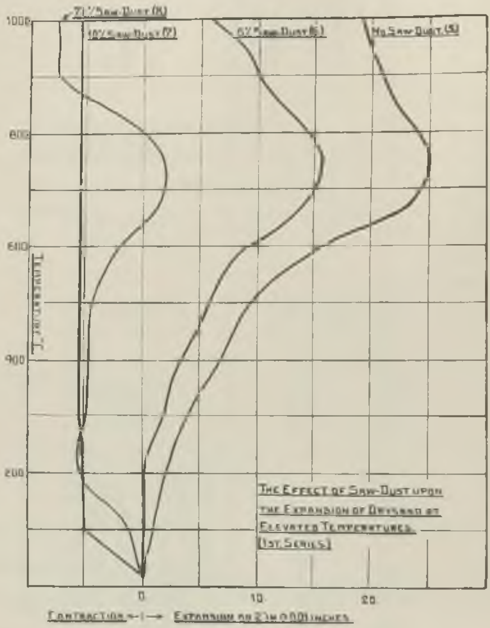



**Fig. 5.**

selves, as individual practice entails such a host of variables which mitigates the value of a general research on the subject. It is also problematical as to whether ramming control will ever become a scientifically-controlled operation common to the whole industry, and unless this can be arranged, any work on the subject is more or less without immediate practical application.

## APPERTAINING TO BRASS AND IRON FOUNDING

### The Effect of Coal Dust Additions

In order to investigate the effect of coal-dust additions upon the properties of mould and core-sand mixtures at elevated temperatures, the base mixture employed was of the dry-sand type. Dry sand was adopted as a base for the very

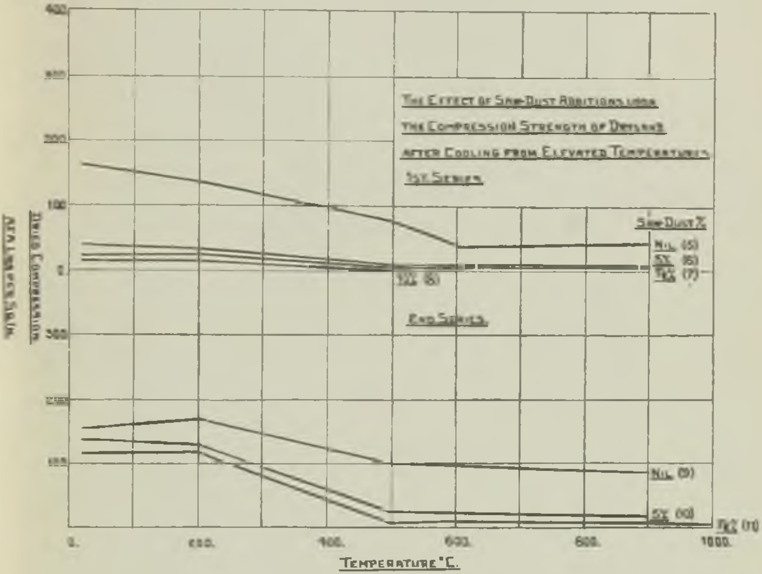



Fig. 6.

obvious reason that upon the addition of certain percentages of coal dust it automatically changes into the green-sand class, and consequently the final results obtained cover both types of sand.

Reference to Table I shows the sand mixtures employed and their physical properties at atmospheric temperature. It will be observed that the investigation covers the properties of an ordinary dry sand to which has been added 5, 7½ and 10 per cent. additions of a superfine coal dust containing around 35 per cent. volatile matter. At atmospheric temperature the effect of increasing additions of coal dust upon the physical properties of the sand under standard ramming conditions tends to:—

(1) Decrease the apparent density.

(2) Increase the green-compression strength. (There appears to be a certain percentage of coal dust which produces optimum green-compression strength. In this case the highest strength value was obtained with 5 per cent. coal-dust additions, and further additions caused a slight reduction in strength.)

(3) Decrease the dried-compression strength.

(4) Decrease the permeability in both the green and dried state.

(5) Increase the percentage loss on ignition or gas evolved.

The effect of the coal-dust additions upon the properties of the sand mixtures at elevated temperatures is shown in Figs. 1, 2 and 3. Considering Fig. 1 first, it will be noticed that the addition of coal dust to dry sand most markedly prevents the large increase in dried-compression strength common to many mould and core compositions. The dry-sand base mixture employed, relatively free from coal dust, has a dried-compression strength value of 640 lbs. per sq. in. at 900 deg. C. Upon the addition of 5 per cent. coal dust this figure is reduced down to 160 lbs. per sq. in. and then subsequently down to 112 and 54 lbs. per sq. in., with 7½ and 10 per cent. additions respectively.

Similarly, the addition of coal dust reduces the total expansion of the sand at 1,000 deg. C., as indicated in Fig. 2, from 0.152 in. per ft. down to 0.128 in., and also promotes easier removal of the sand after the casting operation has been completed, as shown in Fig. 3.

In view of these results, it is suggested that the addition of coal dust to dry-sand mixtures will impart superior physical properties to the sand at elevated temperatures. Its addition will prevent the large increase in strength common to many sands when heated, and this will undoubtedly promote safer casting production. At the same time, fettling costs will be reduced considerably. The effect of coal dust upon the expansion of mould and core materials is perhaps disappointing, and its action in decreasing the

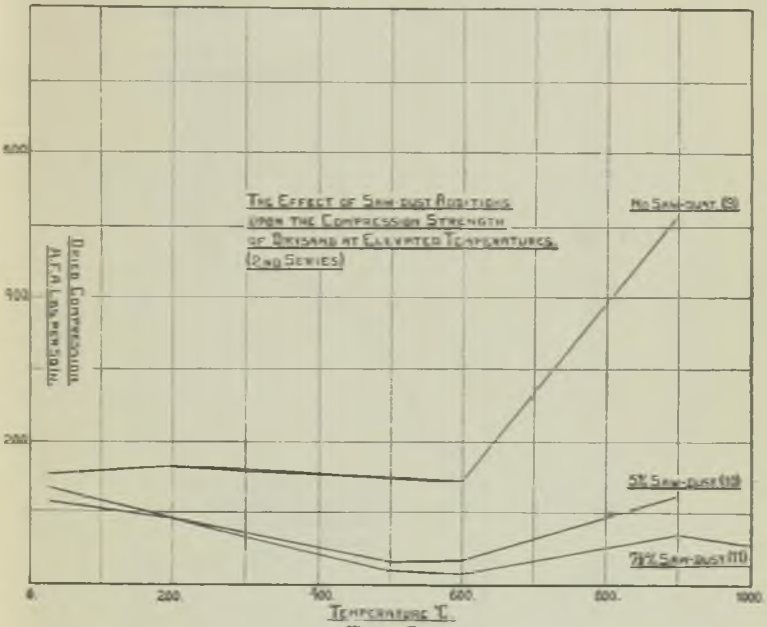



Fig. 7.

permeability, in conjunction with an increase in gas evolution, warrants care being taken in this direction. In an attempt to overcome these latter deficiencies further additions were tried, and the most likely appeared to be sawdust.

### Effect of Sawdust Additions

The tests previously described were repeated, substituting sawdust for the coal dust, and the properties at atmospheric temperature of the mixtures produced are shown in Table II. It will be observed that the effect of sawdust upon a dry-sand mixture under constant ramming conditions causes:—

(1) Large decrease in apparent density.

(2) Decreases the green compression strength.

(3) Large decrease in dried compression strength.

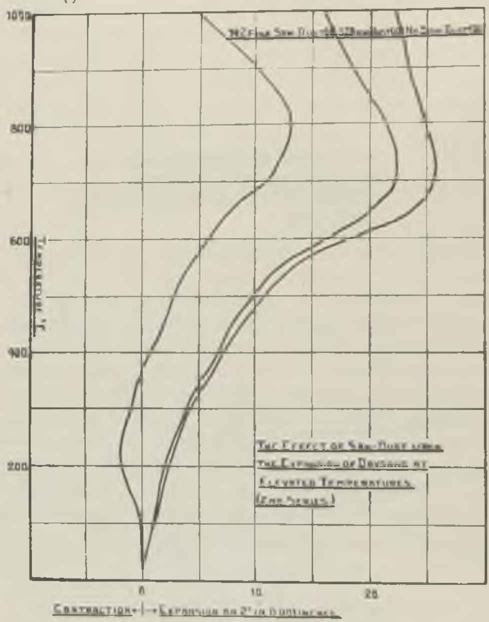



Fig. 8.

(4) Increases the permeability in both the green and dried state.

(5) Increases the percentage loss on ignition or gas evolved.

The outstanding characteristics in the sawdust-bearing sand over the coal-dust additions, so far as the properties at atmospheric tempera-

TABLE II.—*Effect of Sawdust Additions upon the Properties of Dry Sand at Atmospheric Temperatures.*

| Mix No. | Mixture composition. | App. den. | Per cent. moisture. | Compression strength. A.F.A. lbs. per sq. in. | | Permeability. A.F.A. No. | | Per cent. loss on ignition. |
|---|---|---|---|---|---|---|---|---|
| | | | | Green. | Dried. | Green. | Dried. | |
| | *1st Series.* | | | | | | | |
| 5. | 30 per cent. reclaimed oil-sand cores, 69.25 per cent. dry-sand floor sand, 0.75 per cent. bentonite, no sawdust. (Milled 5-10 mins.) .. .. .. | 1.68 | 7.6 | 4.5 | 163.2 | 57.0 | 72.0 | 4.76 |
| 6. | As above, plus 5 per cent. sawdust .. | 1.46 | 9.1 | 3.6 | 40.0 | 73.0 | 118.0 | 8.11 |
| 7. | As above, plus 7½ per cent. sawdust .. | 1.38 | 9.4 | 3.9 | 24.0 | 69.0 | 130.0 | 10.13 |
| 8. | As above, plus 10 per cent. sawdust .. | 1.31 | 10.2 | 3.5 | 17.6 | 73.0 | 140.0 | 13.54 |
| | *2nd Series.* | | | | | | | |
| 9. | 30 per cent. reclaimed oil-sand cores, 69.25 per cent. dry-sand floor sand, 0.75 per cent. bentonite, no sawdust. (Milled 5-10 min.) .. .. .. | 1.66 | 7.5 | 4.5 | 154.2 | — | 104.0 | 4.99 |
| 10. | 30 per cent. reclaimed oil-sand cores, 63.5 per cent. dry-sand floor sand, 1.5 per cent. bentonite, 5 per cent. coarse sawdust. (Milled 5-10 mins.) .. | 1.55 | 11.1 | 5.3 | 136.3 | — | 93.0 | 7.21 |
| 11. | 30 per cent. reclaimed oil-sand cores, 60.5 per cent. dry-sand floor sand, 2 per cent. bentonite, 7.5 per cent. fine sawdust. (Milled 10 mins.) .. | 1.51 | 15.7 | 4.2 | 115.2 | 34.0 | 119.0 | 9.30 |

*Note.*—Mixture No. 11 contained the sawdust in the form of wood flour. In all other cases ordinary patternshop waste product was employed.

tures are concerned, appear to be connected with dried compression strength and permeability. The addition of sawdust causes a much larger decrease in the dried strength than when coal dust is used, but produces a much more permeable sand. In view of the effect of sawdust in causing excessive reduction in dried strength, it is obvious that this aspect must receive further consideration which led to the investigation of a second series of sawdust-bearing sands containing extra bond. The mixtures and properties of this second series are also indicated in Table II. It will be observed that the increase in permeability is maintained in the dried state, although the green permeability value has been decreased, due to the additional bond. In this respect it is interesting to note that, in connection with mixture No. 11 containing 7½ per cent. fine sawdust, whilst the green permeability number was only 34 A.F.A., it increased to 119 on drying.

The effect of sawdust additions in respect to the properties at elevated temperatures are shown for the first series in Figs. 4, 5 and 6, and for the second series in Figs. 7, 8 and 6.

It will be observed that the additions of sawdust act in a similar manner to coal dust, preventing the large increase in strength on heating, and promote easier removal of the sand after casting. The most remarkable effect, however, is in connection with the problem of expansion. In this respect sawdust has a much greater action than coal dust, as it reduced the amount of expansion in Series No. 1 from 0.150 in. per ft. at 1,000 deg. C., progressively down to an actual contraction of 0.032 in. per ft. with the 10 per cent. addition. Even in Series No. 2, using the more heavily-bonded sand, the reduction in expansion was most marked.

It can consequently be concluded that sawdust additions impart better high-temperature characteristics to mould and core materials than does coal dust. In fact, mixture No. 11 has a particularly good range of properties both at

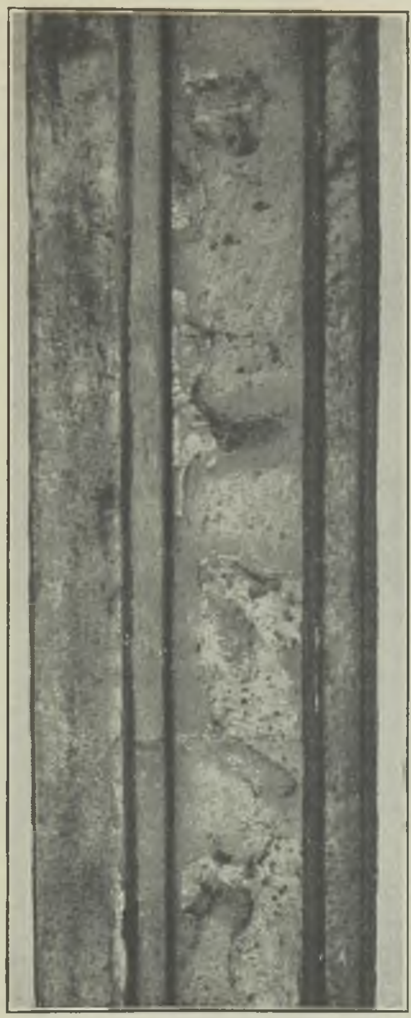


Fig. 9.—Typical Defects due to Sand Buckles from Core on Long Groove Casting.

atmospheric and elevated temperatures, and is very suitable for casting production in dry-sand moulds. Moulds made in such a sand will definitely tend to prevent the formation of buckles and surface scabs, minimise the tendency for cracked castings, and inherent strain, and also give extremely easy fettling conditions.

Further to the effect of coal-dust and sawdust additions upon the properties of mould and core materials at elevated temperatures, other materials were tried with entirely negative results. For example, the addition of blacking or crushed coke had no effect on any of the pro-

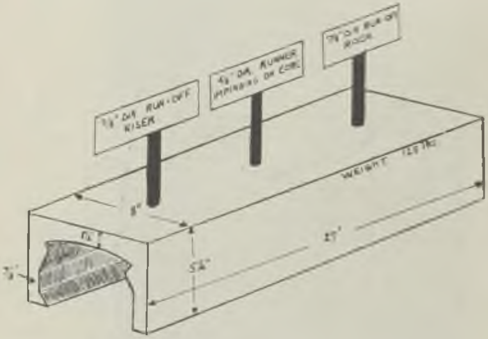
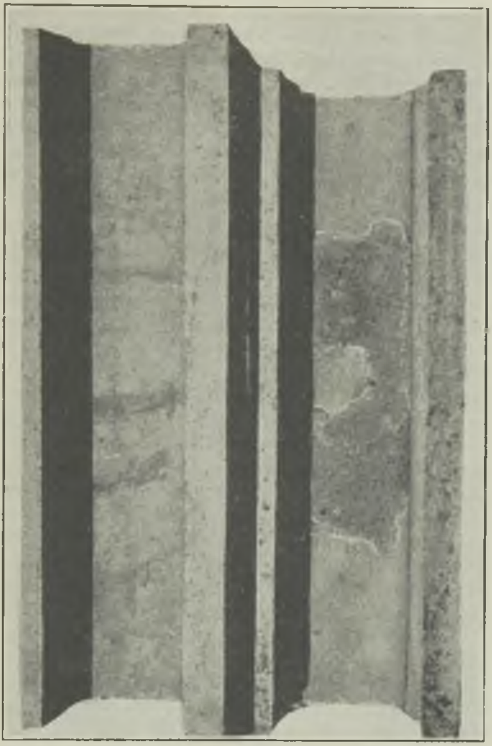



Fig. 10.—Sectional Drawing of Experimental Casting used to determine the Susceptibility of various Sand Mixtures to produce Buckles.

perties at high temperatures. The presence of volatile matter in the addition appears to be essential for the results obtained in this Paper, and apart from those additions investigated the only others likely to act in a similar capacity are horse manure, pitch, oil and cereal binders, etc. The effect of blacking additions are indicated by mixture No 16 (see Table IV and Figs. 12, 13 and 14). At the present stage of this investigation the author cannot give any logical explanation as to the reason for the effect of volatile matter in the direction stated.

The addition of sawdust to dry sand has long been a standard practice in many foundries, but its action has never been fully understood and



A B

Fig. 11.—Illustrating the Effect of using a Sand having Satisfactory Properties at Elevated Temperatures (A), against Material which has Unsuitable High-Temperature Characteristics (B), for Eliminating Sand Buckles on "Dumb Scabs."

it is hoped that the foregoing remarks may help to substantiate the value of this material as an addition to mould and coresand mixtures. There is no doubt whatsoever that as a preventive of buckles and surface scabs the use of sawdust is extremely beneficial. The author has contended for some time that these defects are essentially associated with the question of sand expansion, and a few remarks upon this question may be of interest. In the first case, from personal observation it has been noticed that these defects are most common when the following factors apply:—

(1) *Impingement of metal upon a localised area of mould or core.*—In many instances, castings have to be made when the position of the runner is such as unavoidably to produce the above condition. The likelihood of defects being produced is aggravated when the area exposed to the action remains uncovered by the rising metal in the mould until a late stage in the pouring operation. Furthermore, the higher the casting temperature the greater the risk.

(2) *The design of the casting.*—If the factors as outlined above are associated with mould and core designs leading to a convex surface, the chance of producing sand buckles is still further increased. Large rectangular mould and core surfaces are also most susceptible. In the case of long narrow surfaces such as arise in the production of columns, etc., the defects may occur along the casting length as shown in Fig. 9, whilst on broader sections the defect might possibly occur at the corners, or at such points where opposing expansion stresses meet.

In order to prove that sand expansion has an important bearing upon the production of the defects under review, experimental castings were made as shown in Fig. 10, incorporating a dry-sand core having a convex surface. Furthermore, in order to ensure the worst possible conditions the runner was allowed to impinge upon the centre of the core's convex surface and the pouring temperature was kept as high as possible—between 1,350 and 1,400 deg. C. In each mould the sand used for making the core varied, and the extent of the defects produced noted and recorded as shown in Table III. Those sands having a high coefficient of expansion, and which increased in strength on heating, buckled under the runner in every case, although the physical properties at atmospheric temperature were perfectly safe for casting production. Fig. 11 illustrates a comparison between test castings, showing in one case the core badly buckled under the runner, against a sound casting obtained by the use of a core sand having suitable high-temperature characteristics.

Many practical men attribute the cause of such defects as these to lack of permeability, moulds improperly dried, etc., and it is interesting to compare sands A and B in Table III in connection with the effect of permeability. It will be observed that sand B has a permeability figure of 177, which is high for ironfoundry practice, yet it scabbed just as badly as sand A with a permeability number of 87. In regard to the other factors common to the production of moulds, it might be mentioned that in this series of tests there was no doubt whatsoever about all the cores being dry, and, in regard to the question of ramming, it was found that in those sands susceptible to scabbing various ramming densities did not remove the trouble.

It is also interesting to note the results obtained with sand C containing about 4½ per cent. coal dust. This sand probably scabbed due to not enough coal dust being present to give the requisite high-temperature characteristics required by the conditions of test, although when 7½ per cent. coal dust was added satisfactory results were obtained. It is contended that the cause of surface scabs or buckles is due to the combined effects of expansion and increase of sand strength on heating, and any factor reducing either property will tend to eliminate the trouble. Complete prevention will ultimately depend principally on the design of casting, its

TABLE III.—*Effect of Composition of Mould and Core-Sand Mixtures in Relation to the Formation of Defects.*

| Type of sand. | Mixture. (All milled 5-10 min.). | Physical properties at atmospheric temperature. | | | | | Remarks. |
|---|---|---|---|---|---|---|---|
| | | App. den. | Per cent. moisture. | Compression strength. A.F.A. lbs. per sq. in. | | Dried permeability. No. A.F.A. | |
| | | | | Green. | Dried. | | |
| A. Ord. dry sand | 30 per cent. reclaimed oil-sand cores, 69.25 per cent. dry-sand floor sand, 0.75 per cent. bentonite | 1.69 | 8.0 | 4.6 | 128.5 | 87.0 | Core badly buckled under runner. |
| B. Ord. dry sand | 96 per cent. sea sand, 4 per cent. bentonite | 1.56 | 6.4 | 5.6 | 140.8 | 177.0 | Core badly buckled under runner. |
| C. Ord. green sand | 93.875 per cent. green-sand floor sand, 1.5 per cent. Scottish rotten rock, 4.5 per cent. coal dust, 0.125 per cent. liquid binder | 1.53 | 7.3 | 4.5 | 52.8 | 96.0 | Core badly buckled under runner. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| D. Dry sand containing 7½ per cent. coal dust | 30 per cent. reclaimed oil-sand cores, 61.75 per cent. dry-sand floor sand, 0.75 per cent. bentonite, 7.5 per cent. coal dust | 1.60 | 9.9 | 5.3 | 134.4 | 58.0 | Free from defects. |
| E. Dry sand containing 7½ per cent. sawdust | 30 per cent. reclaimed oil-sand cores, 60.7 per cent. dry-sand floor sand, 1.8 per cent. bentonite, 7.5 per cent. sawdust | 1.38 | 13.8 | 3.7 | 74.9 | 107.0 | Free from defects. |
| F. Dry sand made from crushed old firebricks | 97 per cent. crushed old firebricks, 3 per cent. bentonite | 1.68 | 11.0 | 5.4 | 233.6 | 69.0 | Free from defects. |
| G. Specially-developed sand for steelfounding (mix No. 19) | 89 per cent. crushed old firebricks, balance special mixture of solid and liquid bond plus expansion reducer | 1.55 | 18.4 | 4.0 | 141.8 | 97.0 | Free from defects. |
| H. Oil sand | 87 per cent. sea sand, 10 per cent. Scottish rotten rock, 3 per cent. semi-solid core binder | 1.46 | Trace | 1.0 | 997.4 | 190.0 | Free from defects. |

*Notes.*—In tests A, B, C, and H, the core was protected with ordinary foundry blackwash containing clay water, blacking and a little core-gum, as outlined in Table VI.

In tests D, E, F, and G, the core was protected with blackwash made from 5 parts water, 1 part proprietary binder and enough blacking to form a thin cream, as outlined in Table VI.

size, the position of the runners, pouring speed and the type of metal employed, and to ensure positive results the sand expansion must be reduced to an absolute minimum, whilst the compression strength at high temperatures must be the same or slightly lower than at atmospheric temperature. For steel-casting production the above statement is of particular importance, but some latitude can no doubt be allowed in the case of cast iron. In regard to oil sand H, although this sand has a fairly high degree of expansion, there is no increase of strength on heating, and consequently less chance of localised stresses being produced leading to fracture or buckling of the sand surface. On the other hand, there is a definite possibility of that portion of the oil-sand core underneath the runner being washed away by the metal, due to too rapid a strength decrease, and this must not be confused with the defects under review. In this particular case, the oil-sand mixture contained a considerable percentage of clay bond to minimise the decrease in strength consequent on heating and to prevent undue erosion by the metal stream.

## APPERTAINING TO STEEL FOUNDING

The Paper up to this point has dealt mainly with sands commonly used for the production of iron castings, but before concluding it would be advisable to comment upon the position in the steelfoundry. In the previous Paper* published by the author some tests were conducted at elevated temperatures upon steelfoundry "compo," and the results obtained were far from satisfactory. Consequently an attempt has been made to produce a superior material, using crushed old firebricks as a base. This material was selected in view of its low initial expansion on heating, and also because it is fairly readily obtainable in most foundries. Various additions were made to this base and moulding compositions produced having properties at atmospheric

* "Some Properties of Mould and Core Materials at Elevated Temperatures," FOUNDRY TRADE JOURNAL, December, 5, 1935.

**TABLE IV.**—*Moulding Composition made from a Base of Crushed Old Firebricks.*

| Mix No. | Mixture composition. | App. den. | Per cent. moisture. | Compression strength. A.F.A. lbs. per sq. in. | | Permeability. A.F.A. No. | | Per cent. loss on ignition. |
|---|---|---|---|---|---|---|---|---|
| | | | | Green. | Dried. | Green. | Dried. | |
| 12. | 96 per cent. crushed old firebricks, 4 per cent. bentonite .. .. .. .. | 1.66 | 11.9 | 4.9 | 150.4 | 304 | 501 | 0.86 |
| 13. | 95 per cent. crushed old firebricks, 4 per cent bentonite, 1 per cent. coal dust .. | 1.60 | 11.0 | 5.1 | 211.2 | 188 | 370 | 3.30 |
| 14. | As above, plus 5 per cent. coal dust .. | 1.51 | 10.9 | 5.1 | 176.0 | 242 | 377 | 6.55 |
| 15. | As above, plus 7½ per cent. coal dust .. | 1.51 | 11.2 | 5.9 | 214.4 | 197 | 313 | 8.15 |
| 16. | 91 per cent. crushed old firebricks, 4 per cent. bentonite, 5 per cent. blacking .. | 1.61 | 11.3 | 6.2 | 243.2 | 98 | 163 | 5.40 |
| 17. | 91 per cent. crushed old firebricks, 3 per cent. bentonite, 6 per cent. tar .. .. | 1.61 | 12.3 | 4.1 | 164.8 | 125 | 304 | 6.05 |
| 18. | 90 per cent. crushed old firebricks, balance special mixture of solid and liquid bond plus expansion reducer .. .. .. | 1.55 | 17.5 | 3.8 | 151.2 | 59 | 182 | 7.69 |
| 19. | 89 per cent. crushed old firebricks, otherwise similar to above .. .. .. .. | 1.55 | 18.4 | 4.0 | 141.8 | 30 | 97 | 8.96 |

*Note.*—The base of old dry crushed firebricks had the following preliminary treatment :—

*Mixture* 12.—All grades other than 20-30 mesh removed.

*Mixture* 19.—As crushed. No fines removed.

*Remainder.*—All fines passing 80 mesh removed.

The base material was then milled for 5 to 10 min. with additions.

temperature, shown in Table IV, whilst Figs. 12, 13 and 14 give some indication of the characteristics at elevated temperatures. The result of the research eventually produced mixtures Nos. 18 and 19, which the author considers have nearly ideal properties for casting production.

It will be observed that the effect of heat on mixture No. 18 results in practically no expansion, slight decrease in strength, and an extremely easy fettling operation. Mixtures Nos. 18 and 19 have been most thoroughly tested out in the ironfoundry under all conditions, with extremely satisfactory results, and at present mixture No. 18 is being tried out for steel-casting production. At the time of writing these tests are not completed, but no doubt some further information will be available when the Paper comes up for discussion. So far as one can see, however, mixture No. 18 should be particularly suited for the production of steel castings and superior to many of the moulding compositions at present in service. Table V summarises the main properties at elevated temperatures of the various mixtures covered by this Paper.

## APPERTAINING TO FOUNDING IN GENERAL

### Permeability and Mould and Core Protective Coatings

No investigations have been conducted relative to the effect of elevated temperatures upon the permeability of the various mixtures covered in this Paper in view of previous results obtained. In the first Paper* published it was clearly shown that the action of heat had very little effect upon the true permeability of mould and core compositions, and the apparent reduction in permeability was mainly due to the expansion of air inside the mould. The release of internal mould pressures caused by this factor is probably best catered for at the present time by suitably-placed risers and other artificial vents. This statement is made in view of the paucity of

* *Loc. cit.*

reliable information available relative to the action of protective washes employed in the production of castings in dry-sand moulds. There is a wide field of research open in this direction, and from investigations conducted by the writer it is indicated that the majority of foundrymen completely spoil the advantages likely to be

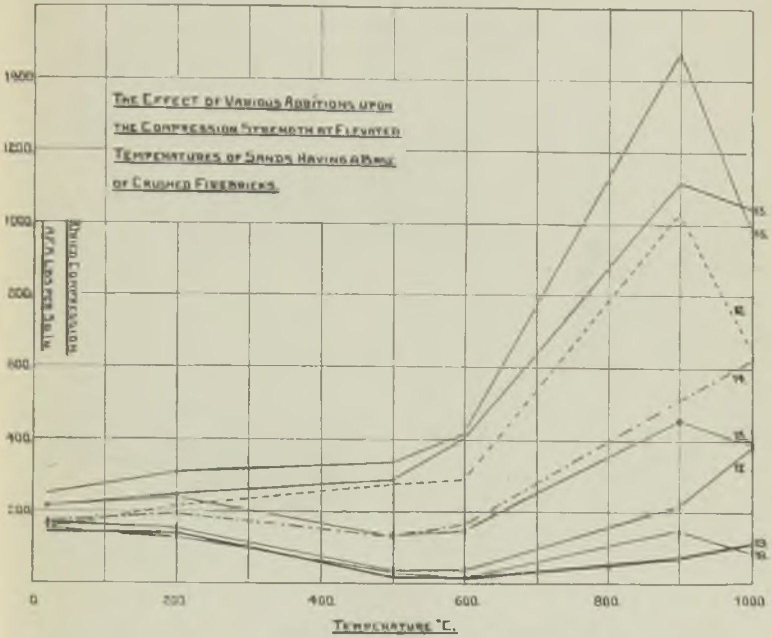



Fig. 12.

gained from the use of permeable sands by effectively sealing surface permeability through the use of unsuitable mould washes.

Actual tests conducted upon this problem are given in Table VI, from which it will be observed that the most commonly used protective wash, made from clay-water, blacking and core gum, reduces the effective mould or core permeability from an A.F.A. number of 84 down to 29.

This is by no means an exceptional result, as even lower values have been obtained. In one instance the author found a reduction in permeability from 85 down to 4.

The subject of this Paper does not permit further discussion of this aspect, but perhaps these few remarks will provide sufficient excuse

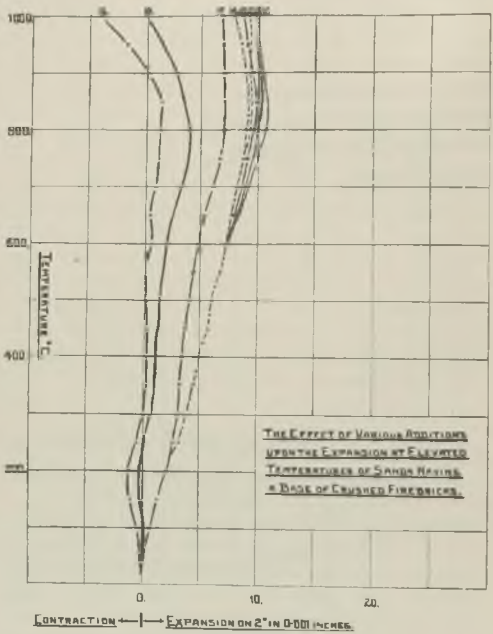



Fig. 13.

for the statement relative to the provision of adequate risers and artificial vents. If the full advantages of this Paper are to be utilised, embracing as it does the addition of gas-producing elements to dry-sand compositions, it is most important to employ a wash which does not reduce the surface permeability of mould and cores. The elimination of the clay in the protective wash, and its substitution by a liquid or oil binder in conjunction with the use of the thinnest possible coat, results in the desired results being obtained, as indicated in Table VI.

In all the practical results conducted in connection with this present work the special sand

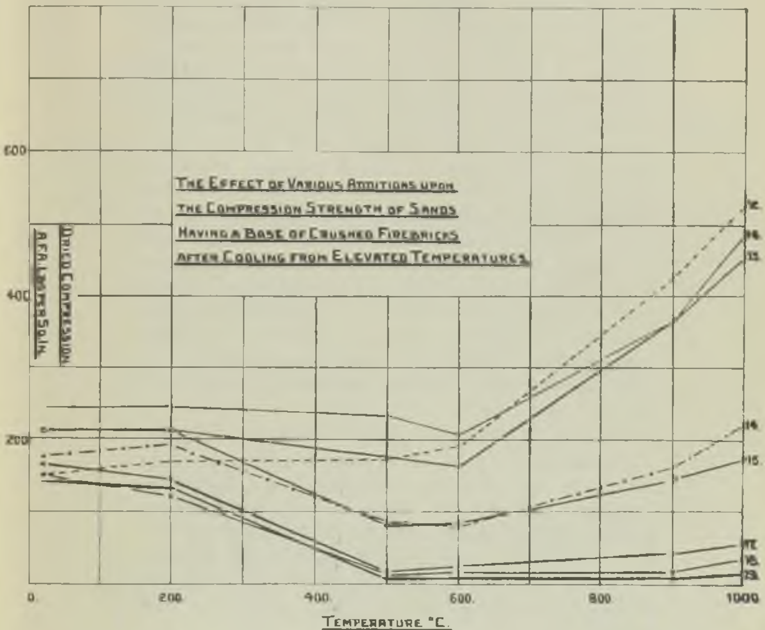



Fig. 14.

mixtures having satisfactory high-temperature properties were protected with washes which did not appreciably reduce their surface permeability. As a matter of interest it might be pertinent to mention that from the results so far obtained it has been found that a sand having an A.F.A. permeability number not under 100, together with a loss on ignition not exceeding 10 per cent., will not " blow " when handled with normal foundry technique, even for the largest dry-sand castings.

In conclusion, one final word of warning in connection with the use of mould and core washes apart from their effect on permeability. It will no doubt be appreciated that it is no good developing a mould or coresand mixture having satisfactory characteristics at elevated temperatures unless the protective wash has similar properties. The usual wash composed of blacking plus clay-water, with or without the addition of a little core gum, etc., may be unsuitable for service with sands having a low expansion, as the wash may have a much greater expansion than the sand, and flaking is then liable to occur. Satisfactory mould and core washes to operate with the mixtures outlined in this Paper must be, as previously mentioned, free from clay, and be composed preferably of a liquid or oil binder plus blacking, silica flour or any other protective medium employed. Such a mixture has high-temperature properties more approaching the base sands, has greater cohesion in the dried state, and does not tend to reduce the permeability so much as clay-bearing coatings.

The author desires to express his thanks to the directors of Messrs. Glenfield & Kennedy, Limited, and Mr. H. Gardner for permission to publish these results, and also to Mr. Lawrie, Mr. R. F. Hudson, and Mr. F. McCulloch for the valuable assistance received in conducting the various investigations in the foundry and laboratory.

## Summary

The main points brought out by this investigation can be summarised as follow:—

(1) Many of the mould and core compositions used in the foundry trade have unsuitable properties at elevated temperatures.

(2) These unsuitable properties are characterised by:—(*a*) Excessive expansion and (*b*) large increase in strength both on heating and cooling.

TABLE V.—*Summary of the More Important Properties at Elevated Temperatures of the Sand Mixtures Investigated.*

| Mixture No. | Total expansion per ft. on heating to 1,000 deg. C. | | Max. compression strength obtained. | |
|---|---|---|---|---|
| | In. | Per cent. | A.F.A. lbs. per sq. in. | Temp., deg. C. |
| No. 1. Dry sand | 0.152 | 1.27 | 640.0 | 900 |
| No. 2. Dry sand + 5 per cent. coal dust | 0.139 | 1.16 | 160.0 | 900 |
| No. 3. Dry sand + 7½ per cent. coal dust | 0.142 | 1.18 | 124.8 | 200 |
| No. 4. Dry sand + 10 per cent. coal dust | 0.128 | 1.07 | 83.2 | 200 |
| No. 5. Dry sand | 0.150 | 1.25 | 326.4 | 900 |
| No. 6. Dry sand + 5 per cent. sawdust | 0.094 | 0.78 | 44.8 | 200 |
| No. 7. Dry sand + 7½ per cent. sawdust | 0.010 | 0.08 | 24.0 | 20 |
| No. 8. Dry sand + 10 per cent. sawdust | Contraction. 0.032 | 0.27 | 20.8 | 200 |
| No. 9. Dry sand | 0.153 | 1.27 | 512.0 | 900 |
| No. 10. Dry sand + 5 per cent. sawdust | 0.133 | 1.10 | 136.3 | 20 |
| No. 11. Dry sand + 7½ per cent. sawdust | 0.078 | 0.65 | 115.2 | 20 |
| No. 12. Dry sand (made from firebricks) | 0.058 | 0.48 | 1,030.0 | 900 |
| No. 13. As above + 1 per cent. coal dust | 0.062 | 0.52 | 1,120.0 | 900 |
| No. 14. As above + 5 per cent. coal dust | 0.055 | 0.46 | 624.0 | 1,000 |
| No. 15. As above + 7½ per cent. coal dust | 0.059 | 0.49 | 448.0 | 900 |
| No. 16. As above + 5 per cent. blacking | 0.065 | 0.54 | 1,472.0 | 900 |
| No. 17. As above + 6 per cent. tar | 0.042 | 0.35 | 384.0 | 1,000 |
| No. 18. Specially-developed sand for steelfounding | 0.009 | 0.07 | 151.2 | 20 |
| No. 19. Specially-developed sand for steelfounding | 0.023 | 0.19 | 141.8 | 20 |

(3) Such properties are detrimental to the production of sound castings as they cause:—(*a*) Surface "scabs" and sand "buckles"; (*b*) cracks, strains and inherent stresses; (*c*) hot tears and "pulls," and (*d*) dimensional inaccuracies between casting and pattern.

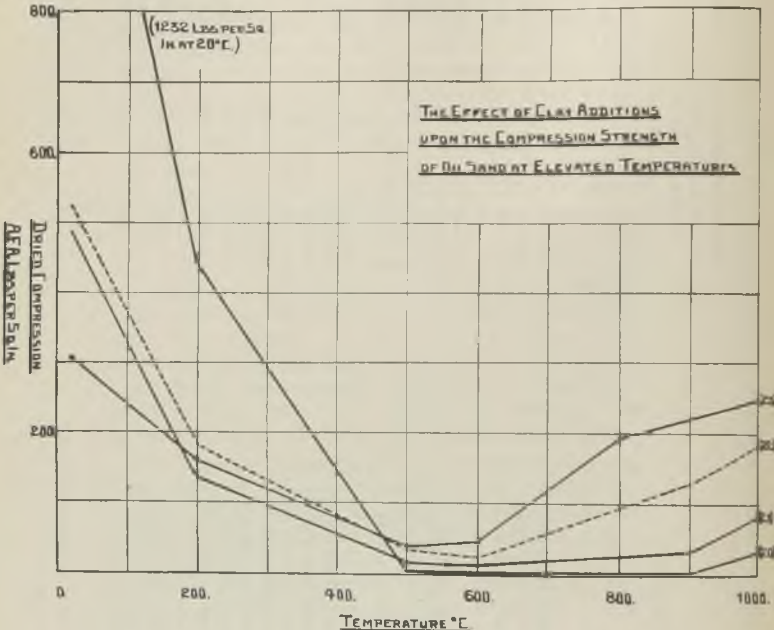



**Fig. 15.**

(4) By the use of suitable sand mixtures the three points stated above can be corrected. The results obtained indicate that a certain coal-dust addition imparts the necessary properties at elevated temperature to green sand. Sawdust additions are most satisfactory for dry sand and loam. In the case of brass and ironfoundry practice the above additions can be made to the existing base sand providing it has a suitable degree

TABLE VI.—*The Effect of Protective Washes.*

Base sand used : Special dry sand containing $7\frac{1}{2}$ per cent. sawdust.

| Treatment. | App. den. | Per cent. moisture. | Compression strength. A.F.A. lbs. per sq. in. | | Dried permeability. A.F.A. No. |
|---|---|---|---|---|---|
| | | | Green. | Dried. | |
| Without protective wash | 1.44 | 14.4 | 5.3 | 74.5 | 84 |
| Usual foundry blackwash, 40 galls. clay water, 224 lbs. blacking, 9 lbs. dextrine or core-gum | 1.44 | 14.4 | 5.3 | 73.6 | 29 |
| Oil wash, 5 parts water, 1 part proprietary binder, enough blacking to form a thin cream | 1.44 | 14.4 | 5.3 | 73.6 | 58 |
| Special wash developed by G. & K. | 1.44 | 14.4 | 5.3 | 60.8 | 89 |
| Base sand used : Normal dry sand. | | | | | |
| Without protective wash | 1.75 | 9.0 | 5.2 | 176.0 | 85 |
| Usual foundry blackwash : | | | | | |
| Wash applied by operator A | 1.75 | 9.0 | 5.2 | 148.2 | 5 |
| ,, ,, B | 1.75 | 9.0 | 5.2 | 131.8 | 5 |
| ,, ,, C | 1.75 | 9.0 | 5.2 | 129.6 | 4 |

of permeability and is controlled by routine sand tests. The use of synthetic clay and liquid binders are strongly advised as a means for assisting control. Oil sand is also capable of giving good service when casting design permits. In connection with steelfoundry practice the above also applies, except it is preferable to

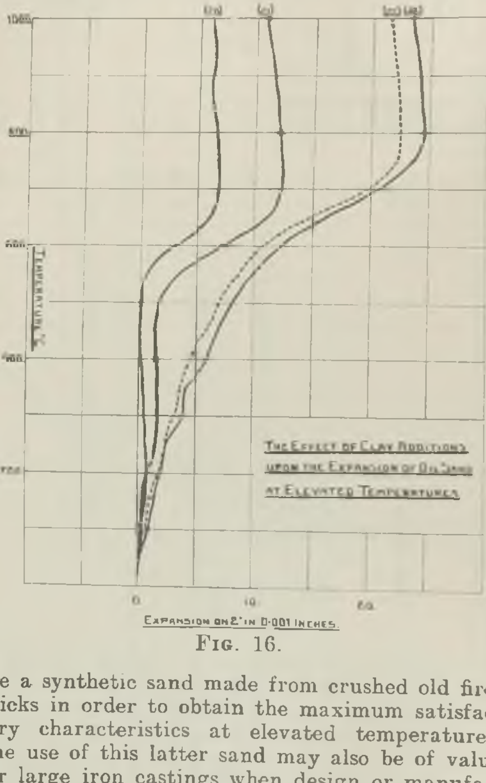



Fig. 16.

use a synthetic sand made from crushed old firebricks in order to obtain the maximum satisfactory characteristics at elevated temperatures. The use of this latter sand may also be of value for large iron castings when design or manufacturing methods warrant its use. The Paper also indicates the effect of other materials which can be alternatively added to promote better properties at elevated temperatures.

TABLE VII.—*Effect of Clay Additions upon the Properties of Oil Sand at Atmospheric Temperatures.*

| Mix. No. | Mixture composition. | App. density. | Per cent. moisture. | Compression strength, A.F.A. lbs. per sq. in. | | Permeability A.F.A. No. Dried. | Per cent. loss on ignition. |
|---|---|---|---|---|---|---|---|
| | | | | Green. | Dried. | | |
| 20 | 97 per cent. dry sea sand, 3 per cent. linseed oil (raw), little water (milled 5 min.) .. .. | 1.58 | 3.9 | 0.74 | 1,232 | 154 | 4.05 |
| 21 | As above, plus 1 per cent. bentonite .. .. .. | 1.55 | 4.6 | 1.3 | 488 | 147 | 4.09 |
| 22 | As above, plus 2 per cent. bentonite .. .. .. | 1.53 | 5.4 | 1.8 | 524 | 149 | 4.12 |
| 23 | As above, plus 3 per cent. bentonite .. .. .. | 1.53 | 4.8 | 3.1 | 307.2 | 152 | 4.30 |

NOTE.—Test cores dried for 1½ hrs. at 300 deg. F.

(5) To obtain the full benefits of these special mixtures the protective wash used must have similar properties at elevated temperatures as the base sand. The majority of protective coatings at present in service are not satisfactory and it is considered that a simple mixture of some liquid or oil binder plus blacking, etc., is preferable to washes containing clay.

(6) In regard to permeability of the sand, this is indirectly affected by the action of heat, due to the expansion of air inside the mould, and the pressure so generated is best relieved by adequate risers and artificial vents. At the same time it is advisable to use permeable sands, provided the protective coating employed does not reduce the permeability to any appreciable extent.

(7) The results obtained indicate the need of further research in at least two directions:—(*a*) Effect of composition on the properties of oil-sand mixtures at elevated temperatures; (*b*) effect of composition on the properties of mould and core protective washes at atmospheric and elevated temperatures.

## APPENDIX

### Effect of Clay Additions upon the Properties of Oil Sand at Elevated Temperatures

Since these experiments were made, further tests have been completed on the effect of clay additions upon the properties of oil sand at elevated temperatures, and in view of the interesting results obtained it was decided to offer them as an appendix.

Table VII indicates the sand mixtures employed and their respective properties at atmospheric temperatures.

Figs. 15, 16 and 17 show the results obtained at elevated temperatures and Table VIII gives a summary of the more important properties as a continuation of Table V. Perhaps the most striking point of interest is in connection with the effect of clay upon the expansion of oil sand. In many instances it has been found necessary in practice to incorporate a certain percentage of clay or bonded sand in oil-sand mixtures for reasons connected with the type of castings being made and other production requirements. It will be observed that the straight sea sand-oil mixture has quite a low expansion on heating, but this is most markedly increased by the addition of clay. The reason for this is quite obviously connected

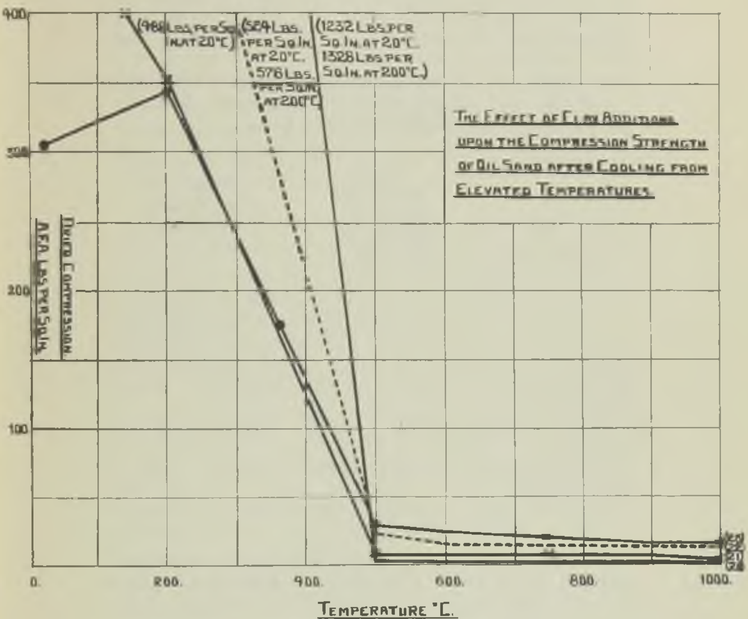



Fig. 17.

with the fact that a sand having its grains bonded with oil alone is unstable at high temperatures, and it is highly probable that the removal, or partial removal, of the organic bond will cause a contraction to offset the expansion of the silica grains themselves. The addition of clay will tend to prevent this contraction taking place and the expansion of each grain of sand will consequently be transmitted to the whole mass.

The effect of clay additions upon the compression strength, both at temperature and on cooling from temperature, are of interest in consideration with the other data given. Probably the point of most value shown by these later tests is the omission by the author to include the effect of clay, as applied to ordinary mould and core compositions, in this Paper. As is usually the

TABLE VIII.—*Summary of the More Important Properties at Elevated Temperatures in Connection with the Effect of Clay Additions to Oil Sand.*

| Mixture No. | Total expansion per ft. on heating to 1,000 deg. C. | | Max. compression strength obtained. | |
|---|---|---|---|---|
| | In. | Per cent. | A.F.A. lbs. per sq. in. | Temp. deg. C. |
| 20 Oil sand | 0.040 | 0.33 | 1,232.0 | 20 |
| 21 Oil sand—1 per cent. clay | 0.074 | 0.615 | 488.0 | 20 |
| 22 Oil sand—2 per cent. clay | 0.135 | 1.125 | 524.0 | 20 |
| 23 Oil sand—3 per cent. clay | 0.147 | 1.225 | 307.2 | 20 |

case, one is apt to overlook the obvious, but this point is well worthy of attention. However, there is no doubt that the text of this Paper will receive greater future consideration by all those who investigate and study the subject of foundry sands, and the author confidently looks forward to not only seeing confirmation of these results, but also to the correction of any omissions there may be.

## DISCUSSION

MR. HUDSON, in a few introductory remarks, explained that the practical trial of sands 18 and 19 for the production of steel casting had shown considerable promise. Through the courtesy of Mr. J. Currie and the Carntyne Steel Castings Company, Limited, mixture 18 had been tried out on a small scale and the following report had been received:—

> "The conclusion to be drawn from these tests would seem to be that the sand is suitable for steel moulding, having definitely improved properties over ordinary moulding sand for the prevention of hot cracks or tears, etc., but further work will have to be carried out in order to produce a surface skin satisfactory for commercial practice."

It should be appreciated that sand No. 18 was very open and inclined to be of a coarse grain like "compo," and this did not assist the production of a good casting finish. The protective wash used was silica-molasses. He expressly desired this sand to be tested first in view of its containing a fairly large percentage of organic matter in order to see if any "blowing" occurred. No disturbance of any kind was apparent during the pouring operations, so it was decided to conduct further practical tests with the less permeable sand, No. 19. These tests were carried out through the courtesy of Mr. J. M. Menzies of the North British Steel Company, Limited, and the finish on the castings produced was considerably improved. He had a photograph (Fig. 18) of one of the test castings made, a half diesel-engine bearing, after sand blasting only, and it would be agreed that the finish was within commercial practice. In fact, he did not think it would be presumptuous to say that he had seen steel castings produced with a worse finish than this. It might be pointed out that the section of the casting was from 2 to 2½ in., and the protective wash was the normal one used in the foundry referred to. The mould cast perfectly quietly. It might also be of interest to mention that the steel in this latter test was converter steel, whilst the first was from the open-hearth furnace.

It was proposed to conduct further tests in connection with steel casting finishes, particularly taking into account the part played by protective washes as well as the sand employed, but from these few remarks it was evident that the findings in the Paper could be applied to the production of steel castings. In connection with the question of protective washes he would like to make it quite clear that any general remarks he had made in the pre-printed Paper were not intended to apply to the steel-founder. Mr. Hudson, in conclusion, expressed his thanks to the Carntyne Steel Castings Company and the North British Steel Company, for their co-operation.

### Saw-dust and Horse Manure

Mr. J. J. McClelland said he would like to compliment Mr. Hudson on his Paper. It appeared to be a very interesting and useful one, but he would like to take some exception to the author's remarks upon the subject of the use of saw-dust. Mr. Hudson had stated that the addition of saw-dust to dry sand had long been a standard practice, but its action had never been fully understood. The speaker could hardly agree with that statement. Whilst there might be some volatile influence from saw-dust, it had nearly always been his experience that saw-dust had not been used for its volatile properties particularly, but more from the permeability point of view. Mr. Hudson had also said horse manure could be used, but, in these days of increased mechanical transport horse manure was getting rather scarce, and he would like to ask if Mr. Hudson had ever known of fine chopped straw or hay being used in localities where horse manure and even saw-dust were unobtainable. He would also like to ask Mr. Hudson if the addition of blacking as a mixture in the sand, in addition to coal-dust, was beneficial in special cases.

Mr. Hudson, in reply, thanked Mr. McClelland for his remarks. He agreed that saw-dust had a very definite action in regard to permeability but he did not mention that fact in view of the title of the Paper. The effect of saw-dust on permeability, according to Mr. McClelland's

Fig. 18.

argument, might not apply at high temperature. He had also heard of chopped straw and hay being used, but that of course was similar, in his mind, to saw-dust or manure. He did not think the passage of time would cause us to be bothered by the absence of horse manure, because one might use, for instance, old rubber tyres in certain applications. In regard to blacking, he had seen many mixtures used embodying a certain amount of blacking in conjunction with coal-dust, and he thought it had definitely beneficial effects for castings of certain types, but for the average engineering founder he failed to see its full advantage. For ornamental work, it probably had a great advantage, and even for very heavy castings in as much as the presence of the blacking definitely prevented fusion of the sand and increased its refractory property. His own opinion, however, was that it was not necessary in a properly balanced sand mixture.

### Experimental Methods Queried

MR. A. SUTCLIFFE said, in reference to Figs. 9 and 11, that he thought it would be impossible to make such castings. A moulder receiving a job similar to Fig. 10 would imagine the foreman had "gone mad." He asked whether the core for this casting had been vented from the bottom, since this only was necessary as it was a dry sand core. He suggested that the runner was too small and had burnt the core where the surface was shown to be rough. He inquired whether the risers were "closed" or "open" during casting. He queried the desirability of having one runner only of $\frac{5}{8}$ in. diameter and two $\frac{7}{8}$ in. uncovered risers, wrongly situated. The job, he said, could have been cast green with a different system of running and the practical man attributed the cause of such defects as were experienced to poor running conditions. Referring to coal-dust in sand, he expressed the opinion that the whole question was best left to the practical foreman, and that the tendency was towards obsolescence in company with such things as road sand, stale beer and horse manure. For castings up to 1 ton in weight they could be moulded in green sand containing no coal-dust and they could be cast the same day. The resulting castings would be greyer than usual, but personally he preferred that type of finish to a mirror one as denoting improved internal soundness. Mr. Sutcliffe suggested that such castings as tank plates twelve feet long by six feet wide having a ⅝ in. thickness of metal and gutters up to twenty foot long, two inches wide and eight to ten inches deep carrying a half-inch section of metal, moulded in green sand and cast the same day constituted the best test for sand. Finally, he asked if camel hair brushes did not rapidly deteriorate when used with oil in wet blacking.

Mr. Hudson, in replying, said in regard to Fig. 10 that he was sorry that Mr. Sutcliffe had not had an opportunity of making these castings, because then he might not have been so keen on saying that he did not know how the defects were produced. Mr. Hudson admitted he had picked the worst examples he could find to illustrate the Paper.

### Too Many Variables

Mr. Robert Ballantine said Mr. Hudson was to be congratulated once more on his very fine work on sands. He had the feeling, however, that Mr. Hudson was moving somewhat rapidly in his deductions, and consequently he would rather see what he might describe as established fundamentals in sand practice before elaborating on the results of innumerable tests. He thought the definition "floor sand" was not convincing, and when one bore in mind that, in various mixtures, close on 70 per cent. was used, one naturally asked what the composition was. Another point was that he could not feel too happy on this juggling with the moisture content. The range, from traces to 18.4 per cent., did not impress him. If convincing data were their aim, then they could only build from a sure foundation by eliminating the variables one at a time. He readily agreed that the subject of the Paper caused some concern, but at the same time the problem was not a major one in the production of good castings.

He was sorry that Mr. Hudson had thought fit to include coal-dust, saw-dust, horse manure, etc., in tests, because it appeared to him that this was a retrograde step. For some considerable period he had observed the results in the production of thousands of tons of flawless ingot mould castings, ranging from 2 to 40 tons in weight, all made in dry sand. The metal thickness ranged from 3 inches to 16 inches, and there were many designs. The core sand was strictly controlled in a modern plant, good-quality Scottish rotten-rock sand was the basis, and a ratio of five reclaimed core sand to one of new was used. The fines were removed, the milling time was five minutes, and moisture content was controlled at 6 per cent. Nothing else was added except ashes in the centre. Internal core barrels were neither used, nor was sprigging allowed, and only a minimum of horizontal gratings of very light section was included. Two types of cores might be quoted, namely: (1) a duodecagonal fluted core, standing 11 ft. 6 in. high, top heavy at 3 ft. 2 in. diameter tapering to 2 ft. 9 in. at the bottom; the approximate weight of sand in the green state was 3 tons 5 cwts. and this had to stand up to a 26-ton casting; (2) a rectangular core 9 ft. high, top heavy at 5 ft. 6 in. by 3 ft. 6 in. as against a bottom size of 5 ft. 5 in. by 2 ft. 10 ins.; the sand weight in the green state was 3 tons 15 cwts. and produced a 34-ton casting. In finishing, the blackwash was liberally applied, fully one-sixteenth of an inch. Thick clay was dried and mechanically pulverised, and then added in powdered form to the mixture. By these methods consistency was assured, and scabbing of the cores was practically unknown. Mr. Hudson had assured them in reference to Fig. 10 that there was no question whatever about the cores being dried, but had he considered the effect of overdrying on moulds and cores? The example in this instance was unquestionably one of proper gating. The sand question was all important, but his feeling was that they should move forward on something definite and not too involved. In conclusion, Mr. Ballantine felt that the branches should have an opportunity for further discussion on this Paper from a practical viewpoint, as in his opinion other factors must be considered.

Mr. Hudson, after thanking Mr. Ballantine for his remarks, said, to his mind, with due respect to Mr. Ballantine, ingot moulds were not a big question so far as casting production was concerned. When articles such as high-pressure castings, automobile castings, etc., were studied, the manufacture of ingot moulds was simple compared with some of these. He suggested that there was one fault in Mr. Ballantine's reasoning since all these factors were dependent on the human element, and perfection would never be attained as long as that very variable factor was present.

### Nebulous Criticism Criticised

Mr. Ben Hird said he thought the practical moulder should not be too hypercritical about a Paper he did not fully understand. It was of no use reading a Paper and then declaring "I never did this." Surely if one wanted to disprove a man's experiments, one ought to try them out, following his instructions, and then if they proved wrong, contradict him; but one should not contradict a new experiment simply because one thought it could not be applied to any particular job.

### Control of Thermal Conductivity

Mr. Adam Dunlop desired to know whether Mr. Hudson could suggest any modification to moulding material mixtures enabling the thermal conductivity to be controlled as it would be very useful to have this property under control. For example, the physical properties of gunmetal could be greatly enhanced by chill casting. It was not possible to chill-cast every job; therefore it would be advantageous if the thermal conductivity of the moulding sand could be increased. On the other hand, however, by reducing the thermal conductivity of the sand the casting of thin sections would be made easier.

Mr. Hudson indicated that he would require time to consider that question.

Mr. J. H. Cooper said he was deeply interested in the Paper, so much so that he was reluctantly compelled to say that he thought it was unfair both to the author of the Paper, and members present, to limit the time for discussing the Paper and in replying to the discussion.

Mr. C. H. Kain asked Mr. Hudson what method he employed for crushing his fire bricks. Could he give any indication of the degree of fineness to which he ground it?

Mr. Hudson replied that the bricks were crushed in a heavy pan mill. At first all material that passed an 80 mesh sieve was rejected. The first castings made in the steel foundry were made from that sand, and the finish was very bad. In the case of the second castings, they removed no fines, and the castings were fairly satisfactory.

## Origin of Organic Additions to Sand

Mr. J. E. Hurst (Past-President) proposed a vote of thanks to Mr. Hudson for his Paper. Regarding the reference to horse manure, he remarked that he once spent some time in endeavouring to find out who the first man was to use horse manure in moulding sand, and it was rather interesting, because the first record of making moulding sand in the commonly accepted manner amongst foundrymen of a few years ago, that is, from natural sands and horse manure, was due to Isaac Wilkinson, the father of John Wilkinson of cupola fame. In the Patent Journals they would find there a Patent.

dated about the year 1750, which was the first written record of the use of moulding sands of the type that were in use to-day.

The vote of thanks was heartily accorded, and Mr. Hudson replied.

## COMMUNICATIONS

### From Mr. J. Dearden

Perhaps the author would be good enough to enlighten us on the following questions:—

(1) Which is the better method for determining whether the proportion of coal dust in the sand circulating through a continuous sand-mixing plant is correct—loss on ignition or volume of gas evolved? Also, at what control figure should the coal dust be maintained for a uniform green sand?

(2) The use of sawdust for reducing expansion in dry sand is recommended in the Paper. Does this also apply to green sand, or is coal dust considered sufficient?

(3) Is fireclay regarded as being a satisfactory artificial bond to use for an iron moulding sand?

### Mr. Hudson's Reply

(1) The more practical method for determining the proportion of coal dust in the sand circulating through a continuous sand mixing plant is by loss on ignition. The control figure to be maintained will be principally dependent upon the permeability of the sand. In his practice he maintained a loss on ignition of approximately 9.5 per cent. with a green permeability number of 80 to 100. This gives very satisfactory results for general engineering castings. For ornamental castings or stove-plate work it is customary to use higher coal dust additions than this, together with lower permeability figures, when casting section permits.

(2) The observations in connection with sawdust for reducing expansion also definitely apply to green sand. In the production of many castings coal dust additions to green sand will pro-

duce satisfactory results, but for castings of certain design, particularly those mentioned in the Paper, it may be necessary to obtain the maximum reduction in expansion, in which case sawdust is recommended. The use of coal dust or sawdust will have to be determined by experience.

(3) It is not considered that fireclay is a satisfactory artificial bond to use for iron-moulding sand. Bentonite is to be preferred, as this gives a better bond distribution and is composed of practically 100 per cent. clay. On the other hand, the average fireclay contains only about 30 per cent. of effective bonding material. Under certain circumstances, fireclay could be used when only small bond additions are required. For example, it is personal practice to use Bentonite for bonding purposes in connection with the production of dry sand. In this connection, from $\frac{3}{4}$ to 1 per cent. is added. If the same practice were adopted for green sand production, it has been ascertained that it would be necessary to add only 0.125 per cent. of Bentonite to each batch, which, in personal opinion, is too small a quantity to permit an even distribution being obtained. In this latter case, recourse would be had to a bonded natural moulding sand or fireclay, and a correspondingly greater amount would be added in order to obtain an even distribution throughout the batch. The whole question raised also will depend upon the efficiency or otherwise of the mixing machines available.

### From Mr. J. Longden

Mr. Hudson has placed foundrymen in his debt by the presentation of valuable data upon the behaviour of sand in high temperature conditions. At the same time, he seems to attempt to reach certain general conclusions, of a practical character, which can hardly be substantiated by the data presented. "It is contended," he says, "that the cause of surface scabs or buckles is due to the combined effects of expansion and increase of sand strength on heating, and any factor reducing either property will tend to eliminate the trouble." The proof offered is the behaviour of a number of dry-sand cores with or without an admixture of coal dust or sawdust. He does not state whether all other conditions are equal; *i.e.*, whether all the cores were rammed by the same man, the venting was adequate and standard throughout, whether the moulds into which the cores were placed were green or dry, whether all the moulds stood for the same length of time before casting and whether in all cases care was taken, in pouring, not to pour straight down the runner but into a part of the basin away from the down-gate. Any variation in these things would affect the results.

In any case, his conclusion is too wide. Whilst it may be true that the high degree of expansion and strength of certain sand mixtures at high temperatures may conduce to scabs, it is quite fallacious to assume that the factors named are totally or even mainly to blame. Scabs are various and may be found writ large in green sand, where coal dust is an ever present factor. Where the act of scabbing can be watched visually (as when casting open-sand plates, etc.) it is always associated with an evolution of gas, *i.e.*, bubbling. Many kinds of scab can be eliminated by intelligent venting. Like patriotism, permeability is not enough. When a mould is filling with molten metal, gases are evolved very rapidly, and unless exit-conductor-channels (vents) are provided in sufficient quantity the gas pressure rises very quickly immediately behind the mould face, resulting in a detachment of part of that face—a scab.

Other scabs may appear where the rammer has been used too near the pattern, on a gagger placed too close to the face or too heavily clay-washed, or in any part of a drysand mould insufficiently dried. Buckles may appear under bars in the top-part of a green sand plate rammed on the jar-ramming machine. Here this part of the mould is softer than the rest. Scabs here can be eliminated by bringing up the hardness of the mould in the region of the bars to equal the rest. The fact that the same kind of thing can happen in the case of plates made in aluminium alloy and in which the moulds are hand rammed shows that the problem, in essence, is not bound up necessarily with high temperature conditions. I seriously doubt, therefore, if Mr. Hudson has found the nigger in the wood pile.

Finally, whilst one can agree that a blacking wash should preferably have a similar coefficient of expansion to that of the sand upon which it is used, why does Mr. Hudson insist that it should be equally permeable? He appears to suggest that mould gases should be exhausted into the mould cavity. This is fatal to the production of sound castings. In all cases, provision should be made for the exhaustion of mould or core gases in a direction away from the mould face, through the body of the mould and into the open air. To the writer, at any rate, the need for permeability in a blackwash does not appear.

## Mr. Hudson's Reply

Mr. J. Longden's remarks are particularly valuable and it should be clearly understood that any conclusions reached relative to the behaviour of mould and core materials at elevated temperatures, and the effect of the combined properties of expansion and increase of strength on heating on the resulting casting, are based on the title of the Paper, namely, *The Effect of Composition.* It is fully appreciated that many kinds of defects are dependent upon practical conditions, but the scope of the Paper was not intended to cover this aspect of the problem, but rather to indicate the effect of those properties directly connected with the composition of the mould or cores employed and the need for these properties to be taken into practical account as a possible cause of defective work in conjunction with those outlined by Mr. Longden.

It should also be understood that, in an investigation of this nature, every precaution was taken to ensure comparative conditions and one can be assured that the results given in Table III were obtained from moulds rammed by the same man, that venting was adequate and standard throughout, etc.

Mr. Longden's remarks are also of personal benefit as they give one innumerable excuses for future reference to return to the man who plucks up enough courage to try out some of the findings in the Paper and then turns round and blames the sand mixture employed for the defective casting produced.

In regard to the effect of black-wash coatings on permeability, perhaps Mr. Longden will refer to the author's previous Paper on the subject.* In this Paper some evidence is given indicating that the greatest amount of gas generated in the casting of a dry-sand mould may be due to the expansion of the air inside that mould and not generated from the mould materials themselves. This air should preferably be exhausted through the risers, but in certain instances it can be imagined that the risers employed may be inadequate and then a permeable mould surface will act as a natural safety valve. Secondly, whilst it is not suggested that actual mould gases should be exhausted into the mould cavity, it does not follow that such an occurrence is beyond practical accomplishment, and in this event there is more likelihood of a sound casting being obtained by the use of a permeable black-wash coating than the presence of pieces of the coating over the surface of the casting, a probability associated with high gas pressures and impermeable black-wash. However, in all fairness to Mr. Longden, it is personally considered that with our present knowledge on this subject one can make no dogmatic statements and we look to the future for enlightenment.

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* loc. cit.

# A STUDY OF THE INFLUENCE OF MANGANESE AND MOLYBDENUM ADDITIONS TO CAST IRON

By J. E. Hurst (Ex-President)

This investigation was undertaken with the primary object of studying the influence of additions of manganese and molybdenum conjointly to cast iron.

## Experimental Procedure

It was decided to study the effect of these conjoint additions when added to a cast iron of a basis composition of approximately total carbon 3.5 per cent. and silicon 1.0 per cent., and the procedure adopted in the preparation of the specimen was designed to maintain these two elements as nearly constant as possible, and to provide specimens with increasing quantities of molybdenum and manganese.

Three base pig-irons were prepared from a mixture of refined white pig-iron and ferro-alloys by melting in a cupola. The chemical composition of these base pig-irons is shown in Table I.

By melting together suitable proportions of pig-iron A and pig-iron B, a series of alloys of low-manganese content containing molybdenum from a trace up to approximately 3.5 per cent. was obtained. Three other series of seven alloys were prepared by melting together the requisite proportions of the three pig-irons and contained approximately 1.0, 2.0 and 2.75 per cent. of manganese respectively. The complete chemical analyses of the four series of specimens thus obtained are set out in full in Table II. The whole of these specimens were prepared by melting in a high-frequency electric furnace and in the case of each individual composition one star bar and one K test-bar was cast. The test-bars were all cast in green-sand moulds. The details of the star bar are given in Fig. 1, from which it will be noticed that the cylindrical portion of this bar was cast solid instead of in the form of a hollow cylinder, as is usual with this type of bar. The K test-bar conformed to the standard dimensions.* The testing procedure included the examination of the bars in the "as-cast" condition, the determination of the Brinell hardness

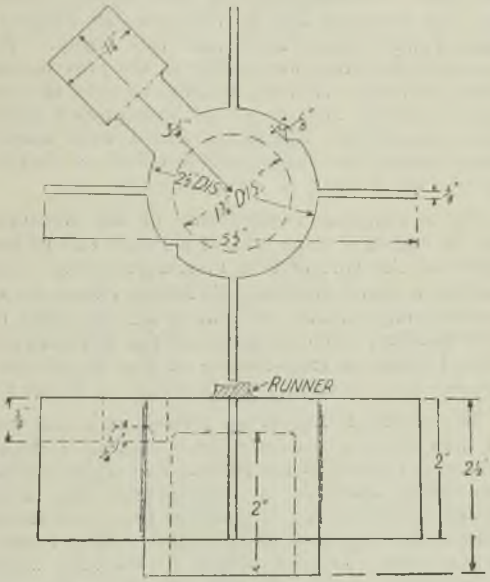


Fig. 1

and the examination of the microstructure. The cylindrical portions from the star test-bars were subjected to an annealing treatment at a temperature of 950 to 975 deg. C., soaked at the temperature for two hours and allowed to cool slowly with the furnace.

In the annealed condition the hardness was again determined, and test-rings machined from

* Cook and Hailstone, Journal of the Iron and Steel Institute, Carnegie Scholarship Memoirs, 1916.

the bars for testing in accordance with the procedure outlined in the author's previous Paper.* The microstructure of the annealed specimens were examined also. Brinell-hardness determinations were determined with a 10-mm. dia. ball and a 3,000-kilogramme load and the Firth diamond hardness using a 30-kilogramme load machine. No difficulty was experienced in casting the test-bars, and in all cases the alloys as melted were quite fluid and ran freely. No special precautions were taken in the provision of gates or feeder risers calculated to take care of any shrinkage and, as would be expected under these conditions, the alloys which were mostly hard showed the characteristic effects of shrinkage in the broken K test-bars.

For a complete examination of the fractures the K test-bars were broken through one of the limbs of the bar, and in almost every case this yielded a sound fracture, shrinkage effects being present only at the junction of all the limbs of this test-bar. The fractures of the test-bars obtained from an examination of the K test-bars are detailed alongside the analyses in Table II.

The specimen free from molybdenum and low in manganese was mostly grey, showing a slight tendency to chill at the corners and edges. With increasing amounts of molybdenum this 1-in. square section of the K test-bars becomes harder, passing through grey mottle up to 0.96 per cent. molybdenum, beyond which it becomes white throughout. With 1.00 per cent. approximately of manganese (Series 2) the fracture in the first specimen of the series was grey mottled, probably due to the presence of 0.32 per cent. of molybdenum. Again, beyond 1.00 per cent. molybdenum the fracture changes to completely white. On the basis of the fracture the increase in manganese appears to have made very little difference, but taking into consideration the slightly higher average total-carbon content, it is

* Proceedings of the Institute of British Foundrymen, 1930-31, p. 375, etc.

TABLE I.—*Composition of Base Pig-Irons.*

| | T.C. Per cent. | Si. Per cent. | Mn. Per cent. | S. Per cent. | P. Per cent. | Mo. Per cent. | Cr. Per cent. |
|---|---|---|---|---|---|---|---|
| Pig-iron A .. | 3.63 | 0.95 | 0.28 | 0.075 | 0.195 | Nil | 0.14 |
| „ B .. | 3.82 | 1.10 | 0.28 | 0.045 | 0.26 | 10.0 | 0.20 |
| „ C .. | 4.15 | 1.22 | 9.00 | 0.052 | 0.183 | Nil | 0.15 |

probably correct to say that the fractures show a slight tendency to increase in hardness.

In Series 3 with slightly over 2.0 per cent. of manganese it is clear, in spite of the presence of 0.32 per cent. molybdenum in the first specimen of the series, that there has been a pronounced increase in hardness of this fracture, and the whole of the K-bar fractures are white. With a still further increase in manganese to slightly over a mean value of 2.75 per cent. in Series 4, a still further increase in hardness of fracture is observed, the whole of the specimens being white throughout. It would appear, therefore, that in a cast iron of this composition, melted and cast in green-sand moulds under the conditions adopted in these experiments, the addition of increased amounts of molybdenum is accompanied by the tendency to produce a white fracture. With a low-manganese content of 0.25 per cent. the fracture becomes almost completely white on passing 1 per cent. of molybdenum, and with increasing quantities of manganese the tendency towards the production of a white fracture increases, and with 2.75 per cent. of this element a white fracture is obtained with 0.39 per cent. of molybdenum.

### Brinell Hardness "As-Cast" Condition

The hardness values in the "as-cast" condition were determined on the cross section of the cylindrical specimen from the star test bars. These at 2.5 in. dia. possessed a substantially larger cross-section than the K test bars. Determinations were made at the outside edge and centre of the area using a standard machine with a 10-mm. diameter ball and a 3,000 kg. load. At midway between the centre and outside edge of the specimens Firth diamond hardness readings were taken using a 30 kg. load with the diamond indenter. Owing to the presence of slight chill at the outside edges of some of the specimens, the hardness results at the outside position were somewhat irregular and only the results at the centre and

TABLE II.—*Analyses, Hardness and Fracture. "As-Cast" Condition.*

| Spec. No. | T.C. Per cent. | Si. Per cent. | S. Per cent. | P. Per cent. | Mn. Per cent. | Mo. Per cent. | Hardness as cast. | | Fracture as cast. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Centre Brinell. | Mean F.D.H. | |
| 1A .. | 3.34 | 0.87 | 0.059 | 0.19 | 0.26 | 0.02 | 248 | 285 | Grey. |
| 1B .. | 3.32 | 0.89 | 0.062 | 0.19 | 0.25 | 0.26 | 255 | 278 | Grey mottled. |
| 1C .. | 3.37 | 0.96 | 0.068 | 0.21 | 0.26 | 0.69 | 262 | 291 | Grey mottled. |
| 1D .. | 3.43 | 0.96 | 0.069 | 0.21 | 0.26 | 0.96 | 302 | 320 | Grey mottled. |
| 1E .. | 3.37 | 1.01 | 0.062 | 0.19 | 0.29 | 1.62 | 418 | 460 | Tick white. |
| 1F .. | 3.37 | 1.05 | 0.071 | 0.20 | 0.28 | 2.07 | 418 | 518 | White. |
| 1G .. | 3.37 | 1.17 | 0.044 | 0.20 | 0.28 | 3.45 | 512 | 627 | White. |
| 2B .. | 3.43 | 0.99 | 0.054 | 0.20 | 1.04 | 0.32 | 196 | 226 | Grey mottled. |
| 2C .. | 3.40 | 0.99 | 0.053 | 0.20 | 1.04 | 0.81 | — | — | Med. mottled. |
| 2D .. | 3.43 | 0.95 | 0.062 | 0.19 | 1.00 | 1.00 | 340 | 352 | Mottled. |
| 2E .. | 3.37 | 1.01 | 0.050 | 0.19 | 0.95 | 1.57 | 430 | 518 | White. |
| 2F .. | 3.40 | 1.01 | 0.055 | 0.19 | 0.98 | 2.17 | 418 | 534 | White. |
| 2G .. | 3.55 | 1.04 | 0.055 | 0.19 | 0.97 | 3.27 | 532 | 649 | White. |
| 3B .. | 3.60 | 0.99 | 0.034 | 0.19 | 2.14 | 0.32 | 302 | 460 | Hard mottled. |
| 3C .. | 3.49 | 1.03 | 0.038 | 0.19 | 2.23 | 0.70 | 512 | 518 | White. |
| 3D .. | 3.55 | 1.08 | 0.035 | 0.19 | 2.17 | 1.06 | 512 | 551 | White. |
| 3E .. | 3.49 | 1.17 | 0.025 | 0.20 | 2.16 | 1.49 | 532 | 627 | White. |
| 3F .. | 3.49 | 1.05 | 0.025 | 0.20 | 1.96 | 1.98 | 600 | 627 | White. |
| 3G .. | 3.55 | 1.03 | 0.015 | 0.20 | 2.22 | 2.61 | 652 | 774 | White. |
| 4A .. | 3.60 | 1.10 | 0.026 | 0.20 | 2.82 | 0.39 | 387 | 390 | White. |
| 4B .. | 3.61 | 1.10 | 0.022 | 0.21 | 2.65 | 0.76 | 512 | 551 | White. |
| 4C .. | 3.60 | 1.05 | 0.021 | 0.20 | 2.72 | 0.78 | 477 | 587 | White. |
| 4D .. | 3.68 | 1.08 | 0.020 | 0.21 | 2.86 | 0.91 | 600 | 627 | White. |
| 4E .. | 3.63 | 1.24 | 0.015 | 0.19 | 2.78 | 1.36 | 652 | 671 | White. |
| 4F .. | 3.71 | 1.05 | 0.010 | 0.19 | 2.83 | 1.82 | 713 | 719 | White. |
| 4G .. | 3.60 | 1.10 | 0.012 | 0.18 | 2.14 | 2.78 | 652 | 832 | White. |

the Firth diamond hardness results at the mean radius are given in Table II. In considering these results in detail it will be noticed in the low-manganese series (Series 1) that increasing quantities of molybdenum do not seriously affect the hardness up to 0.69 per cent. of this element. Beyond this, there is a tendency to increase with increasing percentages up to 3.45 per cent. molybdenum.

In the case of Series 2 containing approximately 1 per cent. manganese, the marked increase in hardness again begins with 1.00 per cent. molybdenum and a similar tendency to increase in hardness is shown with increasing quantities of this element. The hardness values are also generally at a slightly higher level. This is shown more clearly in the diagram Fig. 2. The same diagram shows clearly the substantially higher level of hardness values in Series 3, containing approximately 2.25 per cent. manganese, and in this series the increase of molybdenum to 0.70 per cent. is accompanied by a very marked increase in hardness value (in spite of the difference in total carbon content, to which reference will be made later). The Series No. 4, with a slightly higher manganese content only, shows a still higher level of hardness than Series 3, in the higher molybdenum-content members of this series, but as in all the other series, it will be noticed that increasing percentages of molybdenum bring about increase in hardness and that again 0.70 per cent. of this element is sufficient to bring about a substantial increase in hardness as in the case of Series 3, 2.23 per cent. manganese.

The effect of the slight increase in total carbon contents in each series must be taken into consideration. On the basis of the mean carbon contents, which are 3.37, 3.43, 3.53, and 3.63 per cent., respectively, there is a fairly uniform increment from series to series and it would be anticipated that whilst this would increase the tendency to greyness, it would also have an effect in increasing the general level of hardness in the white condition. Whilst this is true, the results contain ample evidence that the increment in hardness level is in the greater part due to the intrinsic effect of the manganese and molybdenum, and the conclusion that increasing percentages of manganese in conjunc-

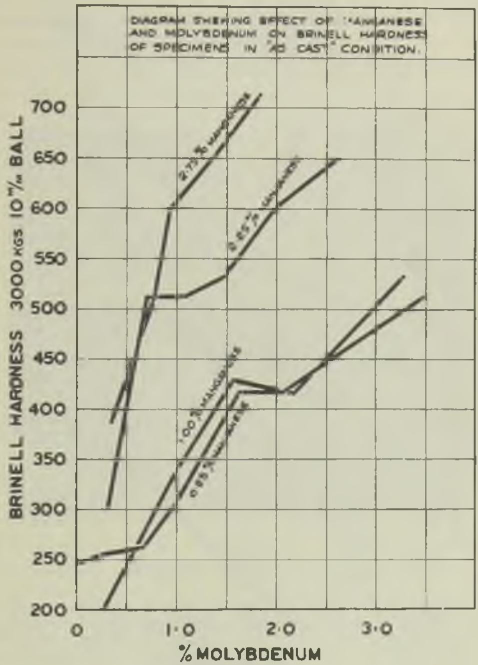


**Fig. 2.**

tion with molybdenum are accompanied by an increment in hardness within the limits of the percentages used in these experiments appears to be justified.

The following further conclusions are not affected by this consideration of the total carbon content, that increase in molybdenum for a given manganese content is accompanied by increase in hardness, and that with low manganese (0.25 per cent.) this effect of molybdenum is not very substantial until the percentage exceeds 0.70 per cent. In the higher manganese-content specimens, the increment in hardness takes place with

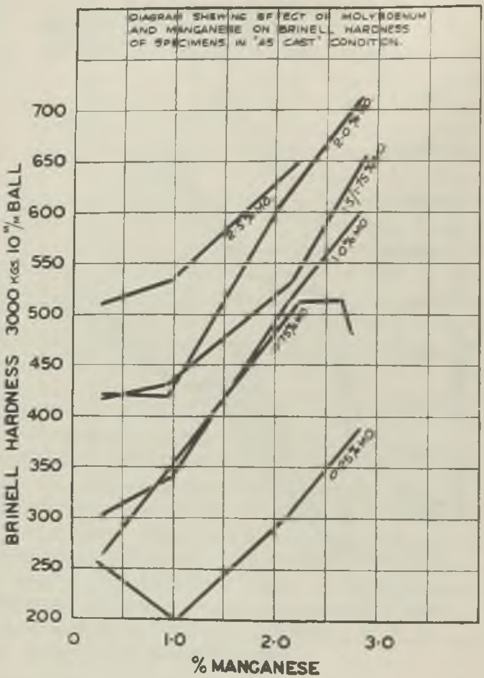


FIG. 3.

a similar molybdenum content and with 2.25 per cent. manganese an amount of 0.70 per cent. molybdenum brings about a substantial increase. This is demonstrated by replotting the results in the manner shown in Fig. 3, using the manganese percentages as the base. The marked increase in hardness begins with the 0.75 per cent. molybdenum curve.

The extremely high hardness values obtained in the specimens containing 2.25 per cent. and more manganese and over 1.00 per cent. molybdenum are deserving of special comment. Brinell hardness values of 600 and over are obtained. These high values are confirmed by the Firth diamond hardness test and it will not be overlooked that they are obtained at the centre of the 2.5 in. dia. specimen.

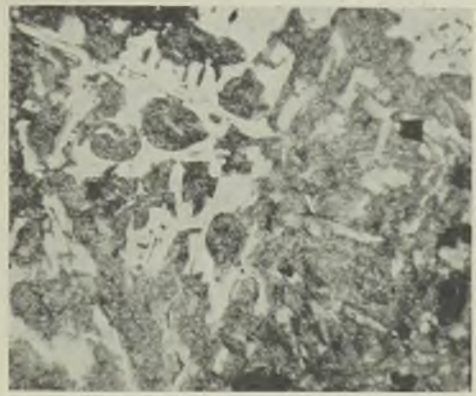

Fig. 4.—1A. As Cast. × 250 dias.
Etched Picric Acid.

The hardness results obtained at the edge and centre of the specimen are compared separately in Table III. The difference in the results in the low molybdenum-content members of the series is due to the presence of chill structure at the outside edge. In the higher members of the series the hardness becomes practically uniform across the section. Series 3 provides an excellent example of this observation.

## Microstructure of "As-Cast" Specimen

The microstructure of the "as-cast" samples has been studied by means of specimens taken from the K test bars. In all cases the specimens have been etched with picric acid and the specimens were examined at magnifications of 250 and 1,500 diameters respectively. The structures in the low manganese Series 1 consist of carbides and a pearlite background. The photographs of the specimens 1A and 1G at magnifications of 250 and 1,500 are illustrated in Figs. 4 to 7. Specimen 1A containing no

Fig. 5.—1A. As Cast. × 1,500 dias. Etched Picric Acid.

molybdenum shows the normal structure of carbides and pearlite and some graphite, and in 1G the increased quantity of carbides and the pearlite matrix is clearly shown. With the increased amount of manganese in Series 2 the carbides are still present and the matrix loses its marked pearlite character and a further constituent appears in the structure, increasing in amount with the amount of molybdenum present.

The photographs Figs. 8 and 9 at 1,500 diameters show specimens 2C and 2G, the greater part of the matrix in 2G being composed of this constituent. Figs. 10 to 13 show respectively

Table III.—*Brinell Hardness at the Outer Edge and Centre of the Specimens. "As-Cast" Condition.*

| Specimen No. | Hardness. Edge. | Hardness. Centre. | Specimen No. | Hardness. Edge. | Hardness. Centre. | Specimen No. | Hardness. Edge. | Hardness. Centre. | Specimen No. | Hardness. Edge. | Hardness. Centre. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A | 351 | 248 | — | — | — | — | — | — | 4A | 477 | 387 |
| 1B | 302 | 255 | 2B | 277 | 196 | 3B | 512 | 302 | 4B | 532 | 512 |
| 1C | — | 262 | 2C | — | — | 3C | 512 | 512 | 4C | — | 477 |
| 1D | 364 | 302 | 2D | 418 | 340 | 3D | 512 | 512 | 4D | 555 | 600 |
| 1E | 418 | 418 | 2E | — | 430 | 3E | 532 | 532 | 4E | — | 652 |
| 1F | 477 | 418 | 2F | 477 | 418 | 3F | 627 | 600 | 4F | — | 713 |
| 1G | 512 | 512 | 2G | 532 | 532 | 3G | 600 | 652 | 4G | 552 | 652 |

the specimens 3F and 4G. From an examination of 4G at 1,500 diameters almost the whole of the matrix appears to be martensitic and whilst not very clearly resolved in the photograph, the additional constituent in the various specimens appears to be martensitic in character. It appears therefore that the conjoint additions of molybdenum and manganese bring about the formation of a martensitic structure increasing

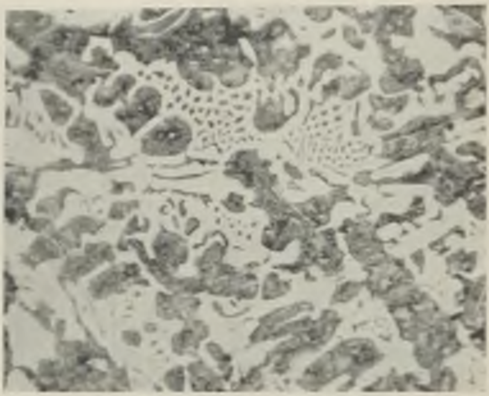

Fig. 6.—1G. As Cast. × 250 dias.
Etched Picric Acid.

in amount with increase in the joint addition of the elements.

With a manganese content of 0.25 per cent. (0.25 to 0.28 per cent.), the microstructures show that with increments of molybdenum up to 3.45 per cent. the structures still remain essentially pearlitic. The general increase in hardness noted in this series is due in the main to the increased amount of carbide constituents which are shown in the photographs and which confirm the observations of the fractures of the specimens. An increment of manganese to the neighbourhood of 1 per cent. in Series 2 is accompanied by a decided change in the character of the pearlite matrix, which becomes finer and much more difficult to resolve. Some of the martensitic constituent begins to make its appearance and with 0.81 per cent. molybdenum and 1.04 per cent. manganese this can be clearly identified and with further increment in molybdenum up to 3.27 per cent. the amount of martensitic constituent in the structure increases substantially. This is clearly evident

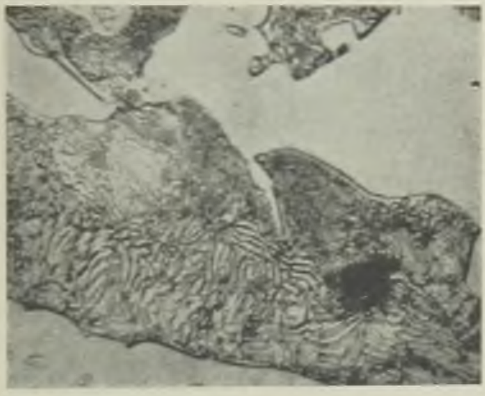

FIG. 7.—1G. AS CAST. × 1,500 DIAS.
ETCHED PICRIC ACID.

from the photomicrographs. With still higher percentages of manganese and molybdenum the martensitic character of the structure increases, a fact which explains the higher hardness values attained in these higher alloy content series.

From an observation of the micro-structure, the diagram Fig. 14 has been constructed in an endeavour to illustrate diagrammatically the relation between the conjoint percentages of molybdenum and manganese and the appearances of the martensitic structures. The specimens were examined carefully with the object of ascertaining the approximate percentage of martensitic constituent visible. These observed percentages plotted in relation to the manganese and molybdenum content yield a series of zones. It will be appreciated that the percentages indicated by the various zones are approximate only.

In considering extrapolation in the direction of no manganese, it will be noted that no martensitic constituent was observed in any of the

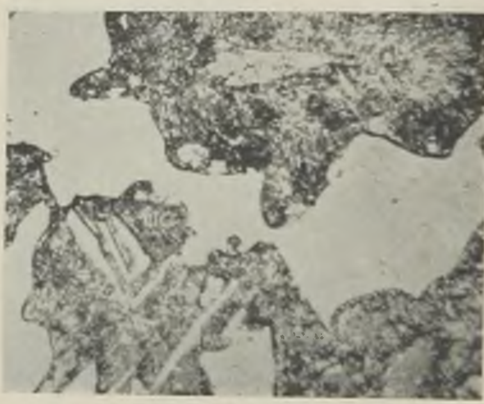

FIG. 8.—2C. AS CAST. × 1,500 DIAS.
ETCHED PICRIC ACID.

specimens containing 0.25 per cent. manganese. It is probable that the lines would turn sharply in a vertical direction and that until the manganese is in the neighbourhood of 0.5 to 0.75 per cent. even traces of martensite constituent cannot be expected. The slope of the lines is sharp in the direction of the higher manganese contents, bringing the zone of martensitic constituent sharply down into the region of low molybdenum content. As the diagram stands, the probability is that 3.5 per cent. of manganese would require something less than 1 per

| Spec. No. | Brinell hardness. | | | EN value lbs. per sq. in. $\times 10^6$ | Tensile, tons per sq. in. | Perm. set. Per cent. | Internal stress, inches. | Resilience value. | Limit of proportionality, tons per sq. in. |
|---|---|---|---|---|---|---|---|---|---|
| | 1. | 2. | 3. | | | | | | |
| 1A | 192 | 192 | 150 | 19.81 | 17.66 | 52.20 | 0.014 | 37.5 | — |
| 1B | 196 | 179 | 149 | 18.12 | 17.53 | 55.07 | 0.016 | 33.0 | — |
| 1C | 196 | 187 | 186 | 20.70 | 22.25 | 26.60 | 0.030 | 48.4 | 12 |
| 1D | 202 | 174 | 206 | 23.89 | 21.68 | 27.00 | Nil | 46.7 | 12 |
| 1E | 217 | 228 | 209 | 21.16 | 22.60 | 14.60 | 0.002 | 49.5 | 14 |
| 1F | 217 | 228 | — | — | — | — | — | — | — |
| 1G | 269 | 262 | 261 | 20.29 | 23.27 | 8.40 | 0.002 | 41.5 | 12 |
| 2B | 196 | 196 | 193 | 20.64 | 21.27 | 28.8 | 0.012 | 29.1 | 14 |
| 2C | — | — | 255 | 23.36 | 26.87 | 21.8 | 0.012 | 33.6 | 20 |
| 2D | 286 | 283 | 273 | 20.35 | 26.99 | 13.1 | 0.002 | 43.7 | 19 |
| 2E | — | 241 | 273 | — | — | — | — | — | — |
| 2F | 302 | 302 | 298 | 23.57 | 27.48 | 8.60 | 0.002 | 44.6 | 17 |
| 2G | 340 | 340 | 335 | 23.21 | 33.32 | 4.70 | 0.004 | — | 21 |
| 3B | 187 | 269 | 278 | — | 24.30 | 18.50 | 0.010 | 20.2 | 15 |
| 3C | 302 | 321 | 298 | 25.00 | 25.24 | 12.80 | — | 32.6 | 23 |
| 3D | 269 | 302 | 305 | — | 22.97 | 13.1 | 0.004 | 32.5 | 20 |
| 3E | 302 | 340 | 371 | 26.22 | 24.32 | 9.3 | 0.004 | 33.3 | 21 |
| 3F | 340 | 340 | 435 | 25.14 | 26.74 | 7.01 | — | — | 21 |
| 3G | 340 | 340 | 448 | 23.96 | 28.45 | 4.60 | 0.003 | 36.0 | 23 |
| 4A | 241 | 255 | 278 | 25.26 | 24.05 | 8.90 | 0.101 | 38.3 | 19 |
| 4B | 340 | 340 | — | — | — | — | — | — | — |
| 4C | 418 | 340 | 360 | 23.66 | 23.62 | 1.87 | 0.004 | 39.5 | 21 |
| 4D | 364 | 340 | — | — | — | — | — | — | — |
| 4E | 418 | 418 | 344 | 22.56 | 22.98 | 18.60 | 0.002 | 32.4 | 20 |
| 4F | 418 | 430 | — | — | — | — | — | — | — |
| 4G | 430 | 430 | — | — | — | — | — | — | — |

(1) Edge of annealed test pieces, 3,000-Kg. load 10-mm. ball. (2) Centre of annealed test pieces, 3,000-Kg. load 10-mm. ball. (3) Test ring, Firth 1-mm. ball, 30-Kg. load.

cent. molybdenum to ensure at least 70 per cent. martensitic structures. It is worth while to remember that these specimens were all sand-cast and the structural character appears to be uniform across the section of the cast bars.

## ANNEALED SPECIMENS

### Hardness

An examination of the properties of these specimens was undertaken after subjection to an

FIG. 9.—2G. AS CAST. × 1,500 DIAS.
ETCHED PICRIC ACID.

annealing treatment in which the specimens were exposed to a temperature of 950 to 975 deg. C. in a gas-fired muffle furnace for a period of two hours, followed by slow cooling in the furnace. The hardness values at the edge and centre of the annealed specimen determined with the standard 3,000 kg./10-mm. ball are given in Table IV, and the determination on the test rings with the Firth diamond hardness machine 30 kg. load representing the hardness of the specimens at a radius of 2 in. from the centre are included also.

The results at the outside edge and the centre of the specimen are in good agreement, showing that the annealing treatment has removed almost completely the irregularity in the hardness at the outside edge which existed in the "as-cast" specimens, and the uniformity in the hardness of the higher members of each series persists after this treatment. In the low manganese Series (No. 1) the increment in hardness with increase in molybdenum content persists after

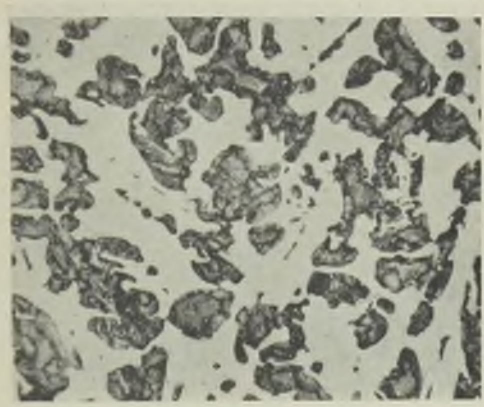

FIG. 10.—3F. AS CAST. × 250 DIAS.
ETCHED PICRIC ACID.

annealing, although the level of hardness is reduced to well within the limits of machinability. With each increment in manganese Series 2, 3 and 4, the tendency of the higher molybdenum content specimens to retain a higher hardness value after annealing is evident. The results are illustrated diagrammatically in Fig. 15, which clearly shows that higher hardness values are retained with molybdenum in excess of approximately 0.75 per cent. and that increment in the manganese also results in the maintenance of substantially higher hardness values.

With 0.75 per cent. molybdenum manganese of 2.25 per cent. and over, the Brinell hardness is maintained at values of well over 300 and in the higher members of the series values of well over 400 are maintained.

### Mechanical Properties

The mechanical test results recorded were all obtained on ring-form test pieces machined from

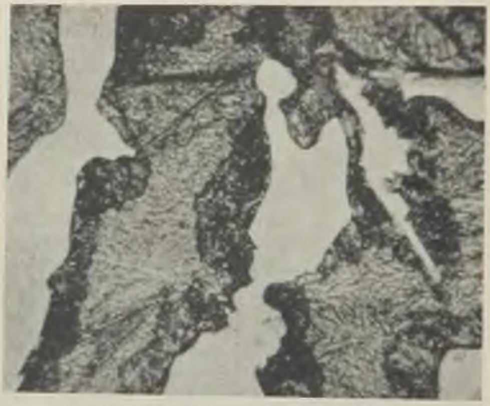

FIG. 11.—3F. AS CAST. × 1,500 DIAS.
ETCHED PICRIC ACID.

the annealed specimens, and the results are recorded in Table IV.

### Tensile Strength (Ring Test)

From the results tabulated in Table IV, it is clear that, with increase in molybdenum in Series 1, there is a substantial increase in the ultimate breaking strength, which appears to begin quite abruptly at a percentage of 0.69 per cent. Mo in specimen 1C. With an increase in manganese in the subsequent series, the general high level of strength is maintained, and the increase due to the manganese appears to be only very slight. There is no decrease with increase in manganese content. In each series, an increment in molybdenum is accompanied by an increase in the ultimate breaking strength of quite a substantial order. An increase of fully 50 per cent. in strength accompanies an increase of from 0.32 to 3.27 per cent. molybdenum in Series 2, and in the two remaining series the maximum increment in molybdenum is accom-

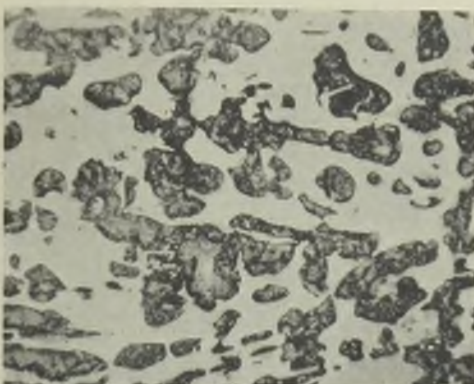

FIG. 12.—4G. AS CAST. × 250 DIAS.
ETCHED PICRIC ACID.

panied by an increase of about 16 per cent. in ultimate breaking-strength value.

### Modulus of Elasticity (EN Value)

In each of the series there appears to be a tendency for increase in molybdenum to be accompanied by an increase in this value. Values of $20 \times 10^6$ lbs. per sq. in. and over in Series 1 accompanying Brinell hardnesses of an easily-machinable order are somewhat unusual, and this would appear to be a distinctly useful attribute of molybdenum additions.

### Permanent Set Values

The very high permanent set values for the samples in Series 1 are not unexpected for the annealed condition Increase in manganese and increase in molybdenum in all cases is accompanied by a marked decrease in permanent set. This may prove to be an important attribute of joint manganese and molybdenum additions, in that they exert apparently a pronounced effect in maintaining the resistance to plastic defor-

Fig. 13.—4G. As Cast. × 1,500 dias. Etched Picric Acid.

mation even after subjection to a fairly drastic annealing treatment and without any loss in ultimate breaking strength or even lowering of the modulus of elasticity (EN value). In other words, the elastic deformation properties are maintained and the plastic deformation qualities are reduced very substantially, particularly with the higher manganese-molybdenum values.

### Internal Stress

As in the case of previous investigations, utilising this method, the author has described as internal stress the amount of movement observed between the free-gap and the gap cut in a restrained condition. The numerical values given which represent the gap movement in inches are all positive, that is to say, that the gap opened or increased on slitting. It is remarkable to find that, even after the fairly

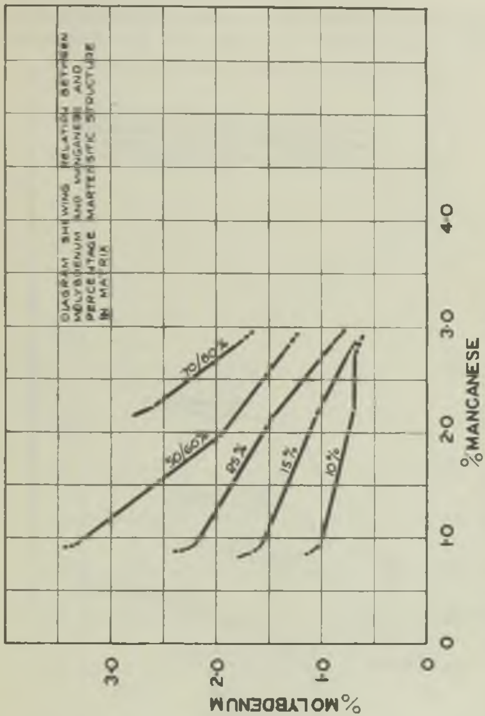


Fig. 14.

drastic annealing treatment to which the specimens have been subjected, there exists a substantial internal stress, as indicated by the gap opening in some of the specimens. It is also quite noticeable and of great interest to observe, particularly in Series 2, that increase in molybdenum content is accompanied by a decrease in the amount of internal stress (gap opening). There is evidence of the same influence on the other series. There does not appear to be any evidence that this is affected in any way by the increase in manganese content.

### Stress/Deflection Curves

The stress/deflection curves illustrating the change in character of these for the specimens

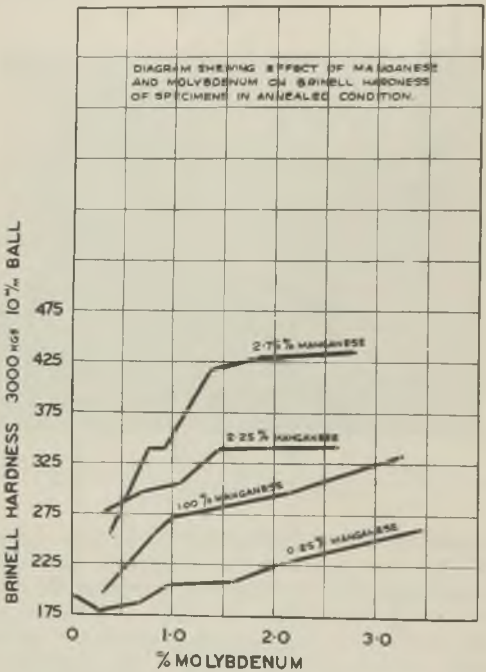


Fig. 15.

Series 1, are illustrated in Fig. 16. With the manganese constant at the low value of 0.25 per cent. approximately, and with molybdenum steadily increasing up to approximately 3.5 per cent., the character of the curves undergoes changes which are typified by the curves 1A, 1C, 1E and 1G. They show clearly the change and increase in modulus of elasticity and the increase in ultimate breaking strength. The pronounced curvature in the specimens free from molybdenum, the effect of plastic deformation, is altered in character somewhat with increasing percentages of molybdenum.

In the molybdenum-free and low-molybdenum

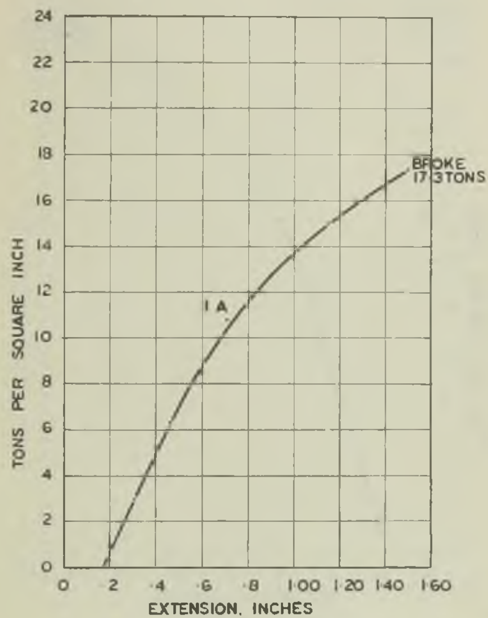


Fig. 16 (*a*).

specimens, the limit of the straight portion of the curve is approximately 6 tons per sq. in. (def. 0.45 in.), and if this be regarded as a limit of proportionality, it will be seen that, with increasing molybdenum, this is raised very substantially to approximately 12 tons per sq. in. in Specimen 1C, containing 0.69 per cent.

molybdenum and slightly higher than 14 tons per sq. in. in the remaining specimens. The total deflection at breaking is very little affected with increase in molybdenum. The included area of the curves, *i.e.*, the resilience value, shows a very pronounced increase in specimen 1C, con-

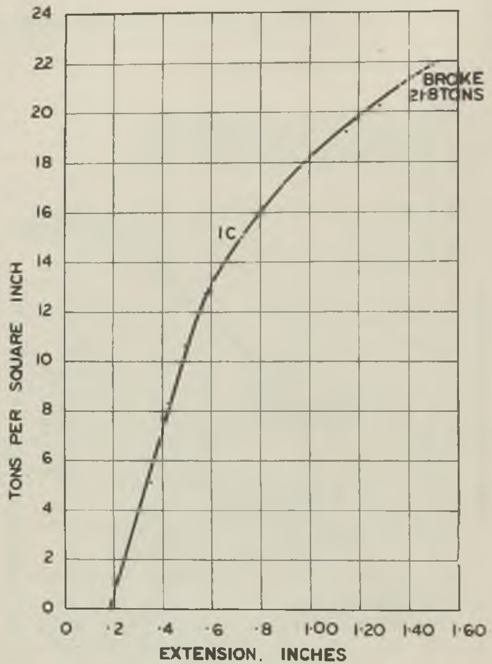


FIG. 16 (*b*)

taining 0.69 per cent. molybdenum. This increase amounts to about 33⅓ per cent., and is apparently not increased very much by increase in percentage of molybdenum above this value.

In the annealed condition the presence of 0.69 per cent. molybdenum therefore brings about an increase in toughness of approximately 33⅓ per cent., which is maintained, but not substantially increased, by further quantities of molybdenum. In addition, the alloys become more truly elastic over a wider stress range (at least 100 per cent. greater than the low molybdenum specimens), and the total deflection or strain at fracture remains practically unaltered.

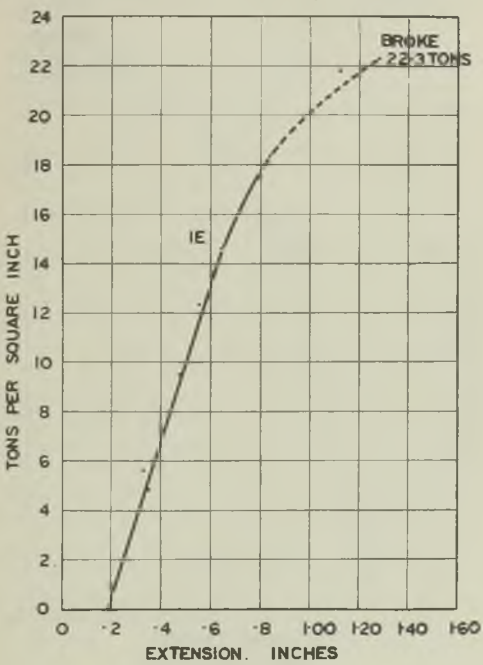


Fig. 16 (*c*).

The effect of increasing manganese content with increase in molybdenum is shown by the stress/deflection curves for Series 2, 3 and 4. The curves 2D, 3D, 3F and 4C illustrated in Fig. 17 are characteristic. The same influence of molybdenum is apparent in each case and the influence of increasing quantities of manganese appears to show a tendency towards increasing the limit of proportionality to a still slightly higher figure in the neighbourhood of 18 tons per sq. in., and even with the higher hardness values the toughness as represented by the resilience values remains practically unimpaired. It is again noticeable that a percentage of

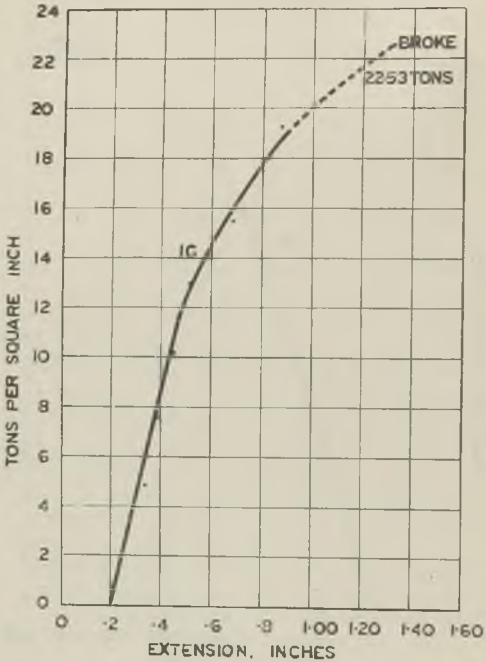


FIG. 16 (*d*).

approximately 0.70 per cent. molybdenum in each of these series appears to be necessary to develop the marked change in properties due to this element.

### Elastic Hysteresis Loops

Test rings were submitted to a complete cycle of stress and the character of the elastic hysteresis loops determined. The method* adopted has been described previously by the author, but is again briefly described as follows:—Starting with closing the test rings, stress was applied gradually and the reduction in gap opening

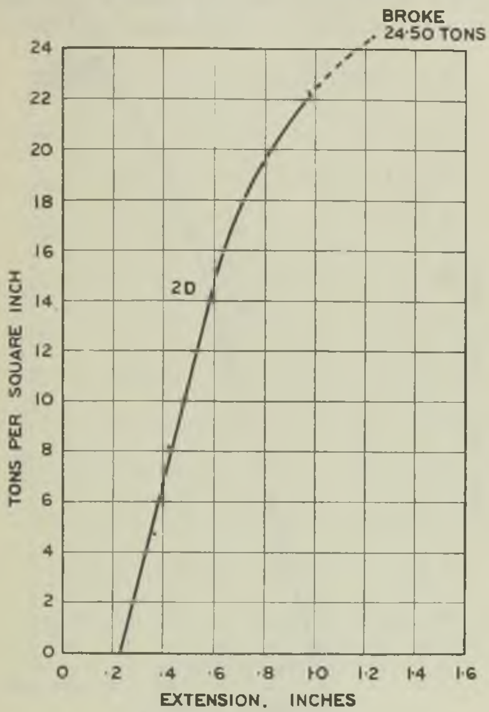


Fig. 17 (*a*).

measured with increasing stress. The stress range adopted was 12 tons per sq. in. calculated on the basis of the relationship given in B.S.I. Specification 5004 and when the stress was attained the load was gradually removed, and

* Foundry Trade Journal, December 27, 1934, p. 405.

the gap dimensions measured with the gradual decrement of stress. The same specimen was then subject to a stress (tensile stress) applied to open the gap following the same procedure in the measurement of the strain. The curves plotted showing the relation between gap opening and the cycle of applied stress yield charac-

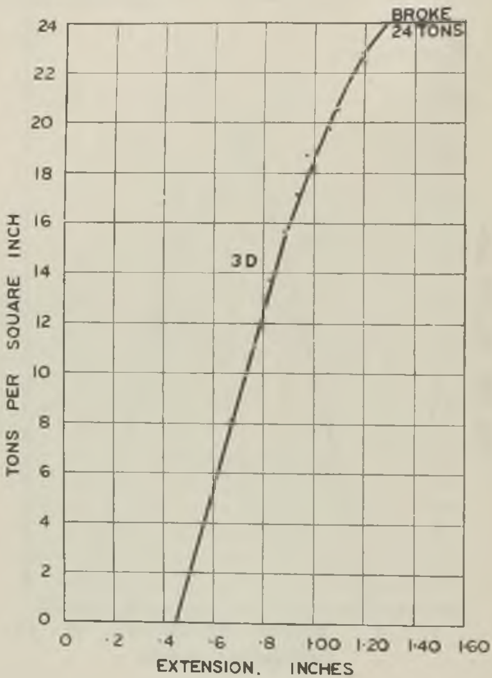


Fig. 17 (b).

teristic hysteresis loops as shown in the diagrams. A complete set of diagrams for the Series 3A to 3G is illustrated in Fig. 18, in that they are typical of the change in character of the diagrams with increasing molybdenum content in each series. With increasing molybdenum content there is a marked steady decrease in the enclosed areas of the loops indicating a decrease in the hysteresis and hysteresis stress with increasing molybdenum content.

There is no striking difference in character between these hysteresis loops with increase in

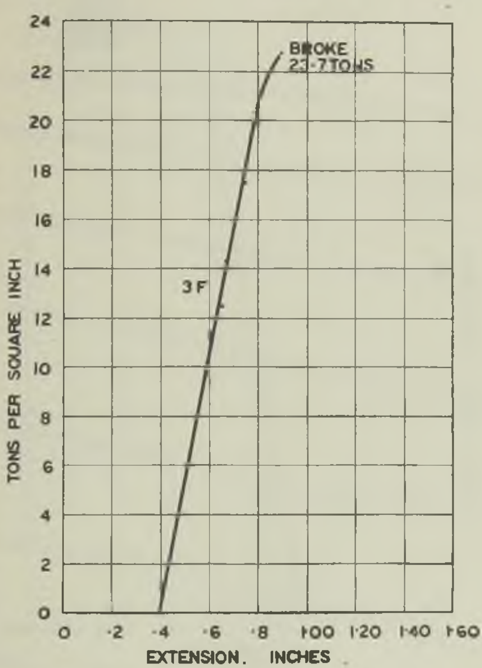


Fig. 17 (*c*).

manganese content beyond 1 per cent., but in Series 1 with 0.25 per cent. manganese approximately, the low manganese specimens 1A to 1C show very much greater hysteresis and hysteresis stress than in other specimens. As in the case of the other properties, the marked change in character of the loops occurs with a percentage of molybdenum about 0.70 per cent. (specimen 1C) and even in Series 1 the specimens with molybdenum in excess of 0.70 per cent. (specimen 1C) yield hysteresis loops which differ very little from those yielded by the higher manganese content series.

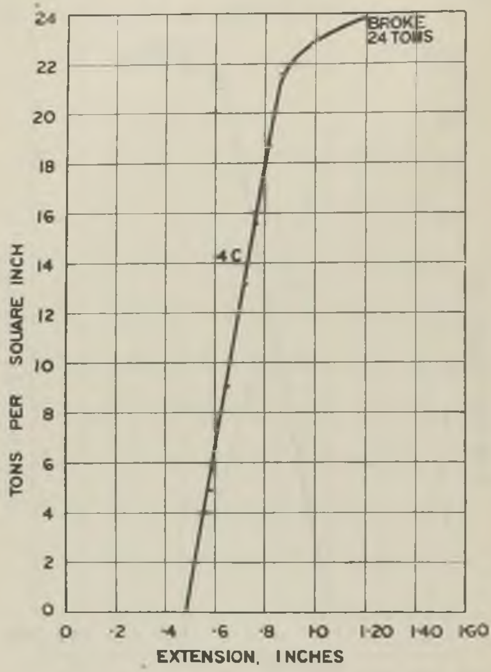


Fig. 17 (*d*).

## Microstructure (Annealed Condition)

An examination of the microstructure of the specimens taken from the annealed samples shows that the structure has undergone a marked change due to this treatment. The photographs Figs. 19 to 22 of the specimens 3 F and 4C will be sufficient to illustrate the change in struc-

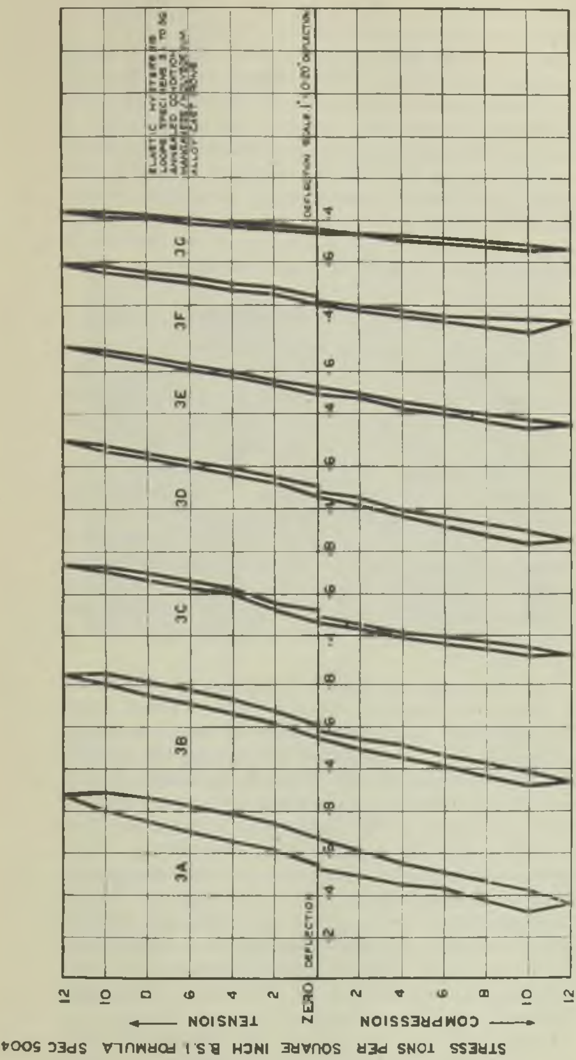
STRESS TONS PER SQUARE INCH B.S.I FORMULA SPEC 5004
TENSION
COMPRESSION
ZERO
12 10 8 6 4 2 ZERO 2 4 6 8 10 12
DEFLECTION
DEFLECTION SCALE 1" = 0.20" DEFLECTION
3A
3B
3C
3D
3E
3F
3G

FIG. 18.

tural character. A comparison of these at the low magnification with those in the "as-cast" condition will show at once that there appears to have been very little change in the amount of the carbide (white) constituent present, but that the martensitic matrix has undergone a marked spheroidising or balling-up. The black constituent in 3 F which resembles troostite also exists in similar quantities in the high molybdenum content specimens of each of the series. This balling-up or spheroidising of the matrix is characteristic of all the annealed specimens.

## Summary and Conclusions

From these experimental results it is clear that increasing quantities of molybdenum additions tend to produce a white fracture and with very low manganese content (0.25 per cent.) an addition of 1 per cent. of molybdenum is required to ensure a white fracture under the conditions of the experiments. With increasing amounts of manganese the amount of molybdenum necessary to ensure complete whiteness decreases, and with 2.75 per cent. of the former element present a completely white fracture is obtained with 0.39 per cent. molybdenum in the "as-cast" condition and without the aid of any chills.

In this same condition the conjoint additions of these two elements have a marked effect upon the hardness. In the presence of small amounts of manganese the effect of increasing the molybdenum content on the Brinell hardness is not very great until a percentage of approximately 0.70 per cent. of this element is attained and further increases beyond this value bring about increased hardness. Increase in the manganese contents brings about a general increase in the hardness level, for a given molybdenum content and extremely high hardness values of 600 Brinell and over are obtained with manganese and molybdenum in excess of 2.25 per cent. and 1.00 per cent. respectively.

Under all the conditions of manganese content examined molybdenum commences to show a marked effect in increasing the hardness when a percentage in the neighbourhood of 0.70 per cent. is reached and the increased hardening effect is obtained uniformly across the section of the specimens examined. This effect of the joint addition of these two elements on the hardness appears to be due to their action in promoting the formation of a martensitic constituent.

Manganese appears to be necessary to ensure the formation of this, and in the specimens containing only 0.25 per cent. manganese none was

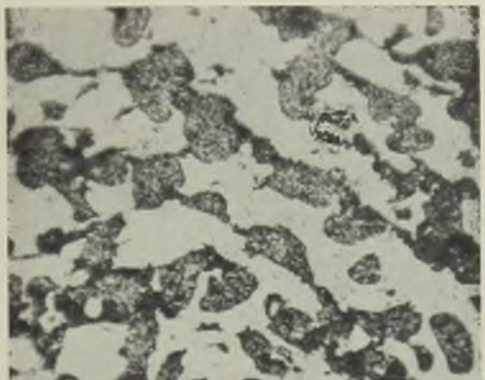

Fig. 19.—3F. Annealed. × 250 dias.
Etched Picric Acid.

observed up to 3.45 per cent. molybdenum. Owing to the fact that no specimens having a manganese content intermediate between 0.25 and 1.0 per cent. were examined, it has not been possible to fix the manganese content at which the martensitic structure begins to form, but by extrapolation from the observations made with higher manganese it appears probable that at least 0.5 to 0.75 per cent. of this element is necessary. With manganese in excess of this amount, increases both in manganese and molybdenum bring about an increase in the amount of martensitic constituent.

Increase in molybdenum alone appears to be accompanied by an increase in the amount of the carbide constituent and this same influence probably persists in conjunction with higher manganese contents. The combined effect of this and the production of the martensitic constituent is probably responsible for the very high hardness values of the high-manganese-molybdenum members of the series.

The annealing treatment adopted in the experiments has had the effect of "balling-up" or

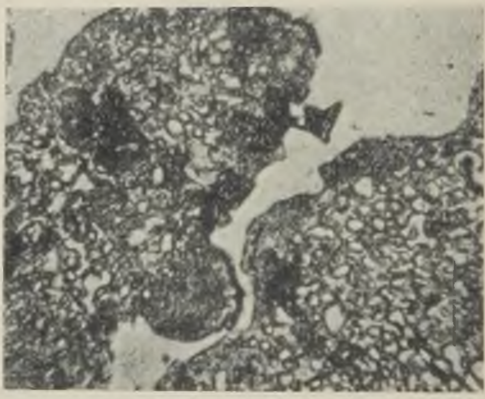

FIG. 20.—3F. ANNEALED. × 1,500 DIAS. ETCHED PICRIC ACID.

spheroidising the pearlitic-martensitic matrices, and in the more highly martensitic alloys a constituent of troostitic character appears. In these same alloys the carbide constituent appears to be very stable and it was difficult to observe any such reduction in quantity of this as appeared in the lower manganese-molybdenum content specimens. This observation has a bearing probably on the substantially-high hardness values maintained after annealing in the higher manganese-molybdenum specimens. All the specimens undergo a reduction in hardness due to annealing but it will be noted that with say 2.75 per cent. manganese and 1.5 per cent. molybdenum hardnesses of upwards of 400 Brinell are still maintained. This is in all probability due to the stability of the carbides in these alloys, the reduction in hardness as from the "as-cast" condition being due in the main to the spheroidising of the martensitic and the formation of some troostite constituent.

Whilst no mechanical tests were made on the materials in the "as-cast" condition, it is

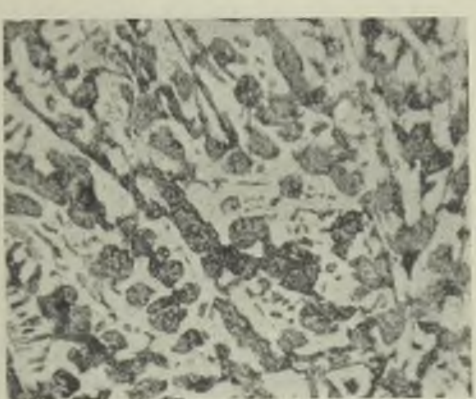

FIG. 21.—4C. ANNEALED. × 250 DIAS. ETCHED PICRIC ACID.

worthy of record that all the specimens appeared to be very tough and strong in handling. The mechanical tests in the annealed condition show that in the main increase in molybdenum is accompanied by increase in strength of quite a substantial order. Again the marked effect of this constituent appears to begin with a percentage in the neighbourhood of 0.70 per cent. Manganese in itself does not appear to be responsible for any increase in strength of a marked order nor does it bring about any reduction in strength. In fact with all the percentages of manganese examined the high strength due to the molybdenum contents appears to be maintained.

The stress/deflection curves and the area of these or the resilience values show that with an increase in molybdenum of 0.70 per cent. this value is substantially raised, but further increments in the two elements do not appear to be accompanied by any further increase in resilience values. They are, however, accompanied by certain other changes in what might

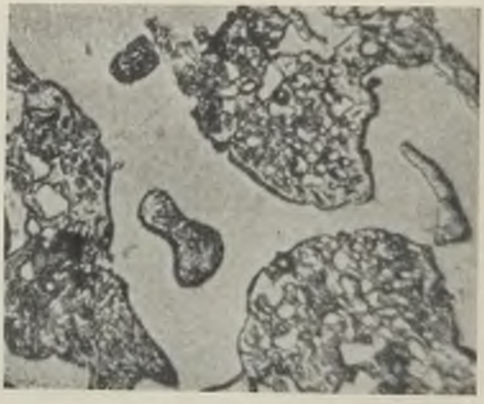

FIG. 22.—4C. ANNEALED. × 1,500 DIAS. ETCHED PICRIC ACID.

be termed the elastic characteristics. Increase in both molybdenum and manganese appear to extend the range of close approach to proportionality and what has been termed the limit of proportionality has been distinctly raised by both these elements. The elastic deformation properties are maintained and the plastic deformation or permanent set properties are reduced. The modulus of elasticity (EN value) shows a marked tendency to increase with increasing molybdenum contents and the elastic hysteresis loops over the stress cycle adopted show a substantial diminution in area with increase in both constituents.

The apparent effect of increase in molybdenum content in reducing the magnitude of the internal stress effects after annealing is also an observation of very great interest. A general observation on the results of the mechanical test results of these specimens in the annealed condition is that the joint addition of these two elements is not accompanied by any diminution in strength characteristics, and on these grounds it would appear that these joint additions could be used with every confidence.

Joint additions of manganese and molybdenum produce cast irons having martensitic characteristics with strengths and attributes of the strength properties of a very high order.

Certain aspects of the results obtained in this investigation are clearly of importance, and it is considered legitimate to make reference in general terms to some of the potential industrial applications in which results of this nature are worthy of consideration.

### Chilled and Grain Rolls

The fact that molybdenum alloy additions are used already in the manufacture of chilled and grain rolls and castings used for crushing, grinding and pulverising machinery was in a large measure responsible for the inception of this investigation. It is well known that castings coming within this category are required to withstand a wide range of duty-conditions. It appears quite likely that the properties obtainable by the joint use of manganese-molybdenum alloy additions may be of value, and certainly worthy of consideration in many aspects of the manufacture of castings of this nature where extremely high hardness values are required as, for example, in chilled rolls for certain operations alloy additions of this type may prove of interest. From this point of view, in addition to the possible high-hardness values, the investigations tend to show that these are accompanied by high-strength values, high resistance to both elastic and plastic deformation, low elastic-hysteresis and possibly high-fatigue resistance.

In this connection the properties of this type of alloy iron in the annealed condition are of interest. The effect of the joint additions in stabilising the carbide constituent and thus enabling a high hardness value to be maintained, is one point of interest. Also it must be borne in mind that the measured values of the various properties have been obtained for these samples in the annealed conditions, and these point to the possibility of obtaining high resistance to deformation and fatigue in addition to high-strength values in this condition. An additional aspect of some importance in considerations of this nature, is the apparent reduction in internal-stress value due to the manganese-molybdenum additions and also the effect of these additions in obtaining uniformity of hardness across the sections examined.

In the production of grain rolls, particularly section rolls, these results may be worthy of consideration. It should be possible, by the use of joint additions of molybdenum and manganese to obtain substantially-high degrees of hardness, still within the limits of machinability desired for castings of this class. These higher hardness values, coupled with the high-strength values as revealed by the results of this investigation, may be found to be accompanied by a greater life under the service conditions demanded of this class of roll.

### Wear Resisting Castings

There are a number of other types of castings used in crushing, grinding and pulverising machinery in which similar properties are required, and where this type of alloy iron might conceivably be of service.

### Engine Castings

The possibility of obtaining high hardness and martensitic characteristics, coupled with high strength values and high resistance to deformation by the use of manganese-molybdenum additions, may be of value in the production of castings such as cylinders, cylinder liners, valve seats, crankshafts and camshafts. Here again, the high strength values and the possible high fatigue resistance may prove to be important properties of this type of alloy.

### General Castings

In the realm of general castings there are numerous examples, such as gear wheels, worm castings, castings called upon to withstand abrasive conditions, where the properties of the type revealed by this investigation may prove of interest.

The above are to be taken as purely general comments intended to focus attention on some directions in which it is possible that results of the type yielded by this investigation might prove of value, and in the hope that they may stimulate further experiment and investigation in a similar direction.

This investigation and research has been carried out in the laboratories of Bradley & Foster, Limited, in conjunction with High Speed Steel Alloys, Limited. The author desires to place on record his thanks for their co-operation and consent to the publication of the results.

# THE INFLUENCE OF WALL-THICKNESS ON THE MECHANICAL PROPERTIES OF CAST IRON

By H. Jungbluth

*(German Exchange Paper)*

## I.—Historical

The fact that grey castings have different strength properties according to their thickness is well-known. In addition to *C. v. Bach** who as early as 1888 studied the mechanical strength of castings of different sectional thickness. W. J. Keep[4] in 1906 drew the general conclusion from a series of investigations that the strength of a casting of given sectional thickness could not be derived by a mathematical formula from the mechanical values obtained for test bars of other dimensions. Although Keep did not arrive at a solution for this problem, he nevertheless clearly formulated the practical aspects of the question. The practical foundryman is concerned with two questions: firstly, what is the strength of a casting at different sectional thicknesses, and secondly, what relation exists between the strength properties in sections of different thickness of a casting and those of a test bar cast either separately or integrally with a casting and which the foundryman uses for his own tests? During subsequent years various investigators studied this problem, the impetus for this work being provided mainly by British and American research workers.

In the first instance numerical data alone were collected and no attempt was made to derive from these experiments any general laws which, if possible, could be formulated quantitatively. Of the few workers who did indeed make some advance in this direction, passing reference should be made to *W. H. Rother and V. M. Mazurie*[20] who proposed the casting and testing

* The Bibliography appears at the end of this Paper.

of several bars of different wall thickness instead of only a single one, and to *J. W. Bolton*[23] who suggested giving the test bars the same ratio of surface to volume as that of the castings. Later *M. v. Schwarz and A. Vath*[46] followed up this suggestion and showed that under certain conditions satisfactory agreement between the strength of a casting as a whole and that of a test bar can be obtained if the diameter of the bar is made twice the wall thickness under test.

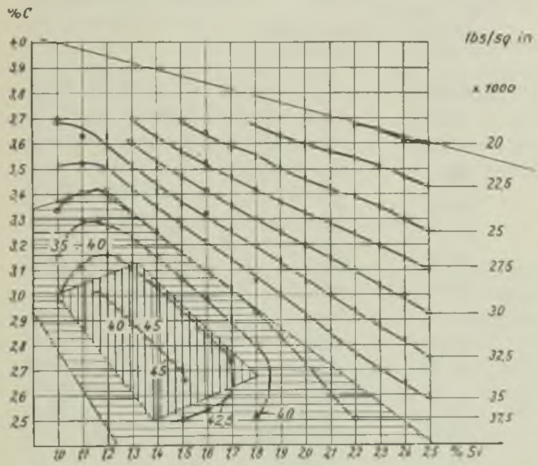


**Fig. 1.—Relationship between C and Si and Constant c, according to Coyle's Formula.**

Subsequently research followed three main directions. On the one hand, as the problem as a whole proved to be too complex, one group of investigators devoted its attention to a partial aspect and attempted to find the quantitative relations existing between test bars of different diameters and different compositions. This was indeed the first part of Keep's[6] formulation of the whole problem. *G. Meyersberg*[38] in 1931 published certain equations which represented the quantitative relationship over a certain range between the diameter of the test bar and the mechanical property in question. But as, however, *F. B. Coyle*[28] had already shown in 1929 that a logarithmic relation existed between the mechanical strength and the test-bar diameter, *H. Jungbluth and P. A. Heller*[39] and *P. A. Heller and H. Jungbluth*[49] employed this observation in order to arrive at a numerical value for the " sectional sensitivity " in terms of the tangent of the slope of the logarithmic line of

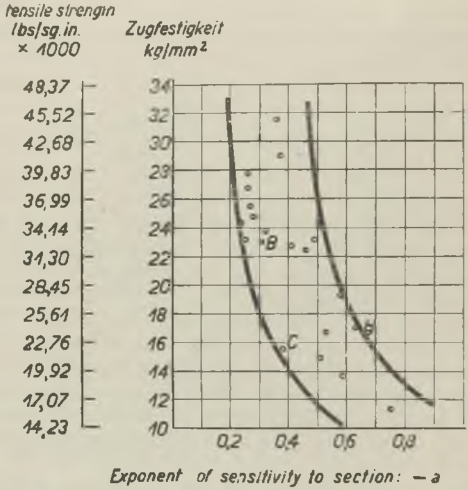


Fig. 2.—Relationship between Tensile Strength and Sectional Sensitivity.

reference. They succeeded in obtaining a definite relationship between the " sectional sensitivity " on the one hand and the Maurer diagram* and the quality of grey iron respectively on the other. This part of the problem was thus solved at that time. On the other hand E. Dübi[40 51] tried to clarify the relationship between the strength of the test bar and that of the casting by introducing the concept

* " s. Kruppsche Mitteilungen," 5 (1924), pp. 115–22 ; " Stahl u. Eisen," 44 (1924), pp. 1522–24.

of a "hardness characteristic curve" ("Härte-charakteristik"), commencing from the assumption that there exists a connection between the strength and the Brinell hardness, at least within a limited range. His purview was therefore the second part of Keep's question.

Finally, the third group of investigators, especially the school of *E. Piwowarsky*[37, 42, 43, 45, 50, 52] attempted to deal with the influence of alloy components not normally present in cast iron on sectional sensitivity. These workers adopted as a fundamental measure the exponent "a" introduced by *H. Jungbluth and P. A. Heller*[38, 40], *i.e.*, the tangent of the slope of the logarithmic line of reference. This is in general outline the progress of the subject under review up to the present day. The problem is, however, not yet finally solved. An exact scientific formulation of the problem is given below.

## II.—Sectional Sensitivity

### (a) Test Bars

The question of the pure sectional sensitivity will be discussed first. The quantitative laws governing sectional sensitivity are based on the conclusion stated by F. B. Coyle[26] that the diminution in the tensile strength of test bars of different thicknesses plotted in a system of co-ordinates with logarithmic axes is represented by a straight line. The relationship between the diameter of the test bar and its strength can therefore be expressed by an equation of the form:

$$y = c \cdot x^m$$

where

$c$ is a constant,
$x$ the diameter of the test bar and
$m$ an exponent.

Expressing this equation logarithmically, viz., $\log y = m \log x + \log c$ shows that $m$ stands for the slope of the straight line plotted in logarithmic co-ordinates, and $c$ for the strength of the test bar with the diameter 1 (for Coyle's case 1). From his curves Coyle deduced that $m = -\frac{1}{2 \cdot 02}$. The different grades of cast iron differ according to Coyle only in regard to the constant $c$; his Table II gives different values of $c$ in relation to the carbon and silicon. These constants were evaluated graphically by the present author and are shown in Fig. 1, which also includes the strength values of cast iron in reference to carbon and silicon content already given by Coyle.* A satisfactory concordance is apparent, and it is seen that Coyle's constants are in fact the tensile strengths for the 1-in. test bar. But as Coyle gives only one value for the exponent $m$, namely, $-0.495$ $(i.e., -\frac{1}{2\cdot 02})$, the slope of his curves in logarithmic co-ordinates is

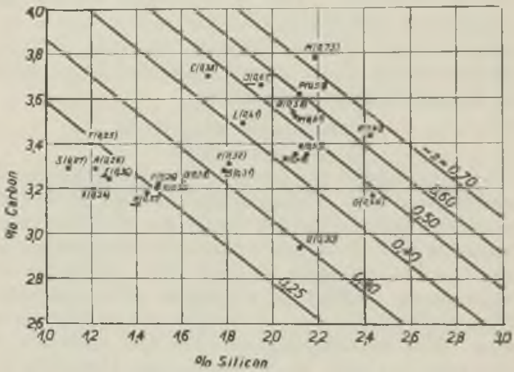


FIG. 3.—DIAGRAM OF SECTIONAL SENSITIVITY.

therefore always the same, *i.e.*, the percentage diminution in strength is equal for each grade of cast iron.

*H. Jungbluth and P. A. Heller* used this Paper as a basis. After showing that not only the tensile strength but also the transverse strength and Meyersberg's "flexure coefficient"† ("Verbiegungszahl") follow the same law,[30] they suc-

* "Iron Age," **124** (1929), pp. 6–7; "Proc. Am. Soc. Test Mat.," **29** (1929), II, pp. 87–93.

† "Giesserei," **17** (1930), pp. 473–81, 587–91; "Kruppsche Monatshefte," **12** (1931), pp. 301–330; "Stahl u. Eisen," **50** (1930), pp. 1305–07.

TABLE I.—*Wall-thickness Exponent "a" for Tensile Strength according to Experiments of A. Koch and E. Piwowarsky.*[42]

| Melt No. | C. | Si. | C + Si. | Mn. | P. | S. | $-a$ at casting temperature 1,440 deg. | $-a$ at casting temperature 1,340 deg. |
|---|---|---|---|---|---|---|---|---|
| 1 | 3.51 | 1.64 | 5.15 | 0.40 | 0.060 | 0.042 | 0.67 | 0.72 |
| 2 | 3.44 | 2.03 | 5.47 | 0.38 | 0.061 | 0.043 | 0.44 | 0.43 |
| 3 | 3.40 | 2.51 | 5.91 | 0.39 | 0.064 | 0.040 | 0.36 | 0.34 |
| 4 | 3.12 | 1.65 | 4.77 | 0.40 | 0.069 | 0.043 | 0.30 | 0.24 |
| 5 | 3.12 | 2.00 | 5.12 | 0.41 | 0.076 | 0.042 | 0.30 | 0.31 |
| 6 | 3.03 | 2.52 | 5.55 | 0.38 | 0.072 | 0.041 | 0.28 | 0.35 |
| 7 | 2.82 | 1.63 | 4.45 | 0.47 | 0.066 | 0.041 | 0.22 | ? |
| 8 | 2.84 | 1.86 | 4.70 | 0.47 | 0.066 | 0.040 | 0.35 | 0.31 |
| 9 | 2.85 | 2.23 | 5.08 | 0.48 | 0.068 | 0.044 | 0.49 | ? |
| 10 | 2.59 | 1.30 | 3.89 | 0.43 | 0.069 | 0.045 | ? | ? |
| 11 | 2.61 | 1.69 | 4.30 | 0.45 | 0.068 | 0.046 | ? | 0.22 |
| 12 | 2.63 | 2.24 | 4.87 | 0.41 | 0.073 | 0.042 | 0.21 | 0.43 |

ceeded[49] later in establishing that in the diminution in strength of a test bar not the constant $c$, that is the strength of the 1-in. bar, but the exponent $m$, representing the gradient of the curve, is the criterion determining the sectional sensitivity. In the following, therefore, sectional sensitivity implies only this diminution in strength as expressed by Coyle's exponent $m$, and has no reference to its absolute value (*i.e.*, without reference to Coyle's constant $c$). Figs. 2 and 3 summarise the relations. It is seen that cast irons with high carbon and silicon contents not only have a smaller Coyle's constant $c$, that is, a lower strength in the 30-mm. test bar (Fig. 2), but also a greater exponent $m$ (or $a$ as

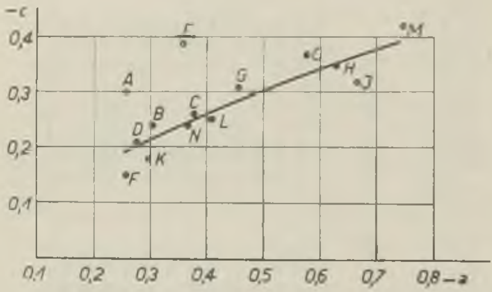


FIG. 4.—RELATIONSHIP BETWEEN EXPONENTS $a$ (TENSILE STRENGTH) AND $c$ (BRINELL HARDNESS), ACCORDING TO HELLER AND JUNGBLUTH.

Heller and Jungbluth have denoted it), *i.e.*, they have a greater percentage diminution in strength compared with a 30-mm. test bar (Fig. 3). Naturally the relations between bar diameter, strength and gradient are not very accurate, as there is a certain tolerance due to the moulding, casting and test conditions.

Nevertheless, probability curves should enable the range of variation and the modulus values to be determined sufficiently accurately so that the diminution in strength of test bars can be expressed numerically, a task which, however, could only be carried out by co-operative research.

TABLE II.—*Wall-thickness Exponents "a" for Tensile Strength and "c" for Brinell Hardness according to Experiments of P. A. Heller and H. Jungbluth.*[49]

| | A. | B. | C. | D. | E. | F. | G. | H. | J. | K. | L. | M. | N. | O. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C + Si .. | 5.51 | 5.07 | 5.42 | 4.83 | 4.52 | 4.72 | 5.61 | 5.86 | 5.61 | 4.69 | 5.36 | 5.97 | 4.63 | 5.63 |
| $-a$ .. | 0.26 | 0.31 | 0.38 | 0.275 | 0.36 | 0.26 | 0.46 | 0.63 | 0.67 | 0.30 | 0.41 | 0.57 | 0.37 | 0.585 |
| $-c$ .. | 0.300 | 0.242 | 0.264 | 0.208 | 0.129* | 0.152 | 0.306 | 0.347 | 0.321 | 0.180 | 0.250 | 0.415 | 0.242 | 0.36 |

| | P. | Q. | R. | S. | T. | U. | V. | W. | X. |
|---|---|---|---|---|---|---|---|---|---|
| C+Si | 5.74 | 5.50 | 5.62 | 4.39 | 4.60 | 5.06 | 5.12 | 5.45 | 4.41 |
| $-a$ | 0.59 | 0.53 | 0.41 | 0.27 | 0.25 | 0.30 | 0.32 | 0.49 | 0.24 |

* Heller and Jungbluth gave the value 0.392 for this material. On re-examination of the figures, particularly by a re-check of Fig. 10 in the Paper cited,[49] the writer finds that it is more advisable to regard the value for the 20-mm. test bar as anomalous and thus reject it in drawing the curve. The new curve then gives the *c*-value included in the table. If this assumption is not accepted, this *c*-value must also be taken as anomalous and omitted.

This part of the problem of sectional sensitivity can therefore be regarded as solved.

For the transverse strength, diagrams similar to those for tensile strength can also be developed, as well as for the Brinell hardness and other strength properties. Fig. 4 shows, *e.g.*, the relationship between the exponent $a$ for the tensile strength and the exponent $c$ for the Brinell hardness,* as plotted by *P. A. Heller and H. Jungbluth.*[40] From the diagram the known

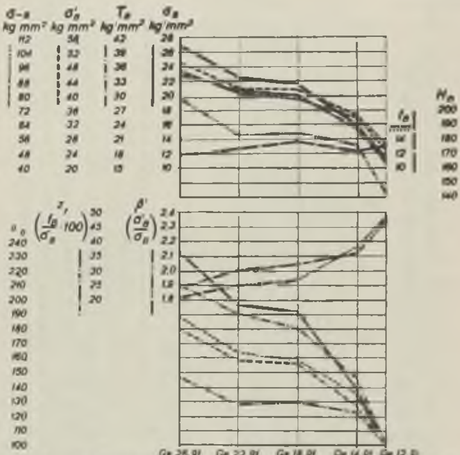

FIG. 5.—RELATIONSHIP BETWEEN MECHANICAL PROPERTIES OF STANDARD GRADES OF CAST IRON.

fact can be deduced that the percentage differences in the Brinell hardness of different wall thicknesses are not as great as those for the tensile strength. The Brinell hardness does not differ as much as the tensile strength, which is also shown by Fig. 5 from *R. Mailänder und H. Jungbluth.*† This result is very important, as much data on cast iron devoid of sectional

* The writer employs the same exponents for the different properties as Heller and Jungbluth.

† "Technische Mitteilungen Krupp," 1 (1933), pp. 83–93.

sensitivity are based on the Brinell hardness, which should be checked occasionally. Fig. 6 shows finally the relationship between the exponent *a* for the tensile strength and the exponent *b* for the transverse strength, also according to *P. A. Heller and H. Jungbluth.*[49] This curve shows that the transverse strength, too, does not vary as much as the tensile strength, which again agrees with Fig. 5. However, it has to be borne in mind that the tensile strength was determined on machined and the transverse strength on unmachined test bars.

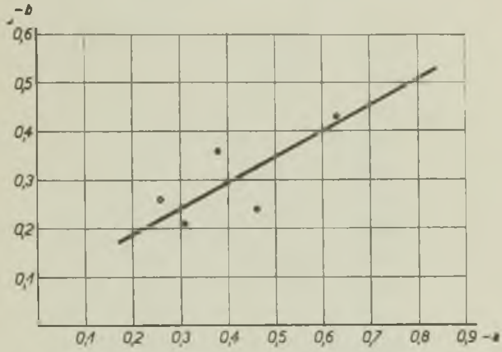


FIG. 6.—RELATIONSHIP BETWEEN EXPONENTS *a* (TENSILE STRENGTH) AND *b* (TRANSVERSE STRENGTH), ACCORDING TO HELLER AND JUNGBLUTH.

*P. A. Heller and H. Jungbluth*[49] used, in addition to their own data, figures given in British and American literature.[20 29] It is still necessary to investigate how far the Paper of *A. Koch and E. Piwowarsky*[43] can be correlated with P. A. Heller and H. Jungbluth's theory. These investigators cast bars of plain cast iron of 22 mm., 37 mm., 52 mm., and 67 mm. dia. This material, being made in the Brackelsberg furnace by a different melting process, was expected to give values not agreeing with those of Heller and Jungbluth. In addition to the influence of different carbon and silicon contents the influence of the pouring temperature was also studied.

The author has calculated (Table I) the exponents showing the influence of wall thickness, only the figures for tensile strength being usable. The value for the thinnest bar did not conform with the curve for transverse strength, because the bar was tested with its skin, while all other pieces had been turned down to 30 mm.

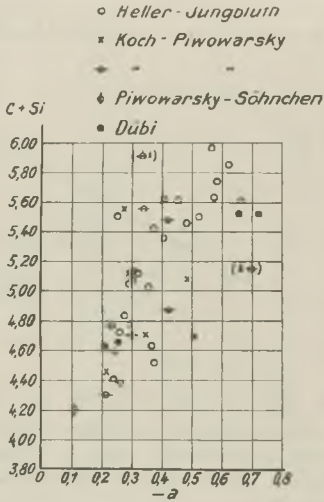


FIG. 7.—RELATIONSHIP BETWEEN C + SI AND *a*.

dia., thus having the skin removed. No data were given of the dimensions of the test pieces for tensile tests, so that it cannot be determined whether on pieces of different diameter an equivalent portion of the diameter was each time tested, as ensured by P. Heller and H. Jungbluth.[49] Nevertheless, the values found agree satisfactorily with those obtained by P. A. Heller and H. Jungbluth[49] and included in Table II. This is seen in particular on plotting these values against the total C + Si, as in Fig. 7. As the influence of the pouring temperature upon *a* is practically negligible, the whole of the numerical data can be used (the test pieces marked × in Fig. 7 were poured at 1,440 deg. C.), and those marked -⊖- at 1,340 deg. C.

It is remarkable that a rising silicon content in melts 1, 2 and 3 did not cause an increase but a reduction in the sectional sensitivity, which

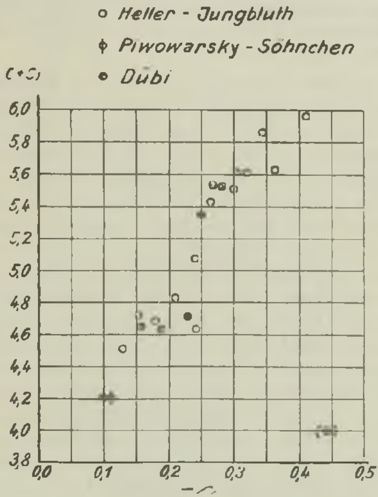


FIG. 8.—RELATIONSHIP BETWEEN C + SI AND *c*.

is in opposition to all previous knowledge. The corresponding points for melts 1 and 2 are picked out in Fig. 7 by a vertical stroke; these must obviously be omitted from the series of points. Some points are also obtained from the data of E. Dubi.[40, 51] Without specifying his melting apparatus, he cast together with test boxes (which will be dealt with later) test bars of plain cast iron with diameters of 30 mm. and 50 mm. Naturally it is rather presumptive to calculate from only two diameters the sectional sensitivity;

it can nevertheless be done, as shown by Figs. 7 and 8, which indicate that the results conform entirely with those already deduced. Only one *c* value does not fall within the curve at all. As the corresponding *a* value is positive, it may be assumed that this cast represents some intermediate stage. It must be admitted that the values so obtained are very scattered, but there is a certain numerical regularity. It may therefore be claimed with some justification that these investigations have reached a certain stage of finality.

The above investigations on the fundamental laws of sectional sensitivity have been amplified by further work on test bars of *alloyed* cast iron in order to determine the influence of alloying elements on the sensitivity factor, particularly by the work of *E. Piwowarsky and E. Söhnchen.*[37, 43] In the first Paper[37] square test bars of 15 mm., 30 mm., 40 mm., 60 mm., and 90 mm. side and 90 mm. long were cast. The shape of these bars differs considerably from those used by P. A. Heller and H. Jungbluth, who used round bars and made a point of maintaining a ratio of length to diameter of 20 : 1, while in the Paper mentioned[37] this ratio varied from 6 : 1 to 1 : 1. Besides, the materials were melted in oil-fired crucibles, and their preparation thus differs considerably from that employed by Heller and Jungbluth. Carbide content and Brinell hardness, as well as the influence of silicon, aluminium, nickel, and chromium, were studied.

From the graphs the present author has obtained the *c* values, having determined the exponents for the reduction in Brinell hardness with such accuracy as was permitted by the original tables (see Table III). It is seen that the *c* values in general are much lower than those of Heller and Jungbluth. The present author considers this due to the fact that in the case in question the pouring conditions approximated more closely to those of large castings, for which the sectional sensitivity is known

TABLE III.—*Wall-thickness Exponent "c" for Brinell Hardness according to Experiments of E. Piwowarsky and E. Söhnchen.*[37]

| Type. | No. | C. | Si. | C+Si. | Mn. | P. | S. | Ni. | Cr. | −c. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S G .. .. | 1 | 2.67 | 1.25 | 3.92 | 0.06 | 0.040 | 0.020 | — | — | 0.056 | |
| S B .. .. | 2 | 2.71 | 2.66 | 5.37 | 0.07 | 0.065 | 0.026 | — | — | 0.116 | |
| S O .. .. | 3 | 2.53 | 2.15 | 4.68 | 0.27 | 0.063 | 0.020 | — | — | 0.081 | |
| S M .. .. | 4 | 2.64 | 2.23 | 4.87 | 0.11 | 0.565 | 0.014 | — | — | 0.205 | |
| S C .. .. | 5 | 2.71 | 1.46 | 4.17 | 0.06 | 0.065 | 0.032 | 1.25 | — | 0.045 | |
| S D .. .. | 6 | 2.69 | 1.46 | 4.15 | 0.06 | 0.068 | 0.032 | 2.50 | — | 0.015 | |
| — | — | — | 1.50 | — | — | — | — | 0.00 | — | 0.060 | Constructed. |
| S Q .. .. | 7 | 2.60 | 2.13 | 4.73 | 0.12 | 0.045 | 0.013 | — | 0.32 | 0.133 | |
| S R .. .. | 8 | 2.40 | 2.12 | 4.52 | 0.05 | 0.048 | 0.007 | — | 0.60 | 0.097 | |

to be smaller than that of separately-cast bars. In addition the effect of silicon (heats 1, 2, and 3) and particularly of phosphorus (heats 3 and 4) in increasing the sectional sensitivity is also clearly brought out. Nickel decreases the sensitivity value (heats 5 and 6), while chromium (heats 7 and 8) does not appear to have much effect for there is only a slight difference between the exponents (0.133 against 0.097).

In other Papers[45, 52] the authors amplify this work, and used round bars of 20 mm., 30 mm.,

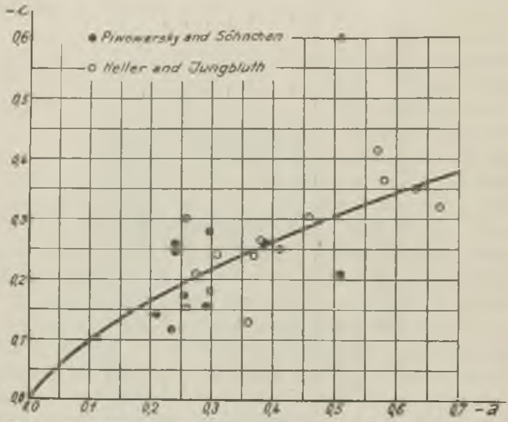


FIG. 9.—RELATIONSHIP BETWEEN EXPONENTS $a$ AND $c$.

40 mm., and 60 mm. diameter and 650 mm. long, thus approximating closely to the conditions chosen by Heller and Jungbluth. The heats were carried out in a 400-kw. electric-arc furnace, thus again with different means as employed by Heller and Jungbluth. The influences of silicon, phosphorus, aluminium, nickel, chromium, and molybdenum were studied and the tensile strength, Brinell hardness and carbide content also measured. Here also the present writer has deduced from the published curves the sectional exponent $a$ for tensile strength and $c$ for the Brinell hardness with the degree of

TABLE IV.—*Wall-thickness Exponent "a" for Tensile Strength and "c" for Brinell Hardness according to Experiments by E. Piwowarsky and E. Söhnchen.*[45]

| No. | C. | Si. | C+Si. | Mn. | P. | S. | Al. | Ni. | Cr. | Mo. | —a. | —c. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 .. | 3.00 | 1.20 | 4.20 | 0.39 | 0.149 | 0.012 | — | — | — | — | 0.114? | 0.110 |
| 2 .. | 3.00 | 1.20 | 4.20 | 0.43 | 0.245 | 0.008 | — | — | — | — | — | 0.102? |
| 3 .. | 2.95 | 1.18 | 4.13 | 0.45 | 0.639 | 0.008 | — | — | — | — | — | 0.179 |
| 4 .. | 2.85 | 1.05 | 3.90 | 0.44 | 0.863 | 0.006 | — | — | — | — | 0.510? | 0.600 |
| 18 .. | 3.10 | 3.56 | 6.66 | 0.54 | 0.121 | 0.012 | — | — | — | — | ? | ? |
| 5 .. | 3.08 | 1.30 | 4.38 | 0.44 | 0.070 | 0.018 | 0.21 | — | — | — | 0.2[illegible]2 | 0.154 |
| 6 .. | 2.98 | 1.48 | 4.46 | 0.41 | 0.076 | 0.016 | 0.47 | — | — | — | 0.386 | 0.260 |
| 7 .. | 2.96 | 1.26 | 4.22 | 0.42 | 0.072 | 0.014 | — | 1.85 | — | — | 0.296 | 0.280 |
| 14 .. | 3.28 | 0.62 | 3.90 | 0.54 | 0.093 | 0.032 | — | 3.10 | — | — | 0.209 | 0.142 |
| 13 .. | 2.82 | 1.12 | 3.94 | 0.42 | 0.774 | 0.013 | — | 1.70 | — | — | 0.510 | 0.208 |
| 15 .. | 3.32 | 3.12 | 6.44 | — | — | — | — | — | 0.57 | — | 0.236 | 0.115 |
| 16 .. | 3.32 | 2.95 | 6.27 | 0.48 | 0.100 | 0.023 | — | — | 0.99 | — | 0.256 | 0.172 |
| 9 .. | 3.04 | 1.28 | — | 0.45 | 0.070 | 0.015 | — | — | — | 0.27 | 0.242 | 0.258 |
| 10 .. | 2.98 | 1.22 | — | 0.41 | 0.076 | 0.010 | — | — | — | 0.50 | 0.242 | 0.246 |

accuracy possible; these are given in Table IV. If these values are compared with those of the first Paper it is seen at once that in general they are higher, which is undoubtedly due to the fact that a different bar shape was used. It is of interest, in spite of the difference in melting conditions, to attempt to correlate the values[45 52] found by Piwowarsky and Sohnchen and those of Jungbluth and Heller.[49] This is naturally only possible for the unalloyed materials, and for these only in so far as the phosphorus content remains within the limits prescribed by Heller and Jungbluth. Therefore as regards analysis only the melts No. 1, 2, and 18 are of value, of which No. 18 is, however, useless, as the wall-thickness exponent could not be determined sufficiently accurately. For melt No. 2 no values for the tensile strength were given; the exponent $a$ for melt No. 1 is in perfect accord with the values found by *Jungbluth and Heller*[49] and *Koch and Piwowarsky*,[48] respectively, as a glance at Fig. 7 will show.

For the Brinell hardness the exponent $c$ of melts Nos. 1 and 2 can be used, and its magnitude also agrees with the values of Heller and Jungbluth, as shown by Fig. 8. The curve is extremely satisfactory. A second observation of a general nature is not without interest. If all exponents $a$ and $c$ (Fig. 9) are compared without regard to the fact that *Heller and Jungbluth*[49] employed unalloyed and *Piwowarsky and Sohnchen*[45] alloyed material, it is seen that these values are also in satisfactory accord. The curve drawn through the various points conforms with that already given by *Heller and Jungbluth.*[49] Regarding the influence of the alloy elements, they confirm the facts already deduced in the first Paper.[37] Nickel (melts 7 and 14) reduces the sectional sensitivity, probably because the silicon content can be lowered. Aluminium (melts 5 and 6) and phosphorus (melts 1, 2, 3, and 4) raise this factor, phosphorus even if the casting contains 1.7 per cent. nickel (melt 13). Chromium (melts 15 and 16) and molybdenum

TABLE V.—*Wall-thickness Exponents "a," "b" and "c" for Box-shaped Castings from Work by E. Dübi.*[40, 51]

| No. | C + Si. | Dimension in mm. | − a. | − b. | − c. | Classification of Dübi.[51] |
|---|---|---|---|---|---|---|
| 1 | 4.70 | 190 × 220 × 650 | 0.036 | 0.072 | 0.016 | Group A b |
| 2 | 4.70 | 190 × 220 × 2,200 | 0.103 | −0.128 | 0.000 | ,, A c |
| 3 | 4.70 | 190 × 220 × 2,200 | −0.208 | 0.120 | 0.000 | ,, A c |
| 4 | 4.06 | 193 × 220 × 2,200 | 0.210 | 0.073 | 0.000 | ,, B a |
| 5 | 4.56 | 191 × 221 × 2,200 | 0.098 | −0.087 | 0.000 | ,, B b |
| 6 | 5.46 | 190 × 220 × 2,200 | −0.025 | 0.000 | 0.030 | ,, B c |
| 7 | 5.54 | 190 × 220 × 2,200 | 0.029 | 0.054 | −0.015 | ,, D a |
| 8 | 5.54 | 390 × 420 × 2,200 | 0.077 | 0.020 | −0.061 | ,, D a |
| 9 | 5.54 | 390 × 720 × 2,200 | 0.029 | 0.025 | 0.000 | ,, D a |
| 10 | 4.66 | 190 × 220 × 2,200 | 0.019 | 0.081 | −0.030 | ,, D b |
| 11 | 4.66 | 390 × 420 × 2,200 | 0.024 | 0.028 | −0.030 | ,, D b |
| 12 | 4.66 | 390 × 720 × 2,200 | 0.108 | 0.020 | 0.024 | ,, D b |

(melts 9 and 10) have but little influence. It was not possible to estimate numerically the influence of silicon, because melt 18 did not allow the calculating of the exponent.

The numerical values published by Piwowarsky and Sohnchen in both their Papers are of great importance, because they provide the first numerical data indicating the influence of alloy elements on the sectional sensitivity. But these two investigators will themselves agree with the writer that their experiments may be regarded merely as tentative ones which require amplification by others of greater precision.

### (b) Castings

However interesting and important investigations on test bars may be, it is natural that investigations on the sectional sensitivity carried out on the castings themselves are of far greater importance. The difficulty of such investigations is, firstly, that the differences in the properties of different wall thicknesses are on the whole smaller and besides depend closely on the shape of the castings. In spite of these difficulties it is imperative to attack this important problem, although it is realised that only partial solutions, and these even only approximate ones, can result.

It is logical to supplement the fundamental investigations on the effect of sectional sensitivity in the case of test bars of unalloyed material, with those on simple castings of unalloyed cast iron. But, unfortunately, the number of the observations available is much smaller than is the case with test bars.

*E. Dubi*[40 51*] has published two interesting Papers, already referred to, bearing on this subject. He cast box-shaped test castings of 30 mm., 50 mm., 60 mm. and 70 mm. wall thickness and between 650 mm. and 2,200 mm. in length, the inner core being in most cases 100 mm. by 100 mm., but occasionally 300 by 300 mm. and 300 by 600 mm. respectively. With the same composition of iron he also cast test-bars of 30 mm. and 50 mm. in diameter and, *inter alia*, determined the relevant tensile and transverse strengths as well as the Brinell hardness. The results obtained with the test bars have already been discussed above. Of the twelve castings investigated, only on the first one was the effect of all four wall thicknesses studied, and the logarithmic law satisfactorily confirmed, thus indicating that it is also valid for castings.

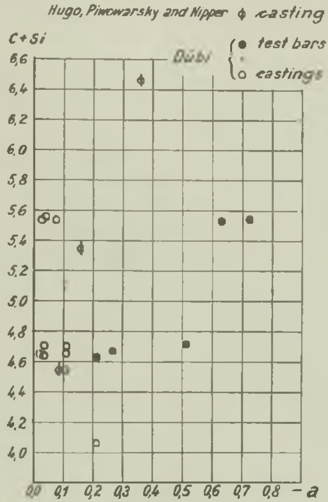


FIG. 10.—RELATIONSHIP BETWEEN C + SI AND $a$, DETERMINED ON CASTINGS AND TEST BARS RESPECTIVELY.

For the other eleven specimens only the strength for a wall thickness of 30 mm. and 70 mm. is given, so that, as with the test bars, the tangent has to be drawn on the basis of two points only. In Table V and Fig. 10, the $a$ values of the ten specimens are given. The two missing ones were positive. For comparison purposes the $a$ values of the corresponding test bars are also included. It is again seen that the $a$ values of the boxes are much smaller than those of the single bars. However, considering the very moderate number of values, no attempt can be made to determine a relation between the *a* values of the test bars and those of the castings.

The following remarks regarding the accuracy of this work are of interest. It can be taken for granted that with cast iron the greatest accuracy which can be obtained in determining the tensile strength does not exceed ± 1,067 lbs.

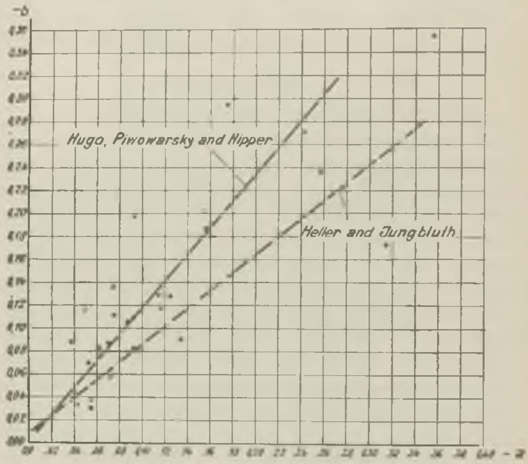


Fig. 11.—Relationship between Exponents *b* and *a*.

per sq. in. (0.75 kg. per sq. mm.), *i.e.*, an overall range of 2,134 lbs. per sq. in. (1.5 kg. per sq. mm.).* A difference in tensile strength of 2,134 lbs. per sq. in. (1.5 kg. per sq. mm.) with a wall 30 mm. or 70 mm. thick, corresponding to a sectional insensitivity, has an exponent *a* of – 0.09. From the ten casts of Dübi six are below this value, and are thus not affected by the wall thickness. Only four are above – 0.09,

* This is only the author's personal view. But even if a greater accuracy is assumed, the remarks which follow still apply.

namely, one with $-0.098$, a second one with $-0.103$, a third with $-0.108$, and a fourth with $-0.210$. In reality only the fourth shows an appreciable difference in the tensile strengths of walls 30 mm. and 70 mm. thick, viz., 6,686 lbs. per sq. in. (4.7 kg. per sq. mm.); with the third, the material with the highest exponent, the difference amounts only to 3,128 lbs. per sq. in. (2.2 kg. per sq. mm.), and therefore is just beyond the limit of experimental error. And just the material with the highest $a$ value has the lowest content of C + Si. It is thus not possible to establish a definite relationship between the C + Si factor and the exponent $a$, as was the case with test bars. Furthermore, no systematic connection appears to exist between the dimensions of the castings and the exponent $a$, at least within the range investigated by Dübi.

In Fig. 10 three values are also included from the work of Hugo, Piwowarsky and Nipper[50 57] (to be discussed below), obtained with unalloyed material with a normal phosphorus content. A glance at the diagram shows a satisfactory differentiation, as compared with Dübi, although the latter did not go up to C + Si contents of about 6.45 per cent. Whether the reason for the better differentiation is to be sought in the fact that Hugo and his collaborators used shorter (450 mm.), but wider (300 by 300 mm.) castings in their investigations cannot be established with certainty. As far as the $a$ values are concerned, Dübi's castings Nos. 10, 11 and 12 indicate something of this kind, although the values for Nos. 7, 8 and 9 do not confirm this assumption. In these circumstances no attempt can be made to utilise the exponents $b$ and $c$ for Dübi's casts in the subsequent critical analysis.

However unsatisfactory the results obtained from Dübi's data may be, although these were assembled and collated with every care and are of extreme interest, at least one important fact can be gleaned from this work. In a great many cases the sectional sensitivity of actual castings appears to be very small, if not altogether in-significant, this being an important practical conclusion. This statement is, moreover, confirmed by a co-operative investigation carried out by the Cast Iron Committee of the Verein deutscher Eisenhüttenleute under the chairmanship of the author, regarding which full details cannot be furnished in this Paper, since the investigations are still in progress.*

As was the case with the test bars, the investigations of Dübi on unalloyed material are supple-

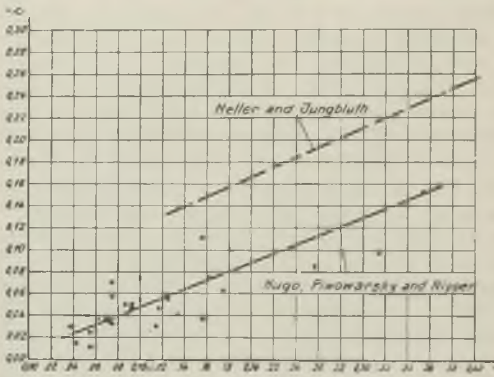


FIG. 12.—RELATIONSHIP BETWEEN EXPONENTS *c* AND *a*.

mented by researches carried out by the Piwowarsky school, which were directed at establishing the influence of alloy additions on the sectional sensitivity of castings. *E. Hugo, E. Piwowarsky and H. Nipper*[50 52] employed for their investigations box-shaped castings with an outside diameter of 300 by 300 by 450 mm. and a wall thickness of 20 mm., 40 mm., 60 mm. and 80 mm. The iron was taken from the cupola and the alloys were added in the ladle. They examined the influence of silicon, phosphorus,

* The early investigations of Sulzer Broth., Winterthur (" C. Jüngst, Stahl u. Eisen," 29 (1909), pp 1177–82), gave the same results.

TABLE VI.—*Wall-thickness Exponents from Experimental Work of E. Hugo, E. Piwowarsky and H. Nipper.*[93]

| Melt No. | C. | Si. | Mn. | P. | S. | Ni. | Cr. | Mo. | W. | Cu. | −a. | −b. | −c. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.35 | 1.20 | 0.67 | 0.20 | 0.135 | — | — | — | — | — | 0.093 | 0.109 | 0.050 |
| 2 | 3.20 | 2.16 | 0.50 | 0.25 | 0.100 | — | — | — | — | — | 0.156 | 0.188 | 0.111 |
| 3 | 3.02 | 3.43 | 0.62 | 0.26 | 0.100 | — | — | — | — | — | 0.355 | 0.353 | 0.153 |
| 4 | 3.29 | 2.16 | 0.63 | 0.42 | 0.135 | — | — | — | — | — | 0.093 | 0.198 | 0.048 |
| 5 | 3.28 | 2.07 | 0.60 | 0.73 | 0.110 | — | — | — | — | — | 0.175 | 0.295 | 0.063 |
| 6 | 3.26 | 1.97 | 0.57 | 1.04 | 0.110 | — | — | — | — | — | 0.242 | 0.271 | 0.080 |
| 7 | 3.26 | 2.11 | 0.60 | 0.20 | 0.115 | 1.03 | — | — | — | — | 0.075 | 0.080 | 0.070 |
| 8 | 3.24 | 2.02 | 0.60 | 0.20 | 0.115 | 2.30 | — | — | — | — | 0.072 | 0.058 | 0.035 |
| 9 | 3.26 | 1.93 | 0.60 | 0.22 | 0.115 | 3.22 | — | — | — | — | 0.055 | 0.030 | 0.025 |
| 10 | 3.26 | 1.64 | 0.60 | 0.23 | 0.13 | 2.17 | — | — | — | — | 0.088 | 0.080 | 0.050 |
| 11 | 3.35 | 1.08 | 0.57 | 0.20 | 0.14 | 3.02 | — | — | — | — | 0.055 | 0.038 | 0.013 |
| 12 | 3.33 | 1.60 | 0.63 | 0.41 | 0.13 | 2.09 | — | — | — | — | 0.135 | 0.090 | 0.043 |
| 13 | 3.33 | 1.60 | 0.63 | 0.77 | 0.13 | 2.11 | — | — | — | — | 0.156 | 0.202 | 0.038 |
| 14 | 3.33 | 1.55 | 0.57 | 0.98 | 0.13 | 2.01 | — | — | — | — | 0.258 | 0.236 | 0.085 |
| 14B | 3.28 | 1.55 | 0.59 | 1.02 | 0.11 | 1.95 | — | — | — | — | 0.315 | 0.173 | 0.098 |
| 15 | 3.22 | 2.20 | 0.54 | 0.21 | 0.18 | — | 0.29 | — | — | — | 0.093 | 0.083 | 0.050 |
| 16 | 3.22 | 2.77 | 0.57 | 0.21 | 0.14 | — | 0.67 | — | — | — | 0.163 | 0.180 | 0.075 |
| 17 | 3.27 | 3.29 | 0.60 | 0.21 | 0.14 | — | 1.13 | — | — | — | 0.182 | 0.301 | 0.100 |
| 18 | 3.27 | 2.15 | 0.63 | 0.23 | 0.14 | 1.36 | 0.69 | — | — | — | 0.115 | 0.129 | 0.030 |
| 19 | 3.25 | 1.65 | 0.59 | 0.20 | 0.12 | 2.20 | 0.71 | — | — | — | 0.070 | 0.088 | 0.038 |
| 20 | 3.33 | 1.32 | 0.59 | 0.21 | 0.12 | 3.14 | 0.78 | — | — | — | 0.043 | 0.033 | 0.015 |
| 21 | 3.35 | 2.25 | 0.60 | 0.21 | 0.13 | — | — | 0.21 | — | — | 0.100 | 0.143 | 0.055 |
| 22 | 3.35 | 2.20 | 0.60 | 0.20 | 0.13 | — | — | 0.47 | — | — | 0.075 | 0.136 | 0.058 |
| 23 | 3.33 | 2.25 | 0.60 | 0.20 | 0.12 | — | — | 1.04 | — | — | 0.038 | 0.088 | 0.030 |
| 24 | 3.36 | 2.25 | 0.60 | 0.22 | 0.11 | — | — | — | 0.10 | — | 0.100 | 0.151 | 0.075 |
| 25 | 3.34 | 2.20 | 0.63 | 0.22 | 0.10 | — | — | — | 0.54 | — | 0.063 | 0.083 | 0.038 |
| 26 | 3.30 | 2.20 | 0.60 | 0.23 | 0.10 | — | — | — | 1.49 | — | 0.118 | 0.119 | 0.045 |
| 26B | 3.26 | 2.06 | 0.60 | 0.21 | 0.13 | — | — | — | 2.22 | — | 0.125 | 0.129 | 0.055 |
| 27 | 3.28 | 2.16 | 0.61 | 0.20 | 0.13 | — | — | — | — | 0.72 | 0.075 | 0.111 | 0.033 |
| 28 | 3.26 | 2.11 | 0.60 | 0.20 | 0.13 | — | — | — | — | 1.91 | 0.088 | 0.106 | 0.040 |
| 29 | 3.26 | 2.11 | 0.61 | 0.20 | 0.13 | — | — | — | — | 2.80 | 0.053 | 0.070 | 0.040 |

nickel, chromium, molybdenum, tungsten and copper. On account of the wide range of this work it is obvious that of a total of 31 melts only two or three heats were available to indicate the influence of each separate element; we are thus again dealing with introductory tests only. The authors themselves already calculated the sectional exponents and correlated these in a diagram. With such accuracy as is determined by the small scale employed the writer has

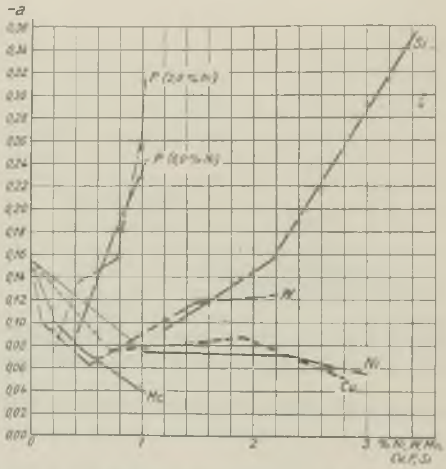


Fig. 13.—Influence of Various Elements on the Sectional Sensitivity, according to Hugo, Piwowarsky and Nipper.

grouped in Table VI those exponents of principal interest. If these values are only roughly compared with those found for test bars (Tables I, II and IV), a first glance shows that the numerical values of $a$, $b$ and $c$ are much smaller, thus bringing out the influence of the test objects. If, in order to make a general survey of the numerical values available, the relationship between $a$ and $b$ and also $a$ and $c$ are plotted graphically (Figs. 11 and 12), it is seen that, contrary to *Heller and Jungbluth*,[48] with *Hugo, Piwowarsky and Nipper*,[52] the transverse strength (Fig. 11) appears to differ more than the tensile strength. This is a remarkable fact for which the present writer cannot offer a satisfactory explanation. Nevertheless, it must be borne in mind that Hugo and his collaborators in their bending tests used machined bars, while the writer and his collaborator employed "as-cast" ones. The trend of the relationship between *a* and *c* (Fig. 12) found by Hugo, Piwowarsky and Nipper is the same as that deduced by Heller and Jungbluth, except that the latter's curve is higher, while they also dealt with materials having higher values.

Fig. 13 shows the relationship between the alloy elements and *a* values, and confirms the long-known result that silicon and especially phosphorus raise the sectional sensitivity considerably (phosphorus even in the presence of 2 per cent. Ni), and that molybdenum and nickel lower it, while copper has the same effect up to 1 per cent., but beyond this has only a slight influence. The effect of tungsten is doubtful. It is worth while to study in more detail the effect of nickel. To do this the writer has drawn Fig. 14, in which the effect of nickel for three different silicon contents is represented. The values for zero nickel and the requisite silicon content are obtained by interpolation from the silicon curve in Fig. 13. It is seen that at a high silicon content, viz., at about 2 per cent., the addition of about 1 per cent. nickel considerably lowers the sectional sensitivity, but that a further increase in nickel has no marked additional influence. (The absolute strength did not in fact increase.) At 1.65 per cent. Si the decrease in sectional sensitivity by adding more than 2 per cent. nickel was only moderate, and at 1.12 per cent. Si practically negligible (only the absolute strength with a wall thickness of, *e.g.*, 20 mm. increased from about 13.9 tons per sq. in. (22 kg. per sq. mm.) to 16.8 tons per sq. in. (26.5 kg. per sq. mm.). The effect of the chromium at different silicon contents is shown

TABLE VII.—*Sectional Sensitivity of Castings in Normal Production.*

| No. | Type of Casting. | Composition. | | | | | | — a. |
|---|---|---|---|---|---|---|---|---|
| | | C. | Si. | C+Si. | Mn. | P. | S. | |
| 1 | Steam cylinder .. .. .. | 3.20 | 1.07 | 4.27 | 0.57 | 0.16 | 0.06 | 0.140 |
| 2 | Steam chest .. .. .. .. | 3.31 | 1.19 | 4.50 | 0.83 | 0.20 | 0.10 | 0.081 |
| 3 | Steam cylinder .. .. .. | 3.31 | 1.42 | 4.73 | 1.13 | 0.13 | 0.08 | 0.070 |
| 4 | Steam cylinder .. .. .. | 3.40 | 1.60 | 5.00 | 0.63 | 0.19 | 0.10 | 0.095 |
| 5 | Wheel body .. .. .. .. | 2.74 | 1.63 | 4.37 | 0.42 | 0.19 | 0.10 | 0.170 |
| 6 | Steam chest .. .. .. .. | 3.36 | 1.43 | 4.79 | 0.95 | 0.21 | 0.09 | 0.189 |

in Fig. 15, which the writer has also based on the data of Hugo and his collaborators. According to these investigations this effect—in each case between 2 and 3 per cent. Si and 0.3 to 1.2 per cent. Cr—causes a diminution of the sectional factor, which is apparent *a priori*.

At the end of this section reference may be made to the sectional sensitivity of castings included in a normal day's output. The writer was able to study specimens of different wall thick-

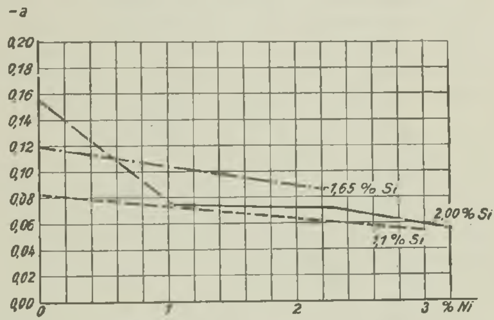


FIG. 14.—INFLUENCE OF NICKEL AND SILICON ON THE SECTIONAL SENSITIVITY, ACCORDING TO HUGO, PIWOWARSKY AND NIPPER.

ness from some discarded castings made by Fried. Krupp A.-G., Essen. The German standard test bar of 30 mm. diameter and 650 to 700 mm. long had also been separately cast and tested. In Table VII the most important data are collated, and Fig. 16 shows graphically the strength values for different wall thicknesses. Nos. 1, 3 and 4 were obtained from locomotive cylinders, weighing about 2,977 lbs. or 1,350 kg., Nos. 2 and 6 from steam storage tanks weighing about 331 lbs. or 150 kg., and No. 5 from a wheel body. A definite relationship between the various values is not immediately apparent. All that can be deduced is that, except for No. 6, the sectional sensitivity is on the whole small.*

### III.—Relations between Strength Characteristics of Wall-Thickness Specimens and of Test Bars

The question of the relationship between the strength properties of wall-thickness specimens and of separately-cast or attached test bars is

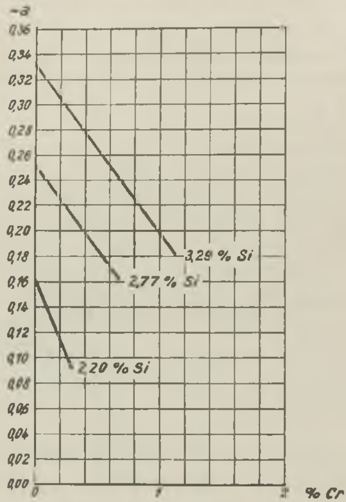


FIG. 15.—INFLUENCE OF CHROMIUM AND SILICON ON THE SECTIONAL SENSITIVITY.

just as important to the foundryman as a knowledge of the sectional sensitivity *per se*. It is so closely connected with this latter characteristic that at least a brief discussion is necessary at this place.

Here, too, only few systematic investigations have been carried out. Firstly, J. W. Bolton's[28]

* The very interesting and perhaps also important fact may be mentioned, that the difference between the strength of the separately-cast test bar of 30 mm. diameter and the strength of the same wall thickness to be interpolated is clearly related to the C + Si content, a fact which is obvious *a priori* and of potential practical value.

proposals must be recalled, that the test bars must have the same ratio of volume to surface as the castings themselves. Furthermore M. v. Schwarz and A. Väth[46] on the basis of their experiments concluded that separately-cast test bars with a diameter double the wall thickness of platelike castings have roughly the same strength properties as the castings themselves. This would indicate, as simple mathematical considerations show, that for one and the same iron the sectional sensitivities of a casting and of the corresponding test bars would be the same, a fact not supported by the experimental data of other investigators. v. Schwarz and Väth also point out in their Paper that for castings of more complicated shapes other laws would be valid than those which they had found in regard to castings of simple shape.

It is perhaps possible to deduce a general law from the observations made by the writer on the above-mentioned discarded castings from Krupp's production, namely that the difference between the strengths of the test bar of 30 mm. diameter and of a wall thickness of 30 mm. becomes steadily smaller with improvement in the quality of the cast iron. This difference is practically zero for high-duty cast iron, and as this material has also only a small sectional sensitivity the 30 mm. test bar already very closely represents, in the opinion of the author, the strength of the casting itself.

It is due to Dübi[40 51] to have introduced an entirely new aspect of the relationship between wall thickness and test bar values, by his proposal of the "hardness characteristic." His suggestion may be formulated as follows: It is definitely not possible to establish fundamental relationships between the different mechanical values of cast iron. But for specific cast irons of similar class, relationships of this type can be found with a satisfactory accuracy to apply to such specific groups, which he deduces from some of his earlier work.* He therefore proposes to cast with the castings to be tested

* Report of discussion No. 37 of the Swiss Institution for Testing Materials at the E.T.H., Zürich, Dec., 1928, pp. 7–18.

two separate test bars of 30 mm. and 50 mm. diameter respectively, of which the tensile strength and Brinell hardness are determined. He then plots the tensile strength of the bars as a function of the Brinell hardness, and thus obtains in his diagram two points which are joined by a straight line called the "hardness characteristic" ("Härtecharakteristik"). If the casting is now tested for Brinell hardness, the hardness characteristic will give the tensile

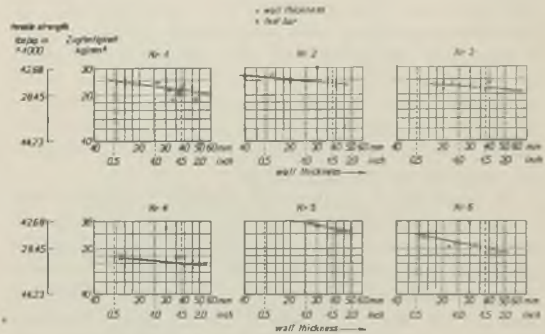

Fig. 16.—Sectional Sensitivity of Castings in Normal Production.

strength corresponding thereto. In Fig. 17 the hardness characteristics are given as drawn from the average value. E. Dübi [51] suggests that the hardness characteristic $H = f\ (\beta z)$ for a specific cast iron is a suitable source of information of the effect of the wall thickness or the sectional sensitivity. The writer does not entirely subscribe to this assumption. However, a theoretical basis seems to be provided, and it is now necessary to collect more experimental data. The above-mentioned investigations of the Cast-Iron Committee of the Verein deutscher Eisenhüttenleute are including consideration of this matter.

## IV.—Sectional Sensitivity of Other Metals

In conclusion it is of interest to consider in what range of values the sectional sensitivity of other alloys may lie, as this alone will show whether cast iron in this respect suffers from a special disability or not. This is definitely the case if an iron casting is compared with steel castings. The writer has analysed data published by A. Rys* on alloyed and plain steel castings. Up to a wall thickness of 120 mm. no sectional effect can be found in the vast majority of cases considered. Even between wall thicknesses of 40 to 400 mm. the $a$ values lie within

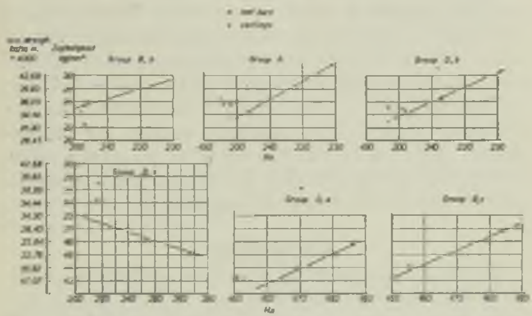

FIG. 17.—HARDNESS CHARACTERISTICS OF TEST CASTINGS (DÜBI).

the range of only 0.03 to 0.07, these values being in fact derived not from castings but from test bars, which certainly show a greater variability than the castings. Black-heart malleable iron, too, gives better results. H. Jungbluth and F. Brügger† determined the tensile strength of American malleable iron on specimens of different diameters. If these values are plotted logarithmically a straight line is obtained with a gradient of −0.18, representing a small value for test bars. On the other hand, the sectional sensitivity of aluminium alloys is of the same order of magnitude as that of cast iron. *H. v. Schwarz*‡ gives a series of strength values for

* "Kruppsche Monatshefte," **11** (1930), pp. 47–76. Cf. Stahl u. Eisen, **50** (1930), pp. 423–38.

† "Schriften des Reichskuratorium für Technik in der Landwirtschaft," Berlin, S.W.11, No. 56 (1934).

‡ "Zeitschrift für Metallkunde," **25** (1933), pp. 269–74.

aluminium alloys, from which *H. Jungbluth and P. A. Heller** selected a "self-improving" German aluminium alloy and compared it with a cast iron of the German standard Ge 14.91, with a tensile strength of about 8.8 tons per sq. in. (14 kg. per sq. mm.). At the time they already came to the conclusion that the sectional sensitivity of the two alloys did not differ very much. If they are expressed by $a$ values, the cast iron in question had a value of $-$ 0.63 and the aluminium a value of $-$ 0.69. These values are in good agreement with those recently found by *E. Söhnchen*† on temperable aluminium alloys and which ranged between $-$ 0.13 and $-$ 0.75.

The material "cast iron" in regard to its sectional sensitivity does not occupy an exceptional position. It shares this property with other cast alloys, while its numerical value is also of the same order of magnitude.

## Conclusions

Summarising the above the following conclusions may be drawn:—

(1) The problem as regards the general law of sectional sensitivity of plain cast iron test bars can be assumed to be solved. Numerical relationship between the C + Si and the sectional exponent $a$, $b$ or $c$ can be stated, which are as close as can be expected only in the case of statistical relationships.

(2) Investigations have also been conducted on the influence of alloy elements on the sectional sensitivity of test bars, which must be regarded as tentative experiments. They present a qualitatively consistent picture, but for quantitative evaluation the number of experiments made is not yet large enough.

(3) The data on the sectional sensitivity of castings are still more meagre. It is for the present by no means sufficient to give a clear conception of the numerical relationships. Especially in this direction a wide field is still open for research.

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* "Stahl u. Eisen," **54** (1934), p. 1092.
† "Giesserei," **22** (1935), pp. 100–108.

(4) Concerning the influence of alloy elements on the sectional sensitivity of castings the data available are as voluminous as those for test bars. Here also only qualitative and not quantitative conclusions can be drawn.

(5) The relationship between the mechanical properties of the wall thickness in castings and in test bars is likewise still obscure. At most it can be said that for high-duty cast iron the mechanical properties of the test-bar coincide up to a point with those of the casting. Systematic investigations are also urgently required in this direction, and in Germany at least are now being carried out.

(6) The sectional sensitivity of cast iron is not peculiar to this material alone. It shares it with other cast alloys, cast iron being thus comparable to aluminium, while black-heart malleable iron has a lower and cast steel no sectional sensitivity.

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# THE FRACTURE OF PIG-IRON AND CAST IRON

By A. L. Norbury, D.Sc. (Member) and
E. Morgan, M.Sc. (Associate Member)

## Introduction

The fracture of pig-iron is in some ways less important in the foundry nowadays than it used to be, when it was the only guide to the fracture to expect in castings made from that pig-iron. Nowadays chemical analysis of the iron is used in many foundries to control the product, and in some cases the analysis is controlled remarkably closely, for example to within $\pm$ 0.1 per cent. of total carbon, silicon, manganese and phosphorus. In other ways, however, the fracture of pig-iron and of cast iron—which is the same material from the present point of view—is taking on a new importance, since chemical analysis of itself does not give a complete guide to the properties of cast iron. It is possible for two pig-irons or two castings of the same general analysis to have different fractures and widely-different mechanical and other properties. The investigation and control of such differences is consequently of considerable importance.

In order to recognise differences in pig-irons not revealed by general chemical analysis, it is first of all necessary to understand how variations in general chemical analysis affect the fracture. Consequently in the present Paper, after describing the various fractures of pig-iron, the effect of composition, and particularly carbon and silicon content, on the fracture, is first dealt with. Following this illustrations are given of differences in fracture which are not revealed by the general chemical analysis, such differences being produced by the presence in the metal of finely divided non-metallic inclusions, particularly those containing titanium.

## Numbering of Pig-Iron Fractures

The coarseness of the fracture of a pig-iron is conventionally indicated by a number or by a name such as "half-bar," "forge," "cylinder," etc. The coarsest fracture is known as a No. 1, and the progressively finer ones as Nos. 2, 3, 4, etc. The openness of the fracture depends on the size of the graphite flakes, which are as large as about $\frac{1}{8}$ in. across in the middle of a No. 1 fracture and up to about $\frac{1}{16}$ in. in the No. 2 fracture. Both these fractures are coarser in the middle than round the outside. In the No. 3 fracture, however, this is not the case. A remarkable difference occurs. The fracture is fine in the lower part of the pig and coarse in the upper part, somewhat as shown in Fig. 1B.* The differences in the coarseness of this fracture are due to local differences in total-carbon content—as shown in Fig. 1—the carbon having floated up during solidification. In the fine part the carbon content is not above the eutectic composition and in the coarse part it is above it, and coarsens the fracture as discussed in detail later. The fine area in this type of fracture can vary in extent from a small patch in the middle of the lower half of the fracture, to a large area extending higher up than shown in Fig. 1B, according to the composition of the pig and consequent extent of the area containing less carbon than the eutectic value. The rim of such a fracture may contain more carbon than the eutectic and be coarse, since it solidifies more rapidly, and this prevents carbon floating up out of it and lowering its composition to below the eutectic.

The next fracture is a No. 4 or forge. This fracture is below the eutectic composition throughout, and is coarser in the middle than at the outside, due to the normal rate of cooling effect. Progressively finer fractures are of

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* From Bulletin, British Cast Iron Research Association, July, 1931, p. 7. "Flotation of Graphite in Cast Iron," by A. L. Norbury, D.Sc., and C. Rowley.

similar type, and are known as No. 5, No. 6, cylinder, etc., and finally there are, of course, mottled, spotted white and white fractures.

In passing, it may be noted that the numbering given by different furnaces to given frac-

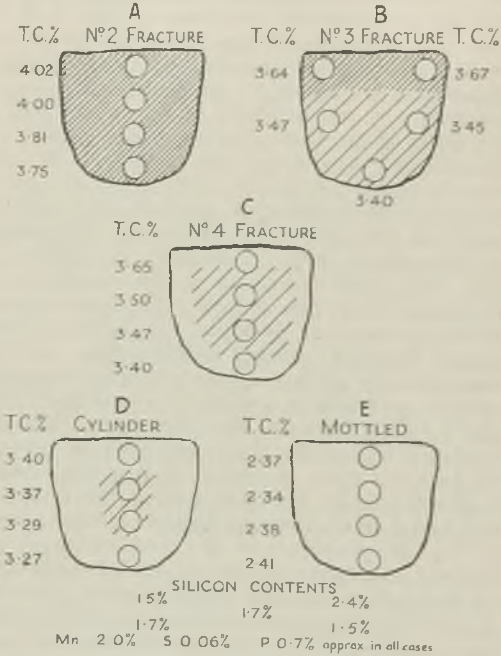


Fig. 1.—Flotation of Graphite in Pig-irons of Different Fracture.

tures varies considerably, since a furnace making close fractured irons only occasionally makes very open irons, and *vice versa*. The result is that a different range of numbering, and sometimes a different number for the same type of fracture, is adopted. It would be an advantage if a standard system of numbering could be devised which could be adopted by all furnaces.

### Effect of Carbon and Silicon on Fracture

The two chief elements of composition which affect the fracture are the carbon and silicon contents. The higher the carbon in a given composition, the coarser the graphite flakes and the more open the fracture. Carbon is, however, not the only element which affects the fracture; silicon has an almost equally important effect. The interdependent effect of carbon and silicon on the fracture is illustrated in Fig. 2, which shows that the fracture of pig-iron made in a given furnace depends essentially on the carbon and silicon contents. Phosphorus has a very similar effect to silicon in reducing the solubility of carbon and sulphur, if not neutralised by manganese, has a chilling effect, but the chief elements of composition which affect the fracture are the carbon content and the silicon content. This was pointed out by Siegle* in 1922. This is shown in Fig. 2, where No. 1 and No. 4 fracture irons, all made in the same furnace, are plotted against total carbon and silicon. It will be seen that a No. 1 fracture iron contains about 4 per cent. total carbon when 2 per cent. silicon is present, but only $3\frac{1}{2}$ per cent. total carbon with 4 per cent. silicon. That is to say, silicon in the iron lowers the total-carbon content necessary to give a certain fracture. When about 10 per cent. silicon is present—as in ferro-silicon—the blast-furnace product which has a No. 1 fracture contains only about 2 per cent. carbon.

The reason it is possible to obtain a No. 1 fracture with 4 per cent. carbon and 2 per cent. silicon, and with 2 per cent. carbon and 10 per cent. silicon is that both contain coarse kish-like graphite flakes, since silicon reduces the solubility of carbon in molten cast iron in the following manner: When no silicon is present, pig-iron can dissolve as much as 4.3 per cent. carbon, but no more, when it is just melted,

* Siegle, Proceedings of the Institute of British Foundrymen 1922, p. 54.

which occurs at about 1,150 deg. C. (If the temperature is raised, more carbon can be dissolved.) This easily melted 4.3 per cent. carbon composition is known as the eutectic = easily melting composition, and its carbon content is reduced by the presence of silicon as follows: When 2 per cent. silicon is present and the metal is just melted at 1,150 deg. C., the metal can only dissolve 3.8 per cent. carbon. Similarly, when 10 per cent. silicon is present, only 1.8 per cent. carbon can be dissolved. In other words,

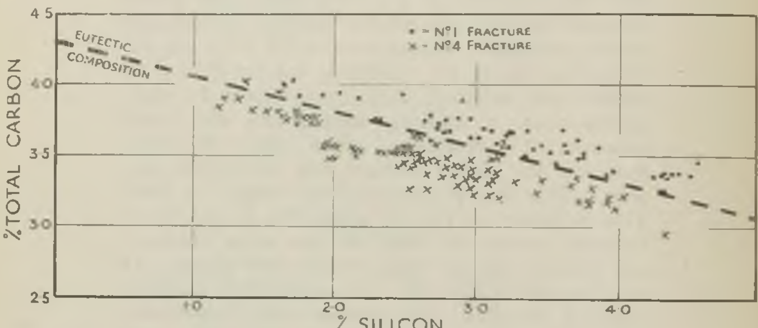


Fig. 2.—Effect of Total Carbon and Silicon Content on the Fracture of Pig-iron.

silicon reduces the amount of carbon that pig-iron can dissolve at the eutectic temperature, *i.e.*, when it is just melted. As the temperature is raised above the eutectic temperature, more carbon can be dissolved; very roughly about 0.2 per cent. more carbon can be dissolved each 100 deg. C. rise in temperature. On cooling, this excess carbon, of course, becomes insoluble and forms solid graphite flakes in the molten metal. These grow to the largest size and are seen in the No. 1 fracture. They also tend to float up out of the molten metal and form kish.

Consequently, in Fig. 2 it will be seen that increasing the silicon content, by reducing the carbon content of the eutectic, reduces the carbon content at which cast iron begins to contain the kish-forming graphite which produces the No. 1 fracture. In Fig. 2, in the case of irons containing less carbon than the eutectic, it will be seen that No. 4 fractures are formed, which are not nearly so coarse as the No. 1, since they do not contain the kish-forming graphite, although they contain uniformly distributed medium-sized graphite flakes. As the carbon is further reduced below the eutectic composition, the micro-

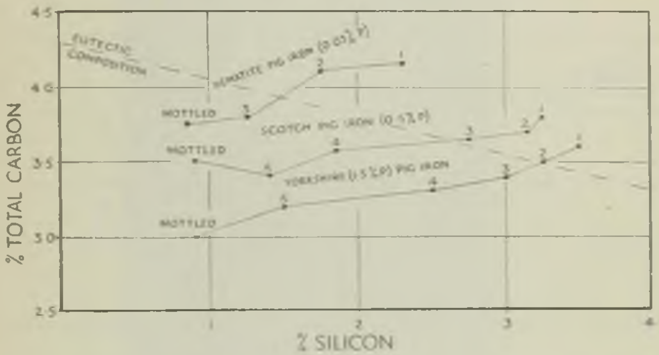


Fig. 3.—Analyses of the Different Fractured Pigs produced by Three Typical Blast-furnaces.

scope shows that the iron becomes interlaced with increasing quantities of fine fern-like crystals which are of a steel-like nature, except in so far as they are brittle in high-silicon irons, due to the silicon dissolved in them. Their effect on the fracture is to make it finer, since they reduce the amount of eutectic graphite present and restrict the growth of graphite flakes by their interlacing formation.

### Effect of Blast-Furnace Operation on Fracture

The production of open or close fractured pig-iron depends on the burden and operating conditions in the blast-furnace and Fig. 3 gives a general idea of the average analyses of the various fractured irons produced by three typical furnaces. It will be seen in Fig. 3, first that both carbon and silicon increase as the fracture becomes more open, and secondly that the silicon content of a given fracture is consistently lower in the case of the hematite irons than it is in the case of the Yorkshire irons, and at the same time the carbon content is also lower in the latter, since the higher silicon and phosphorus contents lower the carbon content, as shown in Fig. 2.

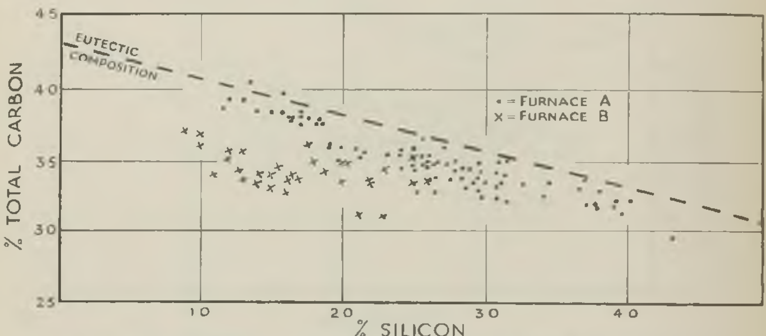


FIG. 4.—DIFFERING ANALYSES OF NO. 4. FRACTURE PIG-IRONS PRODUCED BY TWO DIFFERENT BLAST-FURNACES.

The good qualities associated with the name cold-blast iron are, it is thought, now considered as being due to the irons being relatively low in carbon and consequently stronger, their production resulting from lower furnace temperatures, which result in less carbon being picked up.

## Differences in Pig-Irons and Cast Irons Not Revealed by Ordinary Chemical Analysis

Up to the present the effect of straightforward chemical analysis on fracture has been considered, but this by itself, as stated at the outset, does not completely determine the fracture of pig-iron. This has long been observed and the something else which affects the fracture has been variously termed the "inherent property," "heredity," etc. An illustration of this type of variation in pig-iron is shown in Fig. 4, where it will be seen that the No. 4 fractures made by one furnace have not the same carbon

Fig. 5.—Mixed Fine and Coarse Graphite Structure of Iron A (see Table I). × 200.

content in an otherwise similar analysis as those made by another furnace, and that for a given silicon content the No. 4 iron from furnace B would tend to be stronger than one from furnace A, since its carbon content is lower.

In the past, the superior qualities of one pig-iron over another were probably in many cases largely accounted for by a lower carbon-content or some other analytical difference which was not fully realised. Nevertheless, at the present time, with analytical and test-bar control becoming more and more exact, it is becoming firmly established that differences do exist between different

FIG. 6.—UNIFORMLY - COARSE GRAPHITE STRUCTURE OF IRON B (SEE TABLE I). × 200.

brands of pig-iron which are not revealed by ordinary chemical analysis and which may be reproduced in castings made from them. One of the first investigators of this type of variation was F. J. Cook* in 1908, who drew

* F. J. Cook, Presidential Address, Institute of British Foundrymen, 1908, p. 14, and F. J. Cook and C. Hailstone, "The Effect of Structure on the Physical Properties of Cast Iron," *Ibid.*, 1908-1909, p. 99.

attention to differences in strength and phosphide network structure of grey irons of the same chemical analysis. That grey cast iron can vary in this manner is now well known and illustrations are given in Figs. 5 and 6 and Table I, where the differences in the mechanical properties of irons A and B of the same chemical analysis, are due to differences in the size of the graphite flakes. The more

TABLE I.—*Cast Irons A and B of the Same Analysis and Different Mechanical Properties.* (1.2 in. *Diameter Sand-Cast Bars.*)

| | A | B |
|---|---|---|
| Total carbon, per cent. .. | 2.91 | 2.94 |
| Combined carbon, per cent. .. | 0.62 | 0.80 |
| Silicon, per cent. .. .. | 1.82 | 1.70 |
| Manganese, per cent. .. .. | 0.67 | 1.00 |
| Sulphur, per cent. .. .. | 0.03 | 0.03 |
| Phosphorus, per cent. .. .. | 0.03 | 0.03 |
| Transverse strength (tons per sq. in., 18-in. centres) .. | 23.1 | 39.8 |
| Tensile strength (tons per sq. in.) .. .. .. .. | 14.4 | 23.4 |
| Repeated impact (no. of blows to fracture) .. .. .. | 68 | 3,476 |
| Brinell hardness (10/3,000/30) | 207 | 241 |

uniform graphite structure in iron A, giving a stronger iron in this low carbon composition, than the mixed structure in iron B.

A more extreme difference in graphite size, in two high total-carbon irons of the same analysis (cast in green sand into 3 in. diameter bars, 20 in. long) is shown in Figs. 7 and 8. The fractures of the bars are shown in Figs. 9 and 10 and their different mechanical properties in Table II.

In this composition the almost completely refined fine-graphite bar D is considerably stronger than the coarse-graphite bar C.

Refining the graphite in this manner increases the strength to the greatest extent in high total-carbon irons that are approaching the eutectic composition in carbon content. As the carbon content decreases below this, refining the graphite produces a smaller increase in strength and in the case of very low total-carbon irons it may even decrease it somewhat. It should also be noted that in low total-carbon irons* mixed

TABLE II.—*Cast Irons C and D of the Same Analysis and Different Mechanical Properties. (3-in. Diameter Sand-Cast Bars.)*

| | C | D |
|---|---|---|
| Total carbon, per cent. .. | 3.59 | 3.47 |
| Combined carbon, per cent. .. | 0.73 | 0.28 |
| Silicon, per cent. .. .. | 2.78 | 2.87 |
| Manganese, per cent. .. .. | 0.72 | 0.59 |
| Sulphur, per cent. .. .. | 0.03 | 0.03 |
| Phosphorus, per cent. .. .. | 0.02 | 0.02 |
| Titanium, per cent. .. .. | 0.07 | 0.28 |
| Transverse strength (tons per sq. in. on 18-in. centres) .. | 17.4 | 30.3 |
| Tensile strength (tons per sq. in.) on ⅜-in. bars machined from— | | |
| (1) Half-way between centre and edge .. .. .. | 7.5 | 19.5 |
| (2) Near centre. .. .. | 8.5 | 12.3 |
| Brinell hardness— | | |
| Edge .. .. .. .. | 134 | 179 |
| | 143 | 179 |
| | 163 | 170 |
| 10/3,000/30 Centre .. .. | 152 | 174 |

fine and coarse graphite structures (as shown in Fig. 5) have lower mechanical properties than uniformly coarse structures (as shown in Fig. 6).

## Effect of Titanium Slag Inclusions on Graphite Size and Fracture

The change from the coarse graphite to the fine graphite structure has been produced by

* Attention was drawn to this in a Paper by the authors in the Journal of the Iron and Steel Institute, 1930 (I), pp. 367–392.

Piwowarsky* and others by superheating molten cast iron to above 1,500 deg. C. The authors have found that it may be produced by dissolving a small amount of ferro-titanium in molten cast iron and oxidising it by bubbling carbon-dioxide gas through the molten metal.† Only about

FIG. 7.—COARSE GRAPHITE STRUCTURE OF IRON C (SEE TABLE II). × 50 (UNETCHED).

0.2 per cent. Ti is necessary, and ferro-silicon-titanium is the most easily dissolved ferro-alloy. The bar D, shown in Figs. 8 and 10, was obtained by treating in this manner a similar charge to that used for bar C, shown in Figs. 7 and 9, which was untreated. Both were crucible

* E. Piwowarsky, Transactions of the American Foundrymen's Association, 1926, vol. 34, p. 914.
† British Patent 425,227 of 1935.

melted. It is thought that it is not the titanium itself, but slag inclusions formed by the titanium, which produce this effect on the way the graphite crystallises, since the titanium has to be oxidised before it has this effect. Moreover, if hydrogen is bubbled through a melt treated with titanium

FIG. 8.—FINE GRAPHITE STRUCTURE OF IRON D (SEE TABLE II). × 50 (UNETCHED).

plus carbon dioxide, a coarse, instead of a fine graphite structure, is produced. It is also essential that the metal to be treated should be sufficiently free from other slag inclusions, and this is by no means usually the case with cupola melted metal and is being further investigated. The metal must also be below the eutectic composition for it to be fine, since kish graphite coarsens the fracture.

As a result of the above finding, a number of pig-irons were analysed for titanium, and it was found to be an almost universal constituent, but varied considerably in amount. Hematites have been found usually to contain below 0.1 per cent. titanium, Yorkshire irons about 0.15 per cent.,

Fig. 9.—Fracture of 3-in. dia. Bar of Iron C (see Table II). × $1\frac{1}{3}$th.

Burn Indian pig-iron about 0.25 per cent., and certain Norwegian irons, such as Vantit and Norskalloy, as much as 0.5 per cent. or more. Burn, Vantit and Norskalloy irons are all chill cast; consequently the peculiar sooty nature of their fracture is probably often attributed to their chill casting. Moreover, the sooty fracture is not evident except in small patches unless the carbon content is below the eutectic and kish graphite is absent. When, however, these high titanium pigs are remelted in a crucible with steel to lower the carbon content, the sooty fracture is produced.

FIG. 10.—FRACTURE OF 3-IN. DIA. BAR OF IRON D (SEE TABLE II). × 1TH.

The titanium content of a pig-iron increases as the titanium content of the ores used increases and as the temperature of the blast furnace increases, since it is only reduced from the ores and dissolved in the iron at high temperatures. The slag conditions, etc., in the furnace also affect the amount dissolved. The hematite ores only contain a little titanium, the Indian ores more and the Norwegian ores still more titanium, which is in line with the titanium contents and fractures of the pig-irons produced from them. Some Irish ores also contain appreciable amounts of titanium and were used some years ago in hematite blast furnaces, and had the effect of giving the pig-iron produced quite a different fracture, which was black and sooty when kish graphite was absent.

Titanium slag inclusions in the metal consequently have a remarkable effect in producing the fine graphite, sooty fractures. As stated above, their effect on the fracture of pig-irons is not very evident when the composition is above the eutectic, but when it is below the eutectic a sooty black fracture is formed in the lower part of the No. 3 fracture shown in Fig. 1B, and all finer fractured irons have a uniformly sooty black fracture like that shown in Fig. 10. In most compositions Cook's network structure can also be clearly seen in the fracture and becomes increasingly marked as the phosphorus content is raised. Other types of slag inclusions produce the coarse fracture, and there appear to be all sorts of intermediate conditions, depending on the amounts of the different sorts of slag inclusions in the metal. For the production of the fine graphite structure, however, the titanium slag inclusions appear to have the predominating effect and the differences in fracture and properties ordinarily met with in the foundry which are not revealed by ordinary chemical analysis appear to be related to titanium slag inclusions in the metal more than to anything else.

Finally, it should be pointed out that on remelting there is a tendency for other slag particles to form in the metal and remove, and obliterate the effect of, the original ones, and consequently to obliterate the original type of fracture. The extent to which this occurs depends on the melting conditions, which are at the present time under investigation.

In conclusion, the authors wish to thank the Council of the British Cast Iron Research Association for permission to publish the present results, and to thank members of the Pig-iron Sub-Committee of the British Cast Iron Research Association for data and much helpful information and discussion on the subject.

# THE FOUNDING OF PRESSURE CASTINGS

By H. H. Judson

(*American Exchange Paper*)

Generally speaking, engineering grey iron castings can be divided into two broad classifications, viz.: structural castings and pressure castings. The structural casting field covers those parts of apparatus which serve as frames, foundations or beds. Examples of this class are: motor and generator frames, pump and engine frames, bedplates, gear and transmission casings. The field of pressure castings includes those which, in operation, are subjected to internal pressures, such as: hydraulic pump cylinders and casings, pipes, valve boxes and pressure fittings.

Structural castings are designed from a mass and rigidity standpoint. The provision of sufficient iron to satisfy the mass or inertia requirements automatically meets the rigidity and strength requirements. The iron used in this type of casting need not be of such composition that, throughout any one casting, a close-grained homogeneous metallic structure exists. An open-grained structure in the centre of massive sections is not detrimental. There are exceptions to this, however, noticeably machine-tool beds and frames, but many large structural castings do not depend upon freedom from internal draws, spongy spots, coarse graphite carbon, and upon a dense fine-grained structure for their efficiency. Pressure castings, on the other hand, are quite dependent upon the absence of draws, shrinks, spongy spots, coarse graphitic carbon, and demand a dense, fine-grained homogeneous structure in order to be serviceable. The structure of the iron, as, for instance, the amount of graphitic carbon present, and, more important still, the condition in which this graphite exists, is of paramount interest in castings subjected to pressure.

## Scope of Paper

It is these requirements of cast iron in pressure castings that prompted the author to accept the invitation to write this Paper. Those foundrymen, whose casting requirements are in the structural class, develop methods and techniques to cover their needs. Occasionally they are called upon to produce pressure castings, and then are apt to find that the technique developed for structural castings is not what it should be under the altered conditions. It is hoped that the foundrymen whose normal output does not include pressure castings, can glean something of value from this description of the methods used in the author's foundry. It is not intended to be a treatise on the making of high duty iron in general. Incidentally, this Paper will deal solely with pump castings.

## Two Types of Mixtures

There are two distinct types of iron mixtures used in the Goulds Pumps foundry. The first type, which is in the high duty iron class, is that in which various percentages of steel rails form the major part of the charge, the balance being pig-iron and spiegeleisen. The second type is that in which no steel of any kind is used, the charges being made up entirely of pig-iron and scrap. The returns from the steel mix, or high duty irons, are used in the pig-iron—scrap mixtures for bedplates and frame parts. The first type of iron is used in all castings which are subjected to pressures above 500 lbs. per sq. in. It is also used in the larger sizes of low-pressure pumps. The operating pressures of these pumps may be low, but the overall load on large unsupported sections may be such that a strong iron is required. Pressure tightness is of primary importance, while ease of machining is secondary.

The pig-scrap mixture is used for the parts used in the small hand and power pumps in which the operating pressures do not exceed 200 lbs. per sq. in. Machinability is of equal importance with pressure tightness in this class of work. Castings for pumps which operate at pressures between 200 and 500 lbs. per sq. in. may or may not require a high duty iron. The small sizes in this range are amply strong because of low over-all loads, and the metal sections are light enough so that the cooling rate is sufficiently rapid to ensure good snug iron. The larger sizes in this range usually require a high duty iron. Machinability is not apt to be so important, in this class, yet pressure-tightness can be a problem.

That part of this class of castings which requires iron mixtures in which steel rails are used will be described first. All personal notions concerning the founding of pressure castings, in which steel rails form a part of the cupola charges, date back to 1926, which saw the inception of the two-cupola process for making high duty iron pressure-castings in the author's foundry.*

### The Two-Cupola Process

Two cupolas, one with a 54 in. bore and the other with a 72 in. inside diameter, are used to produce a high duty iron. The 54 in. cupola is used to melt charges of the following composition:—1,400 lbs. of steel rails, 4 in. or larger; 135 lbs. of pig-iron (15 per cent. silicon), and 85 lbs. of spiegeleisen (20 per cent. manganese). The tuyeres in this cupola are set 6 in. to 7 in. above the sand bottom. The height of the bed when charging is begun is 34 in. above the top of the single row of tuyeres. The cupola stands fully charged for 1½ hrs. before the blast is put on. The coke charges are 180 lbs. each, and the blast volume is kept at about 5,500 cub. ft. per min., with 12 to 16 ozs. blast-pressure. Tapping is continuous, and the spout is of the skimming type.

* "High Test Iron for Pressure Castings," A.F.A., Vol. 40, pp. 153-167, 1932.

All of this iron is tapped into one ladle, and will yield the following average analysis: T.C., 2.40; Si, 1.35; Mn, 1.0; S, 0.11, and P, 0.13 per cent. In the meantime the 72 in. dia. cupola is melting, for normal production work, the burden consisting of pig and scrap iron, a soft iron of the following analysis:—T.C., 3.25; Si, 2.40; Mn,

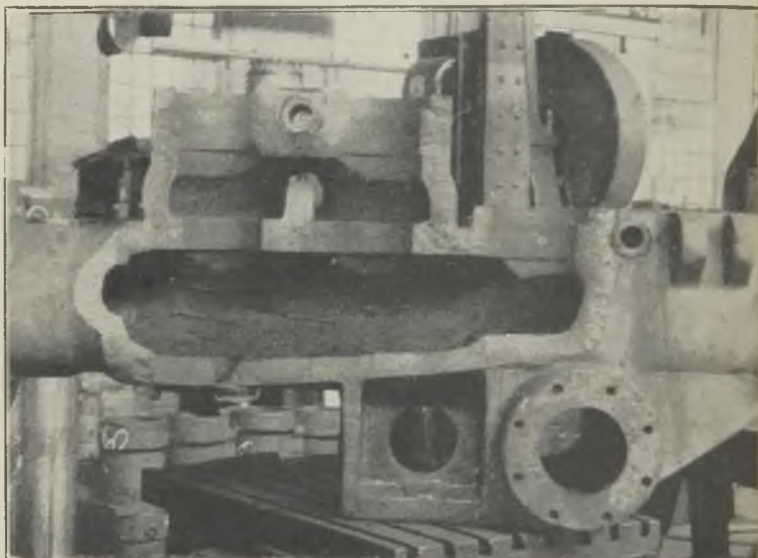

FIG. 1.—LINE PUMP CYLINDER, 2,300 LBS. IN WEIGHT, TESTED TO DESTRUCTION AT 6,000 LBS. PER SQ. IN.

0.55; S, 0.10, and P, 0.35 per cent. A predetermined amount of this soft mixture is run into a crane ladle, suspended from a crane scale, and is then poured into the ladle containing the hard iron from the 54 in. cupola. The resulting analysis of this mixture on the basis of 4 tons of hard iron to 1 ton of soft iron is roughly as follows:—T.C, 2.50-2.65; Si, 1.50-1.70; Mn, 0.90-1.10; S, 0.11-0.13, and P, 0.15 per cent.

This iron is used for castings that operate at pressures up to 1,500 lbs. per sq. in. on oil, and petrol, and which are tested up to 3,500 lbs. per sq. in. These castings weigh from 500 lbs. up to 3,000 lbs. The wall thickness of these cylinders, valve boxes and piping details, average from 2 to 2½ in. in thickness, with valve deck sections as thick as 3 and 4 in. Like other irons of this type it shows a markedly uniform structure across a fracture. Fig. 1 shows a cylinder, weighing 2,300 lbs., that was tested to destruction, failing at 6,000 lbs. per sq. in. pressure. Fig. 2 shows the structure of this iron at 100 magnifications, etched, and Fig. 3 is the same specimen at 500 magnifications.

The tensile strength, taken from test specimens cut from the walls of actual castings, runs from 17.8 tons per sq. in. up to 21.4 tons per sq. in. The Brinell hardness varies from 207 to 217. A standard 1¼ in. dia. test bar is grey throughout, and castings as thin as 1 in. in wall section are quite readily machinable. If there be any white iron in the fracture of the 1¼ in. bar it is a definite indication that the iron is "off-grade." Two heats were made, accidentally, with the silicon at 1.23 and 1.28 per cent. The iron was lifeless, freezing on the lip of the ladle, and showed a white net work in the fracture of the arbitration bar. It was then found that more than a charge of 15 per cent. silicon pig had remained in the drop, which accounted for the low silicon. A return to the charging scheme that would ensure bringing all of this silicon down into the ladle eliminated the trouble.

For the above reasons it is felt that 1.40 per cent. silicon is the lower limit for an iron running 2.50 to 2.70 per cent. total carbon. Silicon, in the cupola charge, is a splendid deoxidiser, and exerts a softening effect through preventing excessive oxidation. In an attempt to force the carbon still lower than 2.50 per cent., a heat was run with the bed and coke charge lower than standard, but with normal blast and metal charges. The carbon dropped to 2.34 per cent. and the silicon to 1.39 per cent., with the manganese at 0.77 per cent. The heat was a total loss. The melting conditions were such that iron was actually burned in the cupola. The charging door resembled a huge fireworks sparkler. The iron was lifeless, shrunk badly and showed a dead white fracture in a 2 in. dia. pouring sprue. Strangely enough, this runner was readily machined with high speed steel, a

FIG. 2.—TWO-CUPOLA IRON. ETCHED. × 100.

tensile piece cut and threaded from it failed at 20.6 tons per sq. in. It is felt that with the method described the low limit of carbon is 2.40 per cent., as there have been produced successful heats with the total carbon just under 2.50 per cent.

Considerable relief from rejections, because of leaks, internal draws and shrinkage on high-pressure parts and also from low-bursting pressures has been had from the use of the two-cupola iron. This is true to such an extent that the process and data deduced from it have influenced personal practice with the high duty irons melted in one cupola. Attempts were made to produce a similar iron in one cupola, the 54 in., but with varying degrees of success. The same materials were used, but a charge of soft iron equivalent to that which would ordinarily be used in the molten condition was added to the steel-mix charges. These additions were made in several different ways. The results never reached standard. The heavy-walled high-pressure castings were apt to sweat at test-pressures of 1,000 lbs. per sq. in. and upwards, at points where fins or flash had been chipped off, indicating a coarser structure. The graphite was coarser, as shown by photomicrographs. The possible reasons for this graphitic condition are given later in this Paper. However, enough satisfactory heats were run to indicate that a technique can be developed that will be quite as successful.

### Conclusions on Two-Cupola Process

The fundamental notions as personally envisaged in the two-cupola process are as follow:—

(1) The materials charged into the 54 in. cupola are almost entirely free of carbon in the graphitic form, and the carbon content of the charges is low. These conditions, coupled with others, make for a finely-divided graphite.

(2) The iron has a low carbon content, which is conducive to high strength, early freezing and a uniformly fine-grained structure.

(3) The best results have always been obtained when this iron has been melted hot and poured as hot as possible. The hotter a cupola-melted iron is poured, the quicker and more uniformly it cools through the freezing range.

### Materials Used

The first of these fundamental notions deals with the materials used. The steel rails, spiegeleisen and high-silicon pig which are charged into one cupola, contain no free graphite. Therefore, there is none to be dissolved. Shortly after this system was started in the author's foundry, Piwowarsky's Paper entitled "Production of High Test Iron" was published. On page 956 of the 1926 A.F.A. Transaction he states:—

"I have, therefore, proposed a simple method for producing high-test cast iron, in

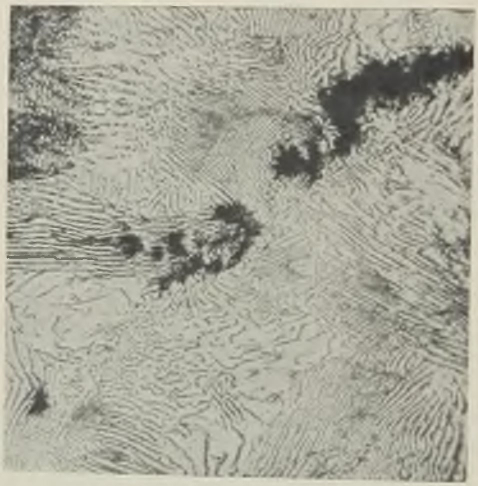

Fig. 3.—Two-Cupola Iron. Etched. × 500.

which all pig-irons—even those with high silicon content—are specified to the furnaces on purchase, to be machine cast; and, if possible, to be water-chilled in addition, irrespective of what they contain. If the melting process in cupola, air furnace or electric furnace is carried through sufficiently rapid, the carbide will nearly all remain intact and go into solution in the melt, and a result is obtained similar to that when the molten metal is given an extended superheating treatment. That is, there is less undissolved graphite remaining in the molten iron. Such iron will then set under conditions of greater spontaneous temperature drops below the freezing point."

This molten hard iron, therefore, partakes of the virtues of a superheated iron. However, it is too hard for any of the grade of castings under consideration, and has a high shrinkage, with little or no graphitisation. This hard iron properly melted has plenty of molten life, as sand-blast nozzles and Sandslinger tips are cast from it with no trouble from mis-runs. The soft iron added provides the softening elements necessary, that is, the graphite nuclei and some silicon. Incidentally, in order to retain the benefits of a superheated iron, the soft iron is added to the hard iron as late as possible in the process so that the graphite structure will not be coarse.

### High- and Low-Temperature Experiments

This premise is based on a personal experience of four years ago. Since this high test iron is poured quite hot it punishes the dry sand moulds and cores severely. The iron was held, in order to cool it, for 20 mins. before pouring. on two successive days. The cylinders from both heats burst at ordinary testing pressures. Tensile specimens were cut from the walls of the cylinders and were tested. There was a decrease of from 5.4 tons per sq. in. to 6.7 tons per sq. in. in strength, as they broke at 14.3 tons per sq. in. to 15.6 tons per sq. in.

The chemical analyses were satisfactory. However, a microscopic examination at 50 dia. showed a vast difference in the graphite structure. The graphite in the dull-poured iron was very coarse, which no doubt accounted for the decrease in strength. Fig. 4 shows the graphite, at 50 dia., of a satisfactory iron. The sample was taken from the 2 in. wall of a cylinder, poured as hot as possible. Fig. 5 shows the graphite, at 50 dia., in a sample taken from the same location as Fig. 1, only from a cylinder poured on the dull side. The iron had been melted hot, but was cooled down in the ladle. Then an examination of the fracture with a low-powered magnifying glass, three or four dia., showed small rounded dark grey patches in a normal silvery grey matrix.

Di Giulio and White, in their Paper " Factors Affecting the Structure and Properties of Grey

FIG. 4.—CYLINDER IRON POURED HOT. GRAPHITE AT 50 ×.

Cast Iron," A.F.A. Transactions, 1935, cover the subject adequately. They report on tests to show the effect of pouring temperatures on the structure and properties. Heats were run at various degrees of superheat, in a 250-lb. electric furnace. A group of bars was cast at the maximum temperature of each heat. The balance of each heat was then allowed to cool down in the furnace, and at intervals more bars were cast. The time elapsed between the pouring of the first and last group of bars from each heat never exceeded 35 mins.

Physical data and photomicrographs were taken, upon which they comment as follows:—

"The results of this series of tests . . . . show that for all irons that have been investigated an optimum pouring temperature exists, that above this temperature there is a slight decrease in physical properties, and that below this temperature the decrease is of much larger magnitude.

"Photomicrographic study was made of representative sections of all of these irons. However, it was thought sufficient to report the typical appearance of only one of them. . . . In the iron poured at 1,665 deg. C. the graphite flakes are smaller and more evenly distributed throughout the matrix than in the iron poured at 1,358 deg. C.

"Apparently, the time during which cooling took place permitted some of the large flakes to partially dissolve and thus decrease in size. As the pouring temperature is further lowered below 1,426 deg. C., the size of the graphite flakes becomes larger. This process continues as cooling takes place until 1,358 deg. C. is reached, when the finely flaked graphite has almost disappeared. The rather large patches are predominant, and the elongated flakes are much longer and thicker."

Hence the soft iron is added to the hard iron not more than 5 mins. before pouring is begun. The mixture is then poured promptly with as little reduction in temperature as possible. An optical pyrometer reading indicates an apparent temperature of about 1,398 deg. C., or actual temperature around 1,482 to 1,510 deg. C. at the spout of the hard iron cupola.

It is thought from personal experience that low total carbon, *i.e.*, from 2.40 to 3.00 per cent., is desirable in unalloyed iron, for high pressure work, since it promotes a fine-grained structure both as to matrix and graphite, so necessary for pressure-tightness and strength, if poured between 1,426 deg. C. and 1,482 deg. C. actual temperatures. This it is admitted is about as hot as it can be melted in a cupola. It makes for uniformity of structure in varying wall sections, as judged from examination of the

FIG. 5.—CYLINDER IRON POURED DULL. HELD IN LADLE 20 MINS. GRAPHITE AT 50 ×.

fractures of several hundred heavy-walled cylinders. Its freezing range is such that, with proper risers, shrinkage and spongy spots are readily avoided. When sections do not exceed 2 in. in thickness risers can be eliminated.

## Risers, Chills and Chaplets

If risers be used, they must be large enough to feed the casting without pumping or churning with a rod. Churning feeding heads in low-carbon iron mixtures in personal experience is actually harmful. The juncture of the riser with the casting always showed large, open shrink-holes. Incidentally, it was learned several years ago that the use of chills or denseners, as well as chaplets and anchors on low-carbon iron castings, was detrimental. Even though the denseners used on internal cores in a large cylinder were quite light as compared to the wall section against which they were used, a fine hair-line chill was formed on the inside. This reduced the bursting pressure of the cylinders tremendously. An improvement in melting conditions removed the need for the risers, and the use of chills. Chaplets and core anchors are apt to produce blow-holes in the castings. Evidently the metal begins to freeze at such a high temperature and develop the mushy state so early in the cooling cycle that the gas formed, when the iron strikes the cold chaplets, is not released by the metal. It is personal practice to bolt all cores down or hang them in the cope. It is only on non-pressure sections of castings and un-machined parts where anchors and chaplets are used.

Any fluttering of the iron against the mould or core is detrimental for low-carbon cast irons. The gas formed is usually trapped in the casting. Thus all core sand and moulding sand mixtures must be open and free-venting. Several so-called " shrinkage " problems were solved by the use of a vent wire.

### Low Total Carbon Content

The second fundamental notion in connection with the two-cupola process deals with the low total carbon content. The lowering of the total carbon is brought about in the cupola by the use of steel rails in the charges which are melted under the following conditions:—

A low bed is used so that the molten iron has less coke through which to pass and absorb carbon. Incidentally, there may be a slight tendency towards an oxidising condition with a low bed, which makes for a reduction in carbon in any mixture. The by-product coke used is a very dense grade, and its analysis is:—Fixed

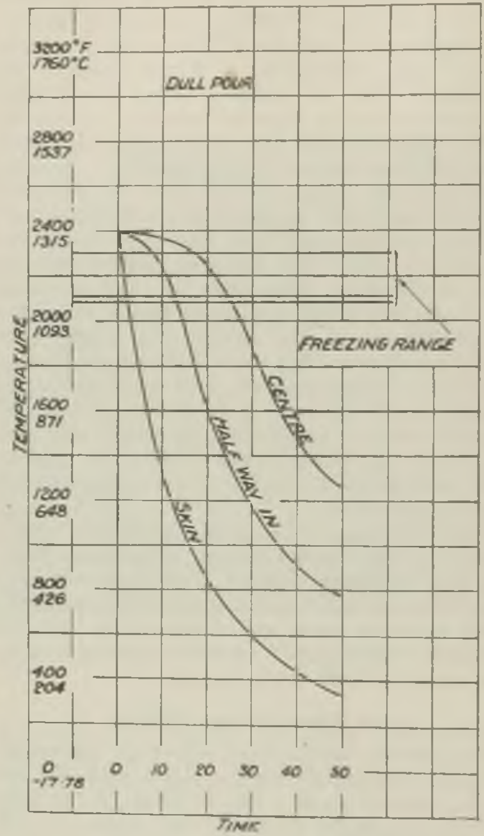


Fig. 6.—Time-Temperature Relationship of the Cooling of a Casting. (Schematic only.)

carbon, 91.5; volatile matter, 0.90; ash, 7.7, and sulphur, 0.58 per cent. It is slow burning and holds up well. The coke charges are low compared with the figures given in other Papers written on the subject of melting a high steel charge in the cupola. The blast used is normal. Evidently this dense, slow-burning coke, coupled with the blast used, maintains the bed at a low point, without dropping it too low. In the pig-iron—scrap iron mixtures a definite decrease in the total carbon content has been noticed. For years it approximated 3.50 per cent. when using a bee-hive coke. Since a by-product coke has been used the carbon has gradually decreased, to between 3.25 and 3.30 per cent. Three different brands of by-product coke were tried, each succeeding brand being denser—that is heavier per unit volume—than the preceding. Each change brought with it a lowering of the total carbon. The present coke is the densest and gives the lowest carbon, possibly because the furnace can and does use less of it per charge, by weight, than any of the others. Thus the grade of coke as well as the bed height affects the total carbon.

The tuyeres are set close to the sand bottom, *i.e.*, 6 to 7 in. above it. Thus the amount of coke below the tuyeres is held to a minimum, and the iron has still less coke through which to pass. Because the tuyeres are set so close to the bottom the tap must run continuously. As fast as the iron melts it is withdrawn from the cupola and also from the carbonising influences of the coke in the well of the cupola. The iron spout is of the skimming type, for the removal of the slag.

### Pouring Temperatures and Pouring Practice

The third fundamental notion is that pertaining to the pouring temperature. Incidentally, what follows covers the pouring practice used on the complete range of pressure castings. All low carbon high-test iron castings are poured as hot as possible, *i.e.*, no time is lost between tapping out and pouring the moulds. It is a personal belief that the hotter the cupola-melted metal is poured, the finer and more uniform the grain structure and the greater the freedom from internal defects and chilled corners. Most

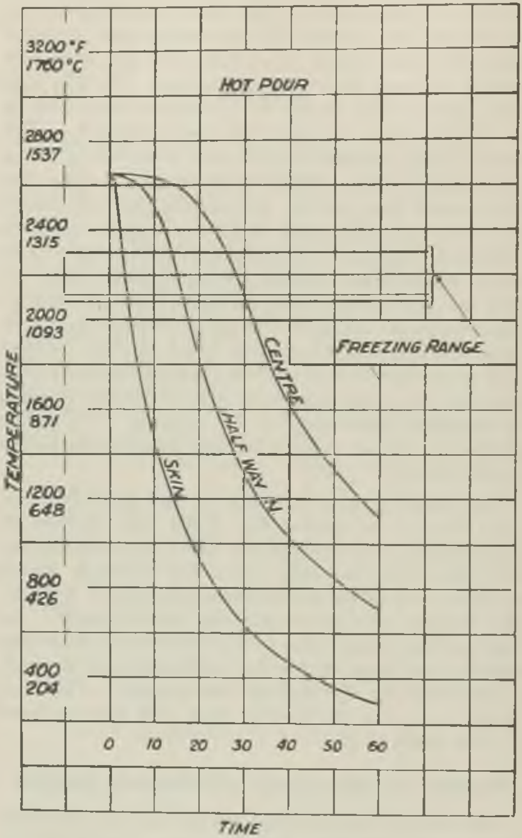


FIG. 7.—TIME-TEMPERATURE RELATIONSHIP OF THE COOLING OF A CASTING. (SCHEMATIC ONLY.)

of the investigational work done on the effect of superheating cast iron on its physical properties has been done in the electric furnace.

The temperatures reached in these experiments are much higher than those obtained in a cupola. The cupola is poured at about 1,455 deg. C. actual temperature. This is approximately the best pouring temperature for superheated electric furnace irons, *i.e.*, an electric furnace iron superheated to 1,537 deg. C. and 1,593 deg. C. will give its best physical properties at a temperature between 1,426 deg. C. and 1,482 deg. C. Thus starting off with a cupola-melted iron in which the carbon is completely dissolved and at a temperature about 1,480 deg. C. some of the benefits of an electric-furnace refined iron are obtained.

There was a period, several years ago in the author's foundry, during which all castings, large and small, for heavy and light pressures, cast in green sand and dry sand, were poured on the dull side. If the metal was hot it was chilled down by adding scrap to the ladle. Then with no other changes, as far as iron mixture, sand, moulding, gating, etc., are concerned, there followed a period during which all moulds, both green and dry sand, were poured as hot as the iron could be taken to them. The machine shop losses from leakers, dirt, shrink and spongy spots, decreased so suddenly that it served as conclusive proof that hot pouring is essential to pressure-tight castings. The improvement in the machine shop results was so marked that hot pouring is now almost a religion.

Professor G. B. Upton, in his book, entitled "Materials of Construction" notes that:

> "If the metal be poured 'cold,' the outer part of the casting cools sharply, in heating up the mould, and the centre cools very slowly during freezing. If the metal is poured 'hot,' the mould will be thoroughly heated long before freezing, and the piece will be cooling rapidly throughout during freezing."

Reference to the cooling-rate curves of steels quenched in various liquids shows that the idea behind the above statement is that an appreciable length of time has passed, after pouring before the establishment of the temperature gradient that governs the cooling rate of the casting, especially the rate through freezing. Pouring near the freezing temperature, brings about a quick freezing of the skin of the casting, by heating up the cold mould, but does not provide the necessary temperature difference

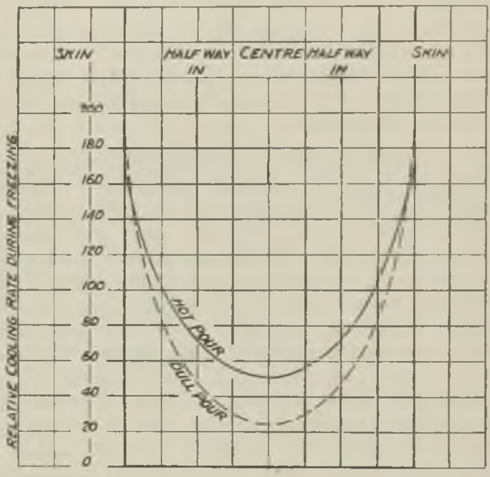


Fig. 8.—Cooling Rates through the Same Temperature (Freezing Range). (Schematic only.)

between the metal and the mould to establish a steep temperature gradient when freezing is approached. Thus the interior of the casting cools relatively slowly. On the other hand, pouring hot heats up the mould and only a very slight skin is formed, leaving the interior still molten and at a sufficiently high temperature so that when the freezing temperature is approached a steep temperature gradient has already been established and relatively rapid freezing occurs.

Fig. 6 and 7 represent, schematically only, the time-temperature relationships in the cooling of two similar castings, one poured from dull metal and one poured hot, from the same ladle of iron. These curves are typical of cooling curves of quenched steels. The skin temperature drops very rapidly down through the freezing range and beyond. The centre does not decrease in temperature at the start. Soon, however, this decrease in skin temperature sets up a temperature gradient between the skin and the centre. The skin then begins to draw heat from the centre, and the decrease in temperature of the skin to the mould is retarded. The centre is now cooling and increasingly greater cooling rates are being established as the time interval after pouring increases.

In the case of the " dull " poured casting, Fig. 6, the casting is poured just above the freezing range, thus before sufficient time has elapsed to permit the development of a rapid cooling-rate, the casting has begun to freeze. The skin has already passed through the freezing range at a very rapid rate, and therefore shows a fine-grained structure. The curve representing the casting halfway between the centre and the skin indicates that the casting is cooling less slowly through the freezing range and will show a coarser structure than the skin. The centre is cooling still more slowly through the freezing range and will have a still coarser structure. There has been insufficient time for the casting to set up a steep temperature gradient in the freezing range so the result is slow freezing and coarse graphite.

Fig. 7 represents a similar casting poured " hot." The skin freezes very rapidly at the start but not as rapidly nor as deeply as in the " dull " pour. Then the centre section begins to feel the effects of the decrease in skin temperature and it begins to cool also. This beginning of the centre to cool occurs high enough above the freezing range to permit of the establishment of a steep temperature gradient so that as the freezing range is approached the maximum rates of cooling have been established clear to the centre of the piece. Hence relatively more rapid freezing of the centre of the casting occurs, resulting in a finer grained structure.

Reference to the curves of both Figs. 6 and 7 shows that in the " hot " pour the cooling rates inside the piece are not only faster but they are

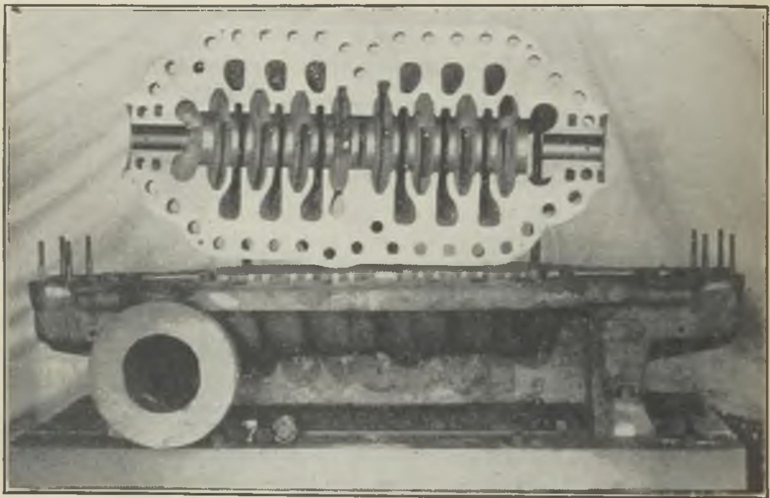

Fig. 9.—Six-in., 8-stage Centrifugal-Pump Casings Operating at 1,000-lb. per sq. in. Pressure on Petrol.

more nearly uniform than in the " dull " pour. Fig. 8 shows schematically the relative cooling rates of the various sections of the hot and dull poured castings, in the freezing range. The cooling rates are merely numbers representing the slope of the cooling rate curves of Figs. 6 and 7 in the freezing range. The greater uniformity of the cooling rates in the " hot " pour over the " dull " pour is noticeable, as are the faster cooling rates.

The practical demonstration of the above views on the effects of pouring temperature on the rate of cooling in castings is shown in the quenching of steel. Given two pieces of steel of identical analyses, one of which is ½ in. diameter and the other 3 in. diameter, to be hardened. The ½ in. piece can be quenched just above the critical temperature and it will be hard throughout. It will be hard throughout, because the cooling rate of this small piece is sufficiently fast. The 3 in. diameter piece must be heated to a much higher temperature before quenching in order to get the hardness throughout the piece. The higher quenching temperature for the heavier piece is necessary so that the time necessary to develop the required speed of cooling for the hardness to extend throughout the piece is available.

Practical experience has shown that results bear out the above theory, at least, for the cast irons melted in the cupola. Since the rate of freezing affects both the amount and size of the graphite particles and since hot-pouring will cause rapid freezing, which in turn makes for a fine-grained structure, all of the pressure castings made by the author are poured on the hot side.

Di Giulio and White state also, in their summary of findings:—

> " Cast iron poured from too low a temperature shows excessively large flakes. The reason for this is to be found in the fact that pouring from such a low temperature will result in a slower rate of cooling in the moulds which permits graphitisation to occur to a great extent. The formation of large graphite flakes effectively breaks up the continuity of the matrix, thus producing weak iron."

Referring again to the experience which obtained in connection with the holding of iron in the ladle for cooling. Adding the soft iron to the hard iron provided the graphite nuclei necessary to promote coarse graphitisation. Holding the mixture provided ample time for any agglomeration of the graphite that might take place and brought about the low pouring temperature. It is felt that the one-cupola process produces heterogeneous results because the soft iron, both in the solid and liquid forms, carries graphitic carbon into the mixture too early in the process. If this soft iron could be obtained in the chilled form (that is, with the carbon mostly in the combined form in the pig) better results would be yielded.

### One-Cupola Process

As was stated earlier, the good results obtained with this two-cupola low-carbon iron led to the closer consideration of the common one-cupola steel-mixes. These one-cupola steel-mixes, charged in the cupola first and therefore tapped out first, to avoid as far as possible the mixing with the soft-iron charges which follow, are used in pump parts which operate at pressures between 200 lbs. per sq. in. and 1,000 lbs. per sq. in.

*Charges.*—The charges for these steel-mix irons, or high-duty irons, melted all in one cupola, contain from 30 to 60 per cent. steel rails, 3 per cent. spiegeleisen and the balance pig-iron, one of which contains 2.25 per cent. Si and the other 3.50 per cent. Si. No scrap of any kind is used. The amount of steel used is governed by the wall-thickness of the castings to be poured. The thicker the wall section the lower the total carbon required, and, therefore, the more steel rails per charge. This particular notion works out satisfactorily when relating to castings up to 2 in. thick. The silicon content, determined by the pig-iron used, is governed also by the wall thickness, from the machinability standpoint. The total carbons of the various mixtures vary between 2.80 and 3.25 per cent., and the silicon content between 1.50 and 2.00 per cent. The machinability of a ladle of iron for the particular jobs to be cast is determined by the depth of a chill in a small bar, 1 in. by 2 in. by 6 in. cast open-sand, against a chill bar. The thicker the wall section, the greater the depth of chill that is desired.

## Control of Chill Depth

Formerly the various depths of chill were obtained by using a fixed steel percentage in the charge and varying the silicon content. In other words, the total carbon was reduced to a more or less fixed point, by using the same amount of steel rails in each charge, while the silicon was varied. When a deep chill was sought, the silicon was lowered and when a light chill was needed the silicon was raised. One objection to this system was that the chill tests were apt to be erratic. The low-silicon mixtures, intended for deep chills, and therefore heavy-walled castings, were apt to give trouble. The machine shop would report certain castings as being hard, and they were very hard, even though the chill test for that particular ladle indicated that the analysis was satisfactory. The leakers were definitely higher at that time also.

The present method is to vary both the silicon, which is about 50 points higher than formerly, and the total carbon. The chill tests are less erratic with these mixtures. Experience has shown that the heavy-walled castings from 1½ in. up to 2 in. thick, give best results on the pressure tests at 1,000 lbs. per sq. in. when the total carbon is 2.80 to 2.95 per cent., *i.e.*, a little below 3.00 per cent. The silicon is then controlled at 1.50 to 1.80 per cent. Incidentally, personal experience checks closely with that of other workers in that the lower-carbon cast irons are not affected, as to unit strength and grain size, by rather appreciable variations in silicon. In the two-cupola process the silicon has been as high as 1.80 per cent. when the standard has been 1.50 per cent., without any apparent ill-effects from softness and excessive graphitisation. Decreasing the total carbon content of an iron mixture, everything else being equal, tends towards making the iron freeze as white iron. However, raising the silicon, in this lower carbon iron offsets this tendency. Incidentally, the ferrite formed is stronger because of the increase in silicon.

Fig. 9 shows an eight-stage centrifugal pump now operating at 1,000 lbs. per sq. in. on petrol. The lower half-casing weighs 2,000 lbs. and the upper half weighs 1,400 lbs. The analysis of the iron is these castings is:—T.C., 2.9-3.0; Si, 1.65-1.8; Mn, 1.04; S, 0.12, and P, 0.15 per cent.

They do not leak when tested with kerosene at 1,600 lbs. per sq. in. pressure. They are operated at 1,000 lbs. per sq. in. on oil and petrol so they must be quite free from internal defects of all kinds. The heavy parting flanges are $2\frac{1}{2}$ in. thick, as cast, the wall thickness of the volutes is $1\frac{1}{8}$ in. and the partitions between the various stages are $\frac{11}{16}$ in. thick, as cast. The cored passages are intricate and the sections vary abruptly all through the casting.

As the wall sections decrease in thickness, the total carbon is increased by decreasing the percentage of steel rails per charge. The silicon may or may not be increased, depending upon the amount the total carbon is reduced. Castings measuring $\frac{3}{4}$ in. in thickness and tested at 500 lbs. per sq. in. are run with iron analysing 3.00 to 3.20 per cent. total carbon and silicon at between 1.85 and 1.90 per cent. Small parts that are from $\frac{1}{2}$ to $\frac{3}{4}$ in. in sections are poured with a mixture analysing 3.15 to 3.25 per cent. total carbon and 1.90 to 2.00 per cent. silicon.

Compared with the practice of 7 or 8 years ago, the present high-duty iron practice calls for mixtures in which the silicon contents range from 40 to 60 points higher and the total carbon from 25 to 75 points lower. The object sought by the use of higher silicon in the low carbon cupola mixes, is that, it can serve as a deoxidiser in the melt, and it also serves to prevent the low carbon irons from freezing out white.

Some experiments were run recently with all scrap mixtures in a 30 in. cupola. Silicon was added to the charge in the form of cement briquettes during one series. In the next heat a comparable amount of silicon in the form of lump and powdered 90 per cent. ferro-silicon was added to the ladle. The iron was cast in chill moulds. The analyses from the two heats showed :—

| Nature of heat. | T.C. | C.C. | Si. |
|---|---|---|---|
| Briquettes in cupola .. | 3.40 | 0.34 | 2.20 |
| 90 per cent. Fe-Si to ladle .. | 3.32 | 1.07 | 2.15 |

The results were doubted and checks were made which were substantially the same as the original. Evidently the addition of silicon to the charge is more potent as a graphitiser, possibly because of its deoxidising qualities. It is felt that if the total carbon be lowered so that the silicon can be controlled at say, 1.75 per cent., instead of 1.25 per cent., the iron is benefitted by the presence of this higher silicon in the charge.

### Soft Iron

So far this Paper has dealt entirely with steel-rail—pig-iron mixtures. The other type of iron used in the author's foundry is that in which no steel rails are used at all; it being a mixture of pig-iron and scrap iron. The analysis which has been followed for years is as follows :—T.C, 3.30-3.50; Si, 2.30-2.50; Mn, 0.50-0.60; S, 0.09-0.11, and P, 0.25-0.45 per cent.

This analysis is a very common one for the general run of small and medium castings. Reference has already been made to the decrease in the total carbon of this particular mixture during the past two or three years. The analysis is so common that it is not necessary to go into any great detail in this connection. It is used in the author's foundry for all the small parts and low pressure pumps where ease of machining is a vital factor, and in some of the larger pumps where the designs lend themselves to such an iron. The sections in which it is used vary from $\frac{3}{16}$ in. up to 1 in., in castings weighing from 4 ozs. up to 500 lbs.

### Melting Hot and Pouring Hot

This mixture, when used on pressure work, gives the best results when it is melted hot and poured hot. Every attempt to economise on coke, both as to quality and quantity used, has resulted in lower spout temperatures, more shrinks and draws in the castings and more leakers in the test floors in the machine shops. Invariably, a heat, in which there has been a dull period, is followed by an increase in defectives due to draws or shrinks, at points which are prone to shrink.

## Combating Internal Defects

Internal defects and shrinkage may be the biggest sources of trouble in a foundry called upon to cast pressure-work. There are six fundamental principles followed in the author's foundry to combat shrinks, draws and internal sponginess in the castings, which are poured from this soft iron mix. The principles and the order in which they are used are:—

(1) The internal defect commonly called shrinkage, may be caused by gas from the mould or core. Whenever shrinkage is considered, reference is made to (*a*) permeability of the moulding and core sands, and (*b*) venting of the moulds and cores.

Innumerable shrinkage troubles have been eliminated through the use of additional vents in the moulds and cores. One rather simple job returned 25 per cent. loss in leakers. Regardless of the gating practice, the iron mixtures used, etc., the leakers continued. The venting of three small pockets in the cores eliminated the trouble, and the loss dropped below 1 per cent. Impellers for centrifugal pumps developed shrinks and spongy spots on the hubs and wearing rings. A very fine sand was used in the core in order to ensure smooth waterways, for high efficiency. The use of a very coarse open sand and a special core oil which enabled the management to use an oil-sand ratio of 1 to 80 provided a free-venting core which removed the " shrinks." The smooth surface on the rough core was obtained by means of a high-grade plumbago-wash. Thus, reference is made to the venting of the moulds and cores first whenever shrinkage shows up in a type of castings.

(2) If venting does not cure the trouble, experiments are made with the gates. The ingate is placed so that the point at which the shrinkage takes place will get comparatively dull metal, *i.e.*, gate as far from the seat of shrink trouble as possible. Usually the ingate is made as small as will run the casting. Thus, feeding is going on while the casting is being run. Part of the runner which connects the down sprue with the ingate is always placed in the cope, to provide a means of ridding the iron of any slag or loose sand.

(3) If the above gating fails, then the ingates may be placed near the massive part that shrinks and increased in size. Possibly the runner is increased as well as the down sprue. A strainer core is then placed in the pouring basin at the top of the cope to serve both as a choke for slow pouring and to keep the basin full to prevent slag and dirt from being carried into the mould. As soon as the mould is full, the sprue then acts as a feeding head. If the strainer core is set in the joint of the mould, the sprue shuts off quickly, and so does not serve as a feeder. The runner and ingate may be enlarged as stated, to further the feeding effect of the sprue.

(4) If the above methods fail, a riser is used. The riser and the opening from it to the casting are made as large as the casting will permit so that feeding takes place until the casting is set. Quite often the use of a riser with this soft grade of iron makes for a coarse open grained structure where the riser joins the casting.

(5) If this be so, then chills are used, but no riser. The use of chills or denseners is never a complete cure, but considerable relief may be had from them.

(6) If all of the above measures fail on any one job, the management discontinues casting

TABLE I.—*Physical Data of the Fe-C-Si System.*

| Per cent. Si. | Per cent. C. | Temperature at which freezing starts. | Temperature at end of freezing. | Per cent. of solid metal when eutectic temperature is reached. | Per cent. of liquid eutectic. |
|---|---|---|---|---|---|
| 1.50 | 2.50 | 1,315 deg. C.<br>2,400 deg. F. | 1,126 deg. C.<br>2,060 deg. F. | 60 | 40 |
| 1.80 | 3.00 | 1,248 deg. C.<br>2,280 deg. F. | 1,126 deg. C.<br>2,060 deg. F. | 35 | 65 |
| 2.50 | 3.25 | 1,201 deg. C.<br>2,195 deg. F. | 1,126 deg. C.<br>2,060 deg. F. | 15 | 85 |
| 2.50 | 3.50 | 1,162 deg. C.<br>2,125 deg. F. | 1,126 deg. C.<br>2,060 deg. F. | — | 100 |

them in soft iron. It then uses a high duty iron, analysing from 1.80 to 2.00 per cent. Si and 3.00 to 3.20 per cent. total carbon, adding 1 per cent. of nickel, in the ladle, for machinability. Usually one can dispense with risers and use common gating practice.

It is a personal belief, in connection with this soft iron mixture, that the condition of the carbon in the charge affects the condition of the carbon in the finished casting. That is, a finely-divided graphite in the pig-iron and the scrap used makes for a finely-divided graphitic carbon in the casting, provided the cupola is operated so as to bring the charges down hot and rapidly. The modern pig now being cast, which weighs only 40 lbs. shows a much finer grain-structure, and a slightly higher combined carbon than the old pig of twice the size, because the small pigs cool much more rapidly. The use of some outside scrap, of such a size and wall section that the graphitic carbon will be finely divided and in not too great a quantity is good practice.

## Conclusion

For castings to withstand internal pressures, the most important element in cast iron is carbon. Personal practice indicates that decreasing the total carbon content below the percentages usually encountered in high duty irons, the means by which it is decreased, and the hot-pouring of these lower carbon irons make for a finer-grained structure. This refining of the grain-size provides both pressure-tightness and increased strength.

An attempt was made to ascertain the manner in which the iron mixtures, mentioned in this Paper, freeze. Data were taken from the works of Hanson, Honda, Murakami, Gonterman, Kriz and Poboril in connection with the liquidus surface of the iron-silicon-carbon system. Table 1 gives these data. The answer to the question of why a casting weighing 2,000 lbs., consisting of sections varying from $\frac{11}{16}$ to $2\frac{1}{2}$ in. in thickness and cast with no feeding heads does not show any signs of internal defects is not apparent to the author in this table. It does show why low carbon irons trap gases given off by the mould and core.

The author takes this opportunity to express his thanks to Prof. G. B. Upton, of Cornell University, for his aid.

## SYMPOSIUM ON CAST IRON

### Joint Discussion on the following Papers:

" A Study of the Influence of Manganese and Molybdenum Additions to Cast Iron."

" The Influence of Wall Thickness on the Mechanical Properties of Cast Iron."

" The Fracture of Pig-iron and Cast Iron."

" The Founding of Pressure Castings."

### The Two-Cupola Method

Mr. F. J. Cook, referring to Mr. Judson's Paper, quoted an example of what he ventured to think was a kind of innoculation, and was to his mind most interesting. He was familiar with a foundry in this country which had been doing similar work for a long time, but from rather a different angle. This foundry was casting throughout the day, and the general run of the work was two mixtures, one of which was white iron, and the other consisted of one grey iron composition for general work. It also happened that there was a fair amount of high-pressure work in the way of cylinders, which was a nuisance to produce, because it affected the regular run of those two classes of metal. As a result the foundry manager had worked out the percentages of the white and soft irons to produce the analysis required for the cylinders; when he tried it out, to his amazement the cylinders produced were very much superior. They were free from shrinkage troubles, and well withstood the pressure tests, whilst the general structure and machineability were much improved. That practice had been continuing for a very long time. Very much superior results were obtained in this way than by producing castings of the same composition, made up of a mixture practically to the same analysis. Ironfounders were generally recommended in this country not to mix white and grey irons, but in mixing them in this way—melting them separately and mixing them—there was a remarkable improvement in structure. Personally he had been intrigued with this, but he could not fathom it, and this Paper did not help him to understand what actually took place, and why these good results should obtain. If the author could throw any light on the problem he would be helping them along the road.

Mr. Judson, in reply, remarked that two years ago they had had a Paper on the subject in New York, and that very question was asked by himself. Incidentally, they tried several times to run the mixture through one cupola, and they did not get the same result at all. They would have a sweating at 3,000 or 4,000 lbs. pressure test. He thought that, probably, if they could get the soft iron addition in the chilled form, that was, chilled forcibly, they might be able to get somewhere.

### Molybdenum and Manganese Additions

Dr. A. B. Everest, dealing with Mr. Hurst's Paper, remarked that, in his opinion, the Paper was a very valuable addition to the literature on the subject of alloy cast irons. Dr. Everest went on to remark that he was somewhat puzzled at the choice of the alloy combination which Mr. Hurst had made, since, generally speaking, when two additions were made to cast iron, they were chosen so that they balanced one another in respect to their effect on chill. In the present instance, however, both manganese and molybdenum acted in the same direction in increasing chill, and no claim could be made to the effect that this was a balanced addition. This led naturally to the result that, when manganese and molybdenum additions were made, the castings tended to become white, and it would seem that the interest of the material lay rather in its properties after a subsequent graphitising anneal, the necessity for which, of course, rendered the combination of doubtful general utility.

### Roll Practice

Dr. Everest stated that Mr. Hurst claimed very high hardnesses for white irons with martensitic structuros produced by the alloy additions. He would be interested to know whether these irons had any special advantage over the well-known "Ni-Hard," which was produced by adding nickel and chromium to a white iron. The structure and hardness in "Ni-Hard" was very similar to that shown in the present series, and it would be of interest to know, therefore, whether any special advantage could be claimed for the hard iron produced with manganese and molybdenum. He thought it of interest to mention in this connection that, in "Ni-Hard" rolls, proportions of molybdenum were frequently used, and also as a result of research work in the United States it was becoming the practice to increase manganese to abnormally high levels. It would thus appear that in the latest type of "Ni-Hard" rolls full advantages of the nickel-chromium and also of the manganese-molybdenum additions were being achieved.

A point which appeared to be of some interest was mentioned about the middle of the Paper, where it was pointed out that, in spite of the relatively high hardness of these alloy irons, they showed in the ring-test less internal stress than normal. Dr. Everest inquired whether this did not appear to some extent to be contradictory, since one would normally expect high internal stress to be associated with hardness. Did the explanation in the present case lie in the heat-treatment?

### The Star Test

One other point that interested the speaker very much was the star test, which Mr. Hurst showed in Fig. 1 of the Paper. He (Mr. Everest) believed that this test originated in the works of the Midland Motor Cylinder Company, and it had been used by himself in some of his early work on aluminium in cast iron. This had been developed for a specific purpose, and, although satisfactory as a check on automobile irons, he had abandoned the test as not being generally applicable to all irons. He would therefore be interested to hear why Mr. Hurst had adopted this test now in connection with his present work.

### Two-Cupola Iron

Commenting upon Mr. Judson's Paper, Dr. Everest remarked that Mr. Judson said he cast the metal as soon as possible. This was a point of particular interest, in view of the question of the relationship between the time factor and inoculation. He stated that he would like to know whether Mr. Judson found a change in the form of the carbon resulting from holding the metal for any length of time or whether the precaution of casting quickly was merely to ensure as high a casting temperature as possible.

### Section Sensitivity

Mr. G. L. Harbach, dealing with Dr. Jungbluth's Paper, remarked that having himself written a Paper on a similar subject, he had read Dr. Jungbluth's contribution with great interest and had found it very informative. There were, however, one or two points that he would like to emphasise. Early in the Paper it was stated, quoting M. v. Schwarz and A. Vath, that under certain conditions satisfactory agreement between the strength of a casting as a whole and that of a test bar could be obtained if the diameter of the bar were made twice the wall thickness under test. Later on in the Paper, however, Dr. Jungbluth showed that the sensitivity was much less, and in fact he quoted a 30-mm. bar as having the same strength as 30 mm. in the casting. That supported the results of his own work and confirmed the fact that sensitivity to section thickness varied considerably with the quality of the iron, so that that particular reference to the diameter of a bar being twice the thickness of the section to be represented could only be applicable under certain conditions, and those conditions would have to be very closely controlled. Then, quoting Coyle's work, Dr. Jungbluth had stated that the percentage diminution in strength was equal for each grade of cast iron. The remainder of the Paper and personal experience certainly suggested that that was not the case.

Mention of hardness as related to tensile strength made him feel that was going a little far, except again under very controlled conditions. To talk in terms of percentage of increase in Brinell hardness in relation to percentage increase in tensile strength was not to his mind correct, because the Brinell hardness did not necessarily vary consistently with the tensile strength. It was possible to produce a low-carbon iron of 24 tons tensile strength with a Brinell hardness of 250 and a low-silicon iron of 14 tons tensile also with a Brinell of 250. Moreover, the high-test iron would machine readily, whilst the low-silicon iron would only be machinable with difficulty. From this it was obvious that the Brinell hardness of different types of iron had no real relationship to tensile strength, neither was it a measure of machining hardness of cast irons. Mr. Harbach concluded his remarks on Dr. Jungbluth's Paper with the observation that the author was to be congratulated for his Paper undoubtedly covered a very wide field, and was in his opinion a valuable contribution to the subject.

### A New Specification and Two-Cupola Iron

Mr. Harbach also made some observations on Mr. Judson's Paper. He remarked that, being in the same line of business and having used irons similar to those mentioned, he had read Mr. Judson's Paper with great interest. The classification of the two types of cast iron—structural and pressure—and their respective requirements was welcome, particularly in view of the fact that a new specification for high-duty cast iron would shortly be issued in this country, and it was very desirable that the high-test irons should be used in a reasonable manner. Once it was accepted that the usual textbook quotation of

10 tons tensile strength was low, there was a danger that the high-strength irons might be adopted as standard and specified for all types of castings, including those in which mass rather than strength was the deciding factor. Such a position would prove a great disadvantage in foundries. A clear distinction between the two classes of cast iron, and the rational use of the high-strength irons was necessary, for the development of the technique for handling low-carbon irons was essential and was often an expensive business when changing over from the production of ordinary irons.

Turning to the mixtures used, Mr. Harbach said it would be interesting to know what was the composition of the steel used, as the analysis of the metal from the 86 per cent. steel mixture suggested a high silicon content in the steel and a low manganese content, or a high loss of manganese in melting. From the fact that all the high-duty irons carried no scrap returns, it would appear that either the pig-scrap mixture was over 50 per cent. scrap or the tonnage of bedplates and frames, etc., exceeded half the total output. Had Mr. Judson used the return scrap from high steel mixtures in the same mixture? It seemed a pity that such good scrap should be used in common iron, as it would obviate the expense of duplexing to raise the total carbon—as indicated quite early in the Paper, a single cupola was capable of meeting the requirements—and enable the common iron to be run with a higher phosphorus.

The high steel-mix iron with 2.4 per cent. total carbon and 1.35 per cent. silicon would certainly require some adjustment, and it matched personal experience with a similar mixture. Further to this, it was often difficult to obtain a sufficiently high carbon from a high steel mix without scrap in the charge—holding the liquid metal in the cupola had little, if any, effect on the carbon—and the silicon was rarely over 2 per cent. as tapped, even if 3 per cent. was charged.

### Nickel Additions Advocated for High-Duty Irons

Increasing silicon had little compensating effect for low carbon around 2.5 per cent., and it had been found that, with a carbon of 2.6 per cent., raising the silicon from 2 to 3.5 per cent. had little effect on the tensile strength, it being about 24 tons throughout. Regarding the difficulty of using low-carbon irons, as far as possible it was advisable to make full use of irons with 3 per cent. or more carbon, and, when a low-carbon iron became necessary, the highest carbon compatible with the strength required should be used. In this respect the use of nickel was often worth while, as higher carbons might be used for the same strength, thus simplifying foundry operations and giving more consistent results. The mixed metal quoted by Mr. Judson (2.5 to 2.65 per cent. T.C and 1.5 to 1.7 per cent. Si) would personally be considered so near the border line that erratic results would be expected in the foundry machine shop and strengths and fractures of test bars, and the low limits quoted of 2.4 per cent. T.C and 1.5 per cent. Si much lower than necessary for an iron around 20 tons tensile. It would be expected that an inocculated cast iron (with or without nickel) carrying its own scrap returns, with 2.8 to 3 per cent. T.C, would give the strength required with improved casting properties, and probably save the extra cost of nickel, if used, by preventing waster castings.

### Cost of Low-Phosphorus Castings

With regard to the soft iron mentioned in the Paper, containing 0.25 to 0.45 per cent. P, and used "where ease of machining is a vital factor," it was a matter of some interest, and he would be glad to know whether the phosphorus was kept low deliberately with a view to assisting machining. Whilst the general view was that phosphorus acted as a hardener, and, therefore, was detrimental to machining, his own view was that, up to 1 per cent., it acted to some extent as a graphitiser, and, also, by lowering the strength and toughness of the iron due to the presence of phosphide eutectic in the structure, the general effect of phosphorus was one of embrittlement which improved rather than detracted from the machining properties. This particular point might be out of the scope of the present Paper, as it dealt essentially with high-duty irons, but it was of importance to the manufacturers of small and non-pressure castings from the financial viewpoint. In this country the reduction of phosphorus cost about 1s. per ton for each 0.1 per cent., so that soft 0.3 per cent. phosphorus iron without steel was roughly 7s. a ton dearer than a 1 per cent. phosphorus mixture. This made a big difference in total metal cost, as over half the output was likely to be in this class of iron. In conclusion, Mr. Harbach said he wished to thank Mr. Judson for a very interesting and informative Paper.

### Fracture of Pig-Iron

Mr. J. G. Pearce said he wished to emphasise a few of the points dealt with by Dr. Norbury in his admirable Paper. Constancy of fracture did not mean, and never had meant, constancy of silicon content. This was well brought out in the Paper. Some writers had made great play with silicon variations for the same fracture and used them to condemn fracture, but, as was shown in the Paper, if the carbon varied in sympathy the chilling properties remained the same, which was what the founder was interested in. Some countries had completely abandoned fracture as a guide for classifying or purchasing pig-iron. Dr. Norbury's Paper showed that the British feeling that fracture did mean something had a scientific justification. It told the ironfounder something not necessarily gleaned from analysis, but it had to be added that pig-iron could not be purchased on a specification including both analysis and fracture unless it was specially selected. The blast furnace could not be controlled to give both.

Another point was the remarkable way pig-iron compositions followed the eutectic line, and the closeness to it of the most widely used foundry iron, No. 3.

### Titanium Refining Process

Mr. Pearce, continuing, said that the titanium refining process was a remarkable development. Nobody had produced such uniformly fine graphite in such sections and with such high carbons. It was a development, however, which at this stage should be regarded as a fundamental investigation into the cause and mechanism of graphite formation rather than as a process, although the possibilities of application were, of course, not being overlooked. If further investigation confirmed that coarse graphite arose from the presence of silicate slag, and that fine graphite was formed when this slag was either absent or prevented from acting in a usual way (as in the titanium process), the greatest single step forward would have been taken in the understanding, and hence in the control, of graphite formation, which meant the control of properties. It looked as if fine graphite was the normal condition of cast iron, and that in a sense coarse graphite was the exception, due to the universal use of silicon in pig and cast iron. Of course, many other possible methods of achieving the fine graphite had been examined. Mr. Pearce remarked that to a body containing those interested in the aluminium alloys and their modification there was interest in the remarkable similarity between these structural changes in cast iron and those occurring in the modification of the aluminium alloys. So much was this so that we spoke of the cast iron as "modified" when it underwent this change, and as "demodified" when the reverse was effected. The explanation in all probability was on similar lines for both metals, and, indeed, it might be said that the main problem facing all metallurgists on cast alloys—cast iron, steel, non-ferrous—was that of the non-metallic inclusion, and investigation on these lines would have far-reaching effects.

### An Ideal Exchange Paper

Commenting upon Dr. Jungbluth's Paper, Mr. Pearce remarked that, in his opinion, it formed an ideal exchange Paper, because it presented developments in the author's country over a period of years in a field with which the author was familiar and in which he himself was a distinguished worker. He thought they were very fortunate in having this Paper from Dr. Jungbluth. In this country the effect of what in Germany was called wall-thickness sensitivity had, of course, been recognised, and the effects of section, composition and alloy additions had been studied, but not to the extent they had been studied in Germany. The reason for this, he thought, was that British investigators were more concerned with the practical than with the theoretical aspects of the question, and while we could whole-heartedly agree that there was a general law, such as that given early in the Paper, it seemed that the variations in composition and graphite size which were obtainable in practice were so wide that each cast had its own constant $c$ and exponent $m$, and that it would be dangerous to attempt to predict sensitivity from formulæ derived from tests on one material applied to another, even of similar composition. Also the moulding, casting and melting conditions had to be considered, as was pointed out by Dr. Jungbluth.

### Brinell Test and Tensile Ratios

Perhaps this point could be illustrated by saying that various Continental writers had suggested a connection (given in a specific formula) between Brinell hardness and tensile strength. These formulæ, of course, differed from each other, and clearly could not all be true, or true of all cast irons. They were true for the particular compositions studied, for the conditions under which the test was made. We therefore said that there was no general connection between Brinell hardness and tensile strength, but that a connection found between these properties for a given composition and thickness might remain true for the same material made in the same way.

The difficulty of formulating these general connections was abundantly shown in Dr. Jungbluth's Paper, and there was cause for congratulation in that he had made no attempt to shirk or minimise the difficulties. The difficulty of drawing curves to fit points in Figs. 6, 7, 8 and 9 was evident. Dr. Jungbluth concluded that the work on alloy irons was calculated to give qualitative results only, and data on castings were meagre, while the relationship between the mechanical properties of wall thickness in castings and test bars was still obscure. If this was the result of the volume of work embodied in the present review, how much more remained to be done? The speaker had been struck many times with the number of curves of a kind which lent themselves to logarithmic treatment and hence provided a mathematical relation between the quantities concerned, but treatment on these lines had shown the results to be too scattered to permit a relation to be formulated, even for one material. Such curves had been given in Papers to the Institute of British Foundrymen and elsewhere, and connected, for example, cast section size and any mechanical test, such as transverse strength, tensile strength, torsional strength, hardness, and also deflection and elastic modulus. Perhaps less erratic results would come out of the application of tests to irons containing completely refined graphite, as described in a parallel Paper by Dr. Norbury. Mr. Pearce concluded with the remark that some work on the connection between test bar and casting was also in progress.

### Tensile Test and Casting Thickness

Mr. C. E. Williams (Past-President) said he would like first of all to thank the authors of the Papers for the Papers themselves, especially their friend from Germany and their friend from the United States, for coming such a long way to present their admirable Papers to the members of the Institute. In the Paper of Dr. Jungbluth Mr. Williams said he was particularly interested in this question of wall thickness. Recently his own firm had some castings weighing 3, 4 or 5 tons, of a thickness of at least 6 in., and they had to cast on to them tensile test pieces. They had had much trouble in getting the test pieces—in fact they had a good deal of trouble with the inspector. He would not pause to tell them how they got over that difficulty. (Laughter.) The question he would ask was: Was there in existence a proper connection between not only the breaking test but the tensile test and the thickness of the casting piece which was being cast? Was there a proper set of data in this country? If not, it was surely a very simple thing for the Institute to take the matter up and look into it, because he could assure them that the specification that came to his firm was impracticable, and it came from one of the largest users of castings in this country. If there were not proper data in this country, he suggested that that was a matter which the Institute could very properly take up.

Mr. A. Sutcliffe asked Dr. Norbury the reason for discrepancies in the analyses of cast iron when received from different centres, and whether a good analysis was a fundamental factor in the making of a sound and satisfactory casting. Other queries related to the ascertainment of the composition of the scrap used in cupola charges; whether satisfactory figures could be obtained from open sand-cast test bars; and if there were factors other than chemical composition which affected the real worth of pig-iron and which were appreciated by the practical man. In connection with this last question he cited the problems of carbon pick-up in the cupola, rapid loss of "life" in the ladle and frothing slags. Finally, he asked—assuming the moulder had made a perfect mould—why the metallurgist should not provide perfect metal which would eliminate any necessity for chills, denseners and nailing.

Mr. Ben Hird mentioned an instance that had come under his own observation bearing on what had been said about the fracture of pig-iron and the resultant fracture in the casting. He admitted that he spoke of a freak batch which had come with a delivery of hematite pig-iron. The fracture was that of a No. 3 hematite iron, tough to break and easy to drill. The graphite showed a peculiar formation like a closed-up star or a daisy. This iron was carefully melted in a clean crucible and poured into a green sand mould containing 1 in. by 1 in. by 14 in. test bars, which were allowed to cool normally; when broken, the fracture was pure white. Another piece of the same pig was melted in the same way and poured into a dry sand mould, containing a 4 in. cube block. When this was split open, the fracture was white at the corners and along the sides, and the remainder deeply mottled white. He thought it would be of interest to the meeting to mention this experience, because it was a very remarkable result to get from what was to all appearances a good No. 3 hematite iron. The compositions of the pig-iron and casting were:—*Pig-iron*: T.C, 3.42; Gr, 2.64; C.C, 0.78; Si, 0.51; Mn, 1.02; S, 0.092; and P, 0.068 per cent. *Test bar*: T.C, 3.294; Gr, 0.034; C.C, 3.26; Si, 0.47; Mn, 0.60; S, 0.082; and P, 0.132 per cent.

Mr. Hird expressed doubt as to the accuracy of the manganese and phosphorus contents in the test bar, as these were checked over with slightly different results, but similar proportions.

Dr. H. A. Nipper (Germany) congratulated Dr. Norbury on his very interesting Paper, and also the Institute and the British Cast Iron Research Association on the valuable work it was doing by its publication of such contributions. He asked Dr. Norbury whether he would offer an explanation of the mechanism of the titanium effect on graphitisation.

A Member asked Mr. Judson if he could give any information upon his cupola practice with reference to mechanical or hand charging. He also felt sure that Mr. Judson must have encountered considerable difficulty in connection with porosity. Mr. Judson did mention that he had to make a special point to utilise the metal as hot as possible, but he did not make any mention of what his temperature actually was.

Mr. J. H. Cooper suggested that their object at such a conference was not so much to criticise any Paper, but to work together as a team and suggest what should be done, and how, to overcome this or that difficulty; if they did that, he thought they would be taking a step in the right direction.

The President (Mr. H. Winterton) said he would like to associate himself particularly with Mr. Cooper's remarks. It was a text which he himself adopted about the year 1907 when he gave his first Paper before the British Foundrymen's Association. He thought it was up to the members of this Institute to collaborate even more together in the future than they had done in the past. As Mr. Cooper had said, they had met not actually to criticise one another's work, except in a manner which would help them all to attain their desired object, and he was quite sure that if they did work together as a team, that object would assuredly be well attained. The President concluded by inviting the authors of the various Papers to reply to the discussion.

## AUTHORS' REPLIES

Mr. J. E. Hurst, in replying to the discussion, said with reference to the points raised by Dr. Everest in connection with his Paper that he would like it to be clearly understood that this investigation was undertaken purely for investigation purposes at the outset, and the object of choosing a low-silicon iron was that they were interested in irons that were likely to be white in character. He was unable to draw any comparison between manganese-molybdenum alloy cast irons and the alloys known as "Ni-Hard," but hardness alone was not necessarily the sole criterion of the advantages of an iron of that class. He could imagine that hardness must of necessity be accompanied by good strength properties in all aspects of those strength properties in the commercial application of alloy irons of that type. He could imagine, for example, that it was highly advantageous for irons used in the roll industry, and in other industries where chilled irons were used, that they should possess high resistance to fatigue, and consequently there was a need apparent for the investigation of the properties of all the alloy irons of this type, including "Ni-Hard." He suggested it would be worth while carrying out an investigation extended to alloys of the "Ni-Hard" type. Mr. Hurst went on to say that the internal stress figure was a figure obtained by the measurement of the movement of a test ring when cutting the gap, and it was assumed that it was a revelation of the internal stress that existed in that ring before the gap was cut. It had always been a matter of some astonishment to him that they had movements of such a substantial order in these test rings after treating. These movements mentioned in the Paper were obtained on the test rings in the annealed condition, that was to say, the test rings that had been subjected to an annealing treatment, and they had always been led to understand that such treatments tended to minimise the internal stress. In spite of that, internal stress of quite a substantial order was revealed by these gap movements, and it appeared that that internal stress was minimised by an increase in the manganese-molybdenum content. If these facts should ultimately turn out to be of commercial advantage, then the experiments should prove worth while. In conclusion, Mr. Hurst remarked that Dr. Everest had commented on the star test piece he had used. The reason why he used this form of test piece was that it enabled him to obtain the form of test rings he had used for this particular test.

Dr. Jungbluth indicated that, as his knowledge of the English language was somewhat limited, he proposed to reply to the discussion in writing.

Dr. Norbury, in replying to the discussion, remarked that Mr. Hird had mentioned an interesting case. It was difficult to say what it might be due to without knowing the analysis and other particulars, but he thought it raised the interesting point that one did get peculiar cases arising in a foundry, and if members brought such cases up at these meetings it was calculated to prove very helpful. Dr. Nipper had asked for information on the mechanism of the titanium effect. The titanium slag inclusions could be seen in the microstructure of the metal, and he thought the explanation was that they were still liquid when the graphite solidified, and consequently did not have an inoculating action, and the fine graphite structure resulted. Dr. Norbury went on to remark that in Dr. Jungbluth's Paper the author was investigating how the strength varied from one section of a casting to another. As Dr. Jungbluth pointed out, these variations were not obtained in steels, and were due to variations in the graphite size, and therefore the solution of Dr. Jungbluth's problem was bound up with the solution of the problem of what affected the graphite size.

Mr. Judson, in replying to the discussion on his Paper, said it had been a very great pleasure to him to have been able to make what little contribution he had made. It was particularly pleasing to him, because his father hailed from Bradford. Mr. Judson went on to explain that the term "inoculation" was not used in the Paper, because they did not want to theorise and they did not want to steal anybody else's thunder. He thought the photomicrographs indicated that too long a time could be allowed to elapse between the inoculation and the pouring. He might say that they did not let the soft iron and the hard iron stand mixed any longer than they possibly could. The proportion of high-pressure castings to the remainder of their production was such that the scrap return was very low. Definitely, they felt that they wanted low carbon. In reply to another query, he wished to say that they charged by hand. With regard to the question of porosity, he thought that, if they had it operating under 1,000 lbs. pressure on petrol, it would show it up instantly. The temperature they got at the spout was in the neighbourhood of 1,310 deg. C. actual.

The PRESIDENT, in closing the proceedings, said he thought they would all agree that at this conference some most excellent Papers had been presented, and he proposed a hearty vote of thanks to the authors of the various Papers as well as to the members who had contributed to the discussion.

## AUTHORS' WRITTEN REPLIES

### Mr. H. H. Judson

Mr. Judson pointed out that a Paper on the two cupola process was given to the American Foundrymen Association meeting in Detroit four years ago.

The temperature (1,410 deg. C.) of the metal at the spout, referred to in Mr. Judson's Paper, was taken with no correction made for emissivity.

In further reply to Mr. Harbach's remarks, MR. JUDSON writes that the steel used is normal railway rail scrap and shows the following analysis: T.C, 0.55; Si, 0.15; Mn, 0.75; S, 0.06; and P, 0.05 per cent. The pig-iron used with the steel rail charges, for the two-cupola process, has a silicon content of 15.3 per cent. The average manganese loss in all of the cupola operations in which Spiegeleisen, containing 20 per cent. Mn is used, is 40 per cent.

The use of the returns from the high-duty heats has already been covered. The amount of these returns is so small as compared with the rest of the tonnage that their use in other mixtures is not a serious matter. The foundry does not use the high-duty returns in high-duty mixtures, preferring to start with as low a graphitic-carbon content in the steel-rail charges as possible. The phosphorus content of the common iron will be dealt with later.

Reference in the discussion was made to a mixture containing 2.40 per cent. total carbon and 1.35 per cent. silicon as requiring adjustment. Never having run such a mixture it is impossible to say definitely. These figures are the low limit, and the foundry has never obtained both in the same heat, and in fact has not attempted to run such a mixture.

The remainder of the discussion which pertains to low-carbon irons is answered by the following. Hundreds of tons of castings for high-pressure pumps, operating on crude oil and petrol, at pressures of 900 lbs. per sq. in. or over, have been cast from mixtures having 2.50 to 2.70 per cent. T.C and 1.50 to 1.70 per cent. Si. The main thought behind the low-carbon iron described is that of pressure-tightness rather than high strength. Tensile strengths, always over 19 tons per sq. in., are obtained from specimens cut from the walls of actual castings and not from test bars, are ample. Waster castings are no problem, and in fact, there are many jobs that the foundry insists on casting with this low-carbon iron because of an almost complete freedom from leakers on test.

The last part of the discussion refers to the phosphorus content of the common iron. The phosphorus content of the pig-irons used for years ran 0.45 per cent., which is not low, and does not command a premium. It is only when the phosphorus is specified below 0.30 per cent. that a premium has to be paid. Incidentally, no attention is paid to the phosphorus content when machineability is being considered.

## Dr. H. Jungbluths' Reply.

Dr. Jungbluth wrote:—

Mr. G. L. Harbach is correct when he says that the rule given by M. V. Schwarz and A. Vath to make the test bar twice as thick as the wall-thickness is only valid in very rare cases.

In fact, the discussion of the relationship between wall-thickness sensitivity in castings and test bars (Section III) was specifically designed to emphasise this lack of generality.

The author is not sure if Mr. Harbach quite understood his remarks regarding Coyle's investigations. He does not think that the percentage drop in tensile value is the same in all qualities of cast iron. But it must be inferred from Coyle's work that he held this view. Hence to characterise different grades of cast iron he employed the coefficient ($c$) of the exponential relationship between the test bar thickness and the tensile strength, while Heller and the author intentionally introduced the exponent ($m$) for this purpose.

The author agrees with Mr. Harbach that a relationship between Brinell hardness and the tensile strength is not easy to establish, so that the Brinell hardness cannot be conveniently used for determining the wall-thickness sensitivity, as has been done by some investigators. It was the author's intention to emphasise this.

Mr. J. G. Pearce, with justice, indicates that owing to the wide dispersion in the values it is difficult to forecast the wall-thickness sensitivity of an individual casting. As yet unpublished, investigations, however, show that at least high-grade cast iron has a very small wall-thickness sensitivity, so that in practice the problem of this factor is considerably simplified.

The author also agrees with Mr. C. E. Williams that the problem of wall-thickness sensitivity is closely associated with the relationship between the tensile strength of a cast-iron test bar and that of the casting itself. Investigations on this question also have been carried out in Germany, details of which will be published shortly.

## COMMUNICATIONS

### On Paper

### By Dr. A. L. Norbury and Mr. E. Morgan

Dr. J. T. Mackenzie (Birmingham, Ala.) wrote:—

In regard to Fig. 1, the segregation of carbon in the pig is a peculiar phenomenon and it is difficult to believe that it is all explainable on the basis of eutectic composition. Of course, it is true that with a hyper-eutectic iron such as shown in Pig A, the tendency would be for kish to segregate to the top. But this does not explain the segregation of a like percentage in the C Pig which on the basis of an average composition would be distinctly hypo-eutectic.

It is quite well established that hot iron loses carbon, as any perusal of the high-temperature work will immediately make apparent. Practically no one has been able to superheat cast iron without producing a lower carbon iron at the same time and a good deal of the speculation on this superheating has been unavoidably mixed up with this phenomenon. It is quite difficult also to check carbons between a thin section and a thick section poured out of the same ladle at the same temperature. Whether this is a difficulty of getting the coarse graphite into the combustion boat or whether it is actually some phenomenon connected with the oxidation of carbon during the solidification process has always been questionable from a personal point of view.

The eutectic lines shown in Fig. 3 (and it is presumed also in Figs. 2 and 4) do not take into account the phosphorus content. If the usual rule of 0.3 per cent. phosphorus were applied to this figure it would be found that the eutectic line will curve sharply to the bottom and practically bisect all three lines. The eutectic with 2 per cent. silicon and 0.5 per cent. phosphorus instead of being 3.80 as shown would be at 3.65, and with 1.5 per cent. phosphorus would be 3.35. This rule has been checked personally in centrifugal castings on phosphorus from 0.01 to 2 per cent., and it is certain that it is of universal applicability, as the centrifugal casting process is the best index of the eutectic available.

Considering the titanium-treated iron in Table II, it will be observed that D is very close to the eutectic, being only 3 or 4 points above, quite within the limits of analytical error, whereas C is 12 or 13 points above. Normally, quite a sharp break in strength is found at the eutectic. It is of interest to query if this should not be held responsible for the increased strength instead of the titanium treatment, especially in view of Dr. Norbury's statement at the end of the first paragraph in the middle column of page 455 that "The metal must also be below the eutectic composition for the graphite to be fine." The example in Table I seems a very good example of difference in strength with the same analysis, but the writer is certainly not impressed by the authors' example in Table II.

### Authors' Reply

We find Dr. MacKenzie's contribution very much to the point, and agree with practically all he says. As he points out, Pig C in Fig. 1 is hypo-eutectic in composition, but the carbon analyses show that the carbon has floated up even in this case. Carbon can, however, segregate from other causes, as shown in the accompanying Fig. A, which shows variation of carbon content from edge to centre of a vertically cast test bar. This type of segregation may also be occurring to a certain extent in the pigs shown in Fig. 1, but the main carbon segregation in these pigs appears to be due to flotation. We have observed that there is usually a certain amount of carbon burnt out of the surface of a casting, and suggest that this is due to the action of steam during the cooling of the casting in the mould. More carbon is burnt out in the case of more slowly cooled heavy castings.

With regard to the effect of phosphorus on the eutectic composition, it is briefly stated in the

Paper that "phosphorus has a very similar effect to silicon in reducing the solubility of carbon," and the phosphorus contents of the pigs are given in Fig. 3, but Dr. MacKenzie's observations are extremely useful, as is his figure of 0.3 per cent. which had been obtained from his personal observations. While the authors agree with his observations regarding Table II, they can assure him that they have obtained just the same sort of differences in graphite size and strength on irons further removed from the

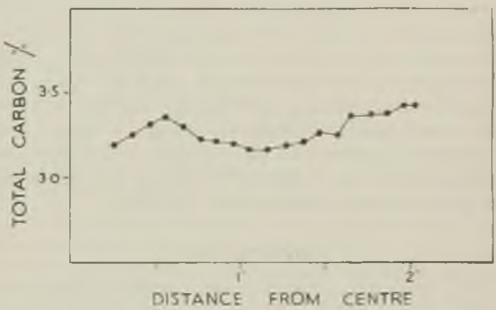


Fig. A.—Carbon Segregation from Centre to Edge of 4.2-in. dia. Vertically-Cast Test Bar in Grey Cast Iron.

eutectic composition, although, as stated, the differences in strength become progressively less as the composition becomes further removed from the eutectic composition.

The authors are presenting a Paper in September to the Iron and Steel Institute, entitled "The Effect of Non-Metallic Inclusions on the Graphite Size of Grey Cast Iron," which deals more fully with the subject. They were very interested in some of the round-table discussions the American Foundrymen's Association have been having recently on the qualities of pig-iron, and if Dr. MacKenzie could refer them to any further discussions and Papers of this sort, they would be very interested to read them.

Mr. S. E. Dawson wrote:—

In introducing this subject, so fundamentally important to the foundry industry, the authors have indicated the function of carbon and silicon in relation to the eutectic composition and temperature. In practice, however, fractures may vary irrespective of these factors, and a No. 3 iron be produced with a lower silicon than a No. 4, even for similar carbons. Does not this suggest other influences than eutectic balance of composition? For example, the effect of $CO_2$ in the presence of Ti, referred to in the Paper, suggests that the composition of the gases in the furnace and in contact with the metal, might have some bearing on the matter.

Also Boegehold, investigating the same problem, and examining the pig-iron from seven blast furnaces, found that the quality of coke had a large effect on the properties and fracture of the iron, and stressed the importance of the combustibility or maximum burning rate of the coke in this connection, a factor which may not be unconnected with the composition of the gases in the furnace. He further found that such different properties were also present in the cast metal from these pig-irons remelted under identical conditions in the cupola. This was especially observed with regard to hardness and fluidity, and the dilatometer test curves showed the same form and characteristics for each pig-iron and the remelt therefrom. Also, he showed that the effect of moisture in the blast increased the combined carbon and chill progressively for equal compositions.

The investigations of W. E. Jominy on about a hundred pig-iron casts, using two extremes of fuel, namely, charcoal and coke, are worth noting. A considerable difference in structure and fracture was observed in the two series, the graphite in particular being smaller and better distributed in the charcoal pig-iron. On remelting twice over in an electric furnace, under conditions to preserve original compositions, the first remelt showed the charcoal irons to be 20 per cent. stronger in tensile and transverse strength than the coke-melted pig-irons, and this same difference persisted through the second remelt.

Other factors influencing graphite size and fracture may include the so-called "silicate slime" or colloidal silicates, the elimination of which contributes to the improvement in structure which may be so obtained.

These points, amongst others, were referred to in some details by the writer in a Paper given before the East Midlands Branch in October, 1935, and the subject is of such importance that the suggestion then made of a joint investigation by all interests concerned might very well be considered.

## RECOMMENDATIONS FOR TWO LEADED GUNMETALS

### By the Non-Ferrous Sub-Committee of the Technical Committee

Leaded gunmetals are very largely used for a wide variety of purposes in engineering practice, and in the absence of any standard specifications for these, alloys are made by the foundry industry to comply with a very large number of different requirements of individual purchasers. The most widely known of the gunmetals is the alloy known as "Admiralty gunmetal," for which the British Standards Institution have

TABLE I.—*British Standard Specification No.* 383—1930, *for* 2/10/88 *Bronze* (*Gunmetal*) *Castings for General Engineering Purposes.*

| | |
|---|---|
| *Analysis :* | |
| Copper .. .. .. | 86.65—88.5 per cent. |
| Tin .. .. .. | 9.75—10.25 ,, |
| Lead .. .. .. | 0.50 maximum per cent. |
| Zinc .. .. .. | 1 75—2.25 per cent. |
| Nickel.. .. .. | 0.20 maximum per cent. |
| Other elements .. | 0.15 maximum per cent. |
| *Physical properties :* | |
| Tensile strength .. | 16 tons per sq. in. minimum. |
| Elongation .. .. | 8 per cent. minimum. |

drawn up a specification, of which the *precis* is given in Table I (B.S.S. No. 383/1930).

The user who requires a gunmetal other than that covered by B.S.S.383 and wishes, quite legitimately, to buy on analysis and physical properties, is faced with the problem of drawing up his own specification or of adopting some other private specification which may not be quite suitable for a particular duty, or may, as is frequently the case, be deficient in one or more particulars which should be in every specification for a cast alloy to ensure material of good quality.

The result has been the production of a very large number of specifications of varying degrees of suitability, in many cases differing from one another in minor respects only. In the preliminary investigation conducted by the Sub-Committee it was found that no fewer than 37 specifications in current use by various purchasers fell within the range of composition given in Table II.

The necessity for constant variations in procedure to meet small points of difference in specifications for what are essentially similar materials is highly inefficient, and militates against the regular production of articles of uniformly good quality.

TABLE II.—*Range of Leaded Gunmetals Covered in* 37 *Specifications Examined.*

| | | |
|---|---|---|
| Copper .. .. .. | 82—93 | per cent. |
| Tin .. .. .. .. | 4—9 | ,, |
| Lead .. .. .. .. | 0—7 | ,, |
| Zinc .. .. .. .. | 1—8 | ,, |

The Sub-Committee considers, therefore, that the interests of manufacturers and users would be well served by the standardisation of suitable compositions of leaded gunmetals which would cover the range of materials indicated in Table II and provide recognised and generally-used materials for duties where a gunmetal cheaper than Admiralty gunmetal would meet the needs adequately and possibly more effectively. Two compositions are indicated in the present report, which also contains the results of large numbers of tests carried out in various bronze foundries on selected alloys. In order that the results obtained in different foundries should be comparable, special forms of test-bar designed to give reproducible results were devised and the details of these test-bars, together with reasons which led to their adoption, are also indicated.

## Test-Bar Preparation

In investigating the problem of suitable alloys to cover adequately the range indicated in Table II, it was found that much divergence of physical test data resulted from great difference

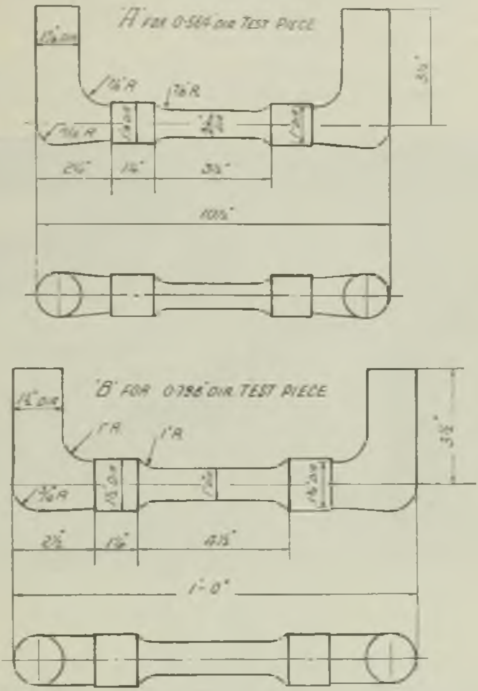


FIG. 1.—STANDARD CAST TEST-BARS FOR GUNMETALS, BRONZES AND PHOSPHOR-BRONZES.

in the manner of casting test-bars, both as regards the shape of these and the method of running them, and the character of the mould, *i.e.*, green sand and dry sand.

Much confusion of thought appears to exist on the subject of the function of test-bars in relation to cast non-ferrous alloys. There is no reason why test-bars, either cast "loose" or "attached," should necessarily give the same physical properties as would be found by cutting samples from the casting itself. Test-bars can only give an indication of the quality of the metal which has been used.

To obtain correct knowledge of the physical properties of the casting, it is necessary to cut

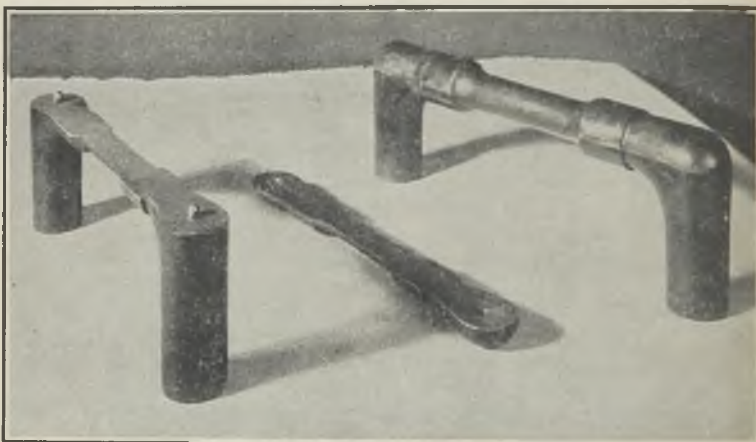

FIG. 2.—PATTERN FOR STANDARD TEST-BAR.

test-pieces from the casting itself in various positions, which is an unnecessary and commercially impracticable procedure for the majority of non-ferrous castings.

The selection of the most suitable type of test-bar and method of moulding and pouring should therefore be influenced not by an endeavour to obtain the highest physical properties possible, but by consideration of uniformity of results throughout the majority of foundries, and of methods not subject to wide variation in results

TABLE III.—*Gunmetals—Composition.*

| I.B.F. designation. | Specification. | Copper. Per cent. | Tin. Per cent. | Zinc Per cent. | Lead Per cent. |
|---|---|---|---|---|---|
| G.M.1 | Admiralty Gunmetal (88:10:2) or B.S.I. 383/30 | Remainder | 9.75—10.25 Min. | 1.75—2.25 Max. | 0.0—0.50 Max. |
| G.M 2 | 87 : 9 : 3 : 1 Gunmetal .. | Remainder | 8 per cent. | 4 per cent. | 2 per cent. |
| G.M.3 | 85 : 5 : 5 : 5 Gunmetal .. | Remainder | 5 per cent. | 6 per cent. | 6 per cent. |

due to slight variation in treatment. The test-bar and the method of casting should be capable of adoption by any foundry with the assurance of repetition of results obtained in other foundries. Studies of various test-pieces and methods of running in general use were made, and it was felt that most of these had been designed to give the highest test results possible (under carefully

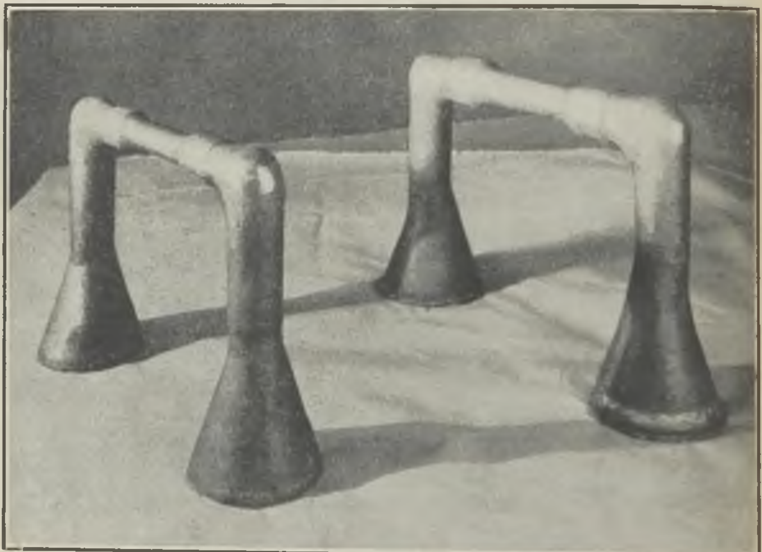

FIG. 3.—THE TEST-BARS AS CAST.

standardised and sensitive conditions), without due regard to the probable physical test results in the castings these bars were presumed to represent.

As indicated above, the Sub-committee have taken the view that it is futile to attempt to devise a test bar which will reproduce the physical characteristics of the related castings.

The Sub-committee has therefore decided to recommend a type of bar and method of casting the keynote of which is simplicity. This is illustrated in Fig. 1. Two sizes are shown, the smaller to turn to 0.564 in. in the effective gauge length, and the larger to turn to 0.798 in. in the effective gauge length. Both bars are suitable for turning to suit any normal type of test-

TABLE IV —*Gunmetals—Physical Properties.*

| I.B.F. designation. | Specification. | Maximum stress. Tons per sq. in. | Elongation. Per cent. |
|---|---|---|---|
| | | Min. | Min. |
| G.M.1 | Admiralty Gunmetal or B.S.I. 383/30 (88:10:2) | 16 | 8 |
| G.M.2 | 87 : 9 : 3 : 1 Gunmetal | 14 | 14 |
| G.M.3 | 85 : 5 : 5 : 5 Gunmetal | 12 | 12 |

Material complying with the above tensile tests may be expected to give the following other physical properties :—

| I.B.F. designation. | Specification. | Brinell hardness, 10 mm. per 1,000 kg. | Density (machined specimens). |
|---|---|---|---|
| G.M.1 | Admiralty Gunmetal (88:10:2) or B.S.I. 383/30 | 65 | 8.50 |
| G.M.2 | 87 : 9 : 3 : 1 . . | 65 | 8.50 |
| G.M.3 | 85 : 5 : 5 : 5 . . | 60 | 8.55 |

ing machine grips, either wedge grips or collared ball seating grips.

It has been thought advisable to specify the dimensions of the ingate and riser for each size of bar and for normal use the Sub-committee recommend that these should be made integral with the pattern as shown in Fig. 2. It is recommended that the size of test-bar used to represent any particular batch of castings shall be that of which

TABLE V.—*Summary of Physical Tests on G.M.2 and G.M.3.*

| Works. | Maximum stress, tons per sq. in. | | | | | | Elongation, per cent. | | | | | | Type of mould. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Large bar. | | | Small bar. | | | Large bar on 3 in. | | | Small bar on 2 in. | | | |
| | Casting temperature, deg. C. | | | | | | Casting temperature, deg. C. | | | | | | |
| | 1,200 | 1,150 | 1,100 | 1,200 | 1,150 | 1,100 | 1,200 | 1,150 | 1,100 | 1,200 | 1,150 | 1,100 | |
| G.M.2— | | | | | | | | | | | | | |
| A .. .. | 16.6 | 18.0 | 17.6 | 16.4 | 14.0 | 15.6 | 28.0 | 26.0 | 21.0 | 25.0 | 10.0 | 12.0 | Dry |
| A .. .. | 18.0 | 17.6 | 17.2 | 15.2 | 18.0 | 18.4 | 35.0 | 25.0 | 20.0 | 17.0 | 23.0 | 32.0 | ,, |
| B .. .. | 13.7 | 14.1 | 15.3 | 12.8 | 15.8 | 14.8 | 12.5 | 12.0 | 16.0 | 7.5 | 18.5 | 12.0 | Green. |
| C .. .. | 16.0 | 17.7 | 16.2 | 17.6 | 19.2 | 15.6 | 18.5 | 21.0 | 8.5 | 24.5 | 27.5 | 7.0 | Dry. |
| C .. .. | 15.8 | 15.6 | 15.2 | 18.8 | 18.0 | 17.6 | 15.0 | 13.0 | 14.0 | 30.0 | 23.5 | 12.5 | Green. |
| D .. .. | — | 17.2 | — | — | 16.5 | — | — | 24.0 | — | — | 17.5 | — | Dry. |
| F .. .. | 13.7 | 14.8 | 16.2 | 16.2 | 16.3 | 16.6 | 15.0 | 18.0 | 20.0 | 20.0 | 20.0 | 19.0 | ,, |
| G .. .. | 11.5 | 12.9 | 18.5 | 16.4 | 16.8 | 17.0 | 18.0 | 11.0 | 33.0 | 20.0 | 23.0 | 27.0 | ,, |
| Average .. | 15.0 | 16.0 | 16.6 | 16.0 | 16.8 | 16.5 | 20.0 | 19.0 | 18.9 | 20.5 | 20.0 | 17.3 | — |
| G.M.3— | | | | | | | | | | | | | |
| A .. .. | 12.8 | 13.2 | 11.0 | 9.6 | 9.6 | 11.2 | 18.0 | 18.0 | 11.0 | 11.0 | 10.0 | 14.0 | Dry. |
| A .. .. | 13.6 | 14.8 | 15.0 | 15.2 | 13.6 | 14.4 | 18.0 | 27.0 | 28.0 | 18.0 | 19.0 | 28.0 | ,, |
| B .. .. | 15.5 | 12.9 | 16.0 | 14.4 | 14.6 | 14.8 | 16.5 | 13.0 | 27.0 | 20.0 | 21.0 | 21.5 | Green. |
| C .. .. | 14.2 | 15.6 | 16.4 | 16.8 | 16.0 | 18.0 | 12.0 | 18.0 | 18.0 | 16.0 | 13.0 | 19.0 | Dry. |
| C .. .. | 16.6 | 15.6 | 16.4 | 16.8 | 15.2 | 18.0 | 19.0 | 17.0 | 17.0 | 19.0 | 10.0 | 19.0 | Green. |
| D .. .. | — | 15.2 | — | — | 15.0 | — | — | 23.0 | — | — | 21.0 | — | Dry. |
| F .. .. | 12.1 | 13.8 | 12.5 | 12.9 | 14.2 | 12.6 | 12.0 | 17.0 | 16.0 | 15.0 | 16.0 | 16.0 | ,, |
| G .. .. | 12.4 | 14.0 | 14.3 | 10.6 | 13.6 | 15.0 | 18.0 | 24.0 | 22.0 | 16.0 | 21.0 | 22.0 | ,, |
| Average .. | 13.9 | 14.4 | 14.5 | 13.4 | 14.0 | 14.8 | 16.0 | 19.6 | 20.0 | 16.4 | 16.5 | 20.0 | — |

*Summary of Brinell Hardness and Density Determinations.*

| Works. | Brinell hardness. | | | | | | Density. | | | | | | Type of mould. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Large bar. | | | Small bar. | | | Large bar. | | | Small bar. | | | |
| | Casting temperature, deg. C. | | | | | | Casting temperature, deg. C. | | | | | | |
| | 1,200 | 1,150 | 1,100 | 1,200 | 1,150 | 1,100 | 1,200 | 1,150 | 1,100 | 1,200 | 1,150 | 1,100 | |
| G.M.2— | | | | | | | | | | | | | |
| A .. .. | 65.5 | 68.8 | 72.4 | 59.5 | 71.0 | 72.4 | 8.46 | 8.66 | 8.79 | 8.52 | 8.66 | 8.84 | Dry. |
| A .. .. | 65.5 | 63.9 | 70.6 | 65.5 | 68.8 | 72.4 | 8.61 | 8.67 | 8.82 | 8.69 | 8.82 | 8.84 | ,, |
| C .. .. | 79.3 | 80.4 | 87.3 | 75.3 | 84.9 | 89.7 | 8.64 | 8.69 | 8.79 | 8.70 | 8.77 | 8.92 | ,, |
| C .. .. | 74.3 | 79.3 | 77.6 | 78.9 | 87.2 | 87.3 | 8.33 | 8.61 | 8.57 | 8.58 | 8.83 | 8.84 | Green |
| D .. .. | — | 89.0 | — | — | 77.0 | — | — | 8.62 | — | — | 8.65 | — | Dry. |
| F .. .. | 69.0 | 76.0 | 78.0 | 68.0 | 75.0 | 78.0 | 8.4 | 8.6 | 8.76 | 8.47 | 8.63 | 8.82 | ,, |
| G .. .. | 62.4 | 70.6 | 76.5 | 82.6 | 78.3 | 72.4 | — | — | — | — | — | — | ,, |
| Average .. | 69.3 | 75.4 | 77.0 | 71.6 | 77.4 | 78.7 | 8.49 | 8.64 | 8.74 | 8.59 | 8.73 | 8.85 | — |
| G.M.3— | | | | | | | | | | | | | |
| A .. .. | 62.4 | 55.8 | 56.8 | 54.3 | 56.3 | 58.1 | 8.5 | 8.66 | 8.8 | 8.57 | 8.71 | 8.88 | Dry. |
| A .. .. | 62.4 | 62.4 | 55.5 | 59.5 | 59.5 | 59.5 | 8.86 | 8.78 | 8.56 | 8.89 | 8.85 | 8.72 | ,, |
| C .. .. | 76.3 | 76.3 | 72.5 | 75.3 | 77.3 | 80.4 | 8.67 | 8.72 | 8.85 | 8.78 | 8.83 | 8.89 | ,, |
| C .. .. | 71.5 | 72.4 | 76.3 | 78.3 | 76.3 | 80.4 | 8.6 | 8.67 | 8.67 | 8.70 | 8.79 | 8.89 | Green. |
| D .. .. | — | 80.0 | — | — | 69.0 | — | — | 8.77 | — | — | 8.70 | — | Dry. |
| F .. .. | 60.0 | 63.0 | 68.0 | 62.0 | 64.0 | 69.0 | 8.43 | 8.59 | 8.81 | 8.44 | 8.66 | 8.83 | ,, |
| G .. .. | 65.5 | 72.4 | 68.8 | 65.5 | 59.5 | 68.8 | — | — | — | — | — | — | ,, |
| Average .. | 66.3 | 69.0 | 66.3 | 65.8 | 66.0 | 69.3 | 8.61 | 8.70 | 8.74 | 8.67 | 8.76 | 8.84 | — |

the cross section more nearly approaches the wall thickness of the casting concerned.

After careful study of the preliminary sets of tests on various alloys by members of the Sub-committee and prominent bronze foundries which agreed to carry out tests, it was decided that the alloys, the composition of which is shown in Table III, would meet all except very abnormal requirements for the gunmetals in the range stated in Table II other than Admiralty gun-metal (B.S.I. Spec. No. 383—1930). For convenience of comparison this alloy is shown in Table III. Table IV shows (B.S.I. Spec. No. 383—1930 included) the physical properties it is recommended be specified as minima for these alloys; the data on which these recommendations have been based are summarised in Table V.

Seven bronze foundries were asked to make a series of test-bars of these alloys—either in green or dry sand, or both, using the test-bars as shown in Fig. 1, and submit their results to the Non-Ferrous Sub-committee. They were asked also to cast both large and small bars at three different temperatures, these to be as near as possible to 1,200, 1,150 and 1,100 deg. C. This procedure in respect to casting temperature was adopted to give indication as to the influence of casting temperature on test results and to guide members of the Institute in any duplication or criticism of the results.

The complete schedule of results obtained by various members of the Sub-committee and co-operators is shown in Table V. Analyses of the alloys used by each co-operator have been purposely omitted but each co-operator has satisfied the Sub-committee that his alloy fell within the limits of Table III. Likewise no mention has been made as to whether all virgin or all scrap metal was used or a proportion of each. Having regard to the large divergence possible, both as regards composition within the limits of the specification and grade of metal used, the Sub-committee feels satisfied with the results obtained.

It is not felt that any useful purpose could be served by discussing the detailed results, since many details regarding the exact procedure which each investigator adopted are not available. The results are indicative of the results to be obtained under strictly works conditions, but naturally with some measure of control such as any well-ordered bronze foundry adopts to-day.

It has been thought advisable to include in the physical properties (though not for acceptance tests) both Brinell hardness and density as both these are simple inexpensive tests which the most modest of foundries and purchasers can adopt and which will give a very good indication (even without tensile test) of the quality of the material.

The introduction of density figures is somewhat novel, but this test is of great and insufficiently-appreciated value in cast non-ferrous alloys, and can be easily applied to a variety of forms and pieces. The method recommended for ascertainment of density is the simple one of weighing in air and then in water. Weighing in paraffin to avoid formation of air bubbles clinging to the specimen is sometimes an improvement. By the usual formula and using a reasonably sensitive balance results accurate to the first place of decimals can readily be obtained.

The density of the alloys concerned is not seriously affected by variation in composition but very largely by quality of metal, melting practice and casting temperature.

In the particular series under discussion samples varying from 7.9 to 8.9 have been examined by the Sub-committee, the former representing porous and weak metal and the latter close dense material resulting from chill casting in small sections.

The Sub-committee is very anxious to obtain the fullest expression of opinion on these recommendations both from makers and users with a view to making representations in the proper quarters for their adoption as standards subject to any modifications that may be deemed advisable after all opinions have been secured.

# DIMENSIONAL TOLERANCES FOR CASTINGS, WITH PARTICULAR REFERENCE TO MALLEABLE CAST IRON

By the Malleable Iron Sub-Committee of the Technical Committee

## Introduction

There is no bibliography on the subject of "Tolerances on Dimensions of Castings," and this may be accounted for by the fact that it is only in recent years that the demand for great accuracy in general castings has arisen. During the early part of 1933 the Malleable Sub-Committee in considering their Report* and the discussion thereon, presented at the Newcastle Convention, gave some attention to the subject of dimensional tolerances. A brief report was made to the Technical Committee in May, 1933, and further investigation was undertaken and a lengthy report made in December, 1933. At this stage the co-operation of the Steel, Grey Iron and Non-Ferrous Castings Sub-Committees was sought, and experimental work was carried on by members of these Committees throughout 1934, and a further report was made in December of that year. This report has formed the basis for the Paper here presented.

Modern methods of mass-production and machine shop practice, together with the highly competitive spirit which is present in the engineering world to-day, have established a need for greater precision in the making of castings. Difficult situations often now occur between the castings producer and the consumer because of the difference of opinion as to what is a reasonable degree of accuracy. Unfortunately, the question of accuracy to dimensions does not usually arise until after the castings are made and supplied to the customer, when the position naturally becomes very troublesome to both parties.

* Proc. I.B.F., Vol. XXV, p. 254.

Machining operations are performed upon castings chiefly to ensure accuracy of dimensions. The machined dimensions given upon drawings always carry a tolerance. This, admittedly, may be small, but it is definitely stated and may be measured during manufacture. The amount of this tolerance is governed by two factors: (*a*) the accuracy necessary for the part to fulfil its function and (*b*) the limitations of the machining equipment which can be utilised. Standard tolerances have been arrived at for the product of the rolling mills, and the figures have been embodied in specifications.

Attention has been given to the permissible variation in dimensions of forgings, most notably by H. Kaessberg,* whose recent publication is worthy of close study, as it deals in a most comprehensive manner with the factors affecting variations.

Consideration of existing tolerance specifications upon various products, and such literature as is available, shows that the degree of accuracy specified is within the limitations of the equipment used for economical production. When closer limits are required, it may be possible to employ special technique, but where this is practicable, it will always be at an increased manufacturing cost.

### Current Dimensional Clauses

A review of specifications for castings shows that generally the subject of dimensions is dismissed in a clause, the interpretation of which is dependent on individual opinion. The following extracts from existing specifications will demonstrate this.

### Specifications for Malleable Cast Iron

*B.S.L.* 310/1927.—" . . . shall conform as nearly as it is practically possible to the patterns or drawings."

*Admiralty*, *DNC/M/37C.*, *August*, 1932.—

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* "Metal Treatment," p. 198. Trans. from "Masch.-Betreit. Maschinenbau" (Der Betrieb), No. 19-20, October, 1935.

" The castings are to be to the dimensions specified within reasonable limits. When required, castings must admit of being machined to the exact dimensions stipulated."

*Post Office*, 75*B*.—" The dimensions to be in close agreement with those given on the drawing."

*British Railway*.—" . . . shall be accurately moulded in accordance with the pattern or drawing supplied."

*Electrical Firm*.—" A variation of $\frac{1}{16}$ in. per ft. from dimensions specified will be the maximum variation allowable."

*American Society for Testing Metals, No. A47-T, June*, 1932. *Tentative*.—" The castings shall conform substantially to the patterns or drawings furnished by the purchaser, and also to gauges which may be specified in individual cases. The castings shall be made in a workmanlike manner. A variation of $\frac{1}{8}$ in. per ft. will be permitted."

**A number of prominent motor vehicle and railway companies** do not include a clause relating to dimensions.

### Specifications for Grey Cast Iron

*B.S.I.* 321/1928.—" The castings shall be accurately moulded in accordance with the pattern or working drawings supplied by the engineer."

*British Railway*.—" . . . to be accurately moulded in accordance with the pattern and/or drawings supplied."

*Private Firm*.—" All core holes shall be cast true and all unlimited dimensions shown in the drawings must be adhered to within $\frac{1}{64}$ in. (plus or minus)."

### Specifications for Steel Castings

*B.S.I.* 24, *Part* 4, 1930.—" The castings shall be accurately moulded in accordance with the pattern or working drawing supplied by the engineer (or by the purchaser)."

*Admiralty*.—" The castings are required to conform accurately to the drawings and/or templates. Reasonable local variations of thickness will be permitted at the discretion of the overseer, but a general excess or deficiency of thickness will not be permitted."

*British Railway.*—" Each casting to be accurately moulded to the pattern supplied with the order by the railway company."

*Private Firm.*—" All castings shall permit of being machined to the dimensions on the drawings of the parts. The dimensions of parts which are not machined shall be strictly adhered to."

### Specifications for Non-Ferrous Castings

BRITISH STANDARDS INSTITUTION.

*B.S.S.* 208, 1924. *Special Brass Castings.*—" The dimensions of the castings shall be in accordance with the drawings and all surfaces marked for machining shall have a sufficient allowance for that purpose."

*B.S.S.* 383, 1930. *Bronze (Gun-Metal Castings, for General Engineering Purposes).*—" The castings shall be made to the dimensions specified and shall be capable of being machined to the finished dimensions. All machined surfaces shall clean up without visual evidence of the cast surface remaining."

*B.S.S.* 421, 1931. *Phosphor-Bronze Castings for Gear Blanks.*—" The castings shall be made to the dimensions and tolerances specified by the purchaser or to the pattern supplied by him and, after machining, shall be clean, sound, and free from blowholes and other defects. Any casting may be rejected for faults of manufacture, defects, or incorrectness of dimensions, whether discovered during inspection or subsequently during machining, notwithstanding that it has been passed previously as conforming to the analysis and mechanical tests of this specification."

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*D.T.D.* 264. *Aluminium-Alloy Sand or Die Castings.*—*D.T.D.* 289. *Magnesium Alloy Castings.*—(3) *Dimensions.* " The castings shall be made to the dimensions specified within the limits given in Clause 4 and shall be capable of being machined where required to the finished dimensions without leaving evidence of the cast surface."

(4) *Margins of Manufacture.* The thickness of castings where not machined shall be not less than the nominal thickness and shall not exceed it by more than 10 per cent. (These clauses are also incorporated in B.S.S. 361, 362 and 363 for aluminium alloys.)

*Admiralty Specification.*—301, General. The castings are to be sound, clean, free from blow holes, etc. The thickness of the castings will be measured by the overseer, and any material increase of thickness discovered beyond the approved drawing dimensions will render them liable to rejection.

## Suggested Improvements

Such phrases as "reasonable limits," "close agreement," "accurately moulded," cannot be translated into definite dimensions, and their meaning must remain a matter of opinion and, unfortunately, a subject for dispute. The limits given in two of the specifications quoted are unsatisfactory, as will be seen later.

It is suggested that the present state of affairs is capable of improvement by some or all of the following methods:—

(*a*) The removal of lax wording from specifications and the substitution of unambiguous phraseology.

(*b*) The publication of defined limits which would form an authoritative reference.

(*c*) The inclusion of such defined limits in the dimensional clauses of specifications.

(*d*) The education of engineers, inspectors and buyers in the operations of casting production whereby they may realise some of the phenomena confronting the founder and gain a more sympathetic outlook.

This Report purposes to show some of the problems with which the founder has to deal, to show how the founder has by experimental work and practical experience endeavoured to cope with these problems, and finally to put forward tentative tolerance proposals which would be suitable for inclusion in specifications, or, preferably at this stage, as would be useful for reference purposes.

### Factors Governing the Size of a Casting

The ultimate size of any casting produced from a given pattern is dependent on a wide range of factors, both physical and mechanical. Inherent characteristics of the metal used, physical and metallurgical changes in the metal itself, and many mechanical variables, all help to determine the amount of variation from pattern size shown by the finished casting.

With negligible exceptions both ferrous and non-ferrous metals show contraction on cooling from the molten state to atmospheric temperature. Contraction allowance, therefore, is perhaps the primary consideration when producing castings to meet a definite requirement.

### Contraction

Although slight expansions during cooling may, and do, occur at various critical temperatures in certain metals, these are rarely great enough to balance the contraction which occurs in cooling from the casting temperature, and a casting is, generally speaking, always smaller than the mould in which it was cast. The extent of this contraction has been carefully investigated by foundrymen over a number of years, and it is usually expressed as a linear function. As determined after pouring metal into a mould 12 in. long and $\frac{1}{2}$ in. square, $\frac{3}{4}$ in. square, or 1 in. square cross section, typical contraction constants for a number of the common casting metals may be cited as examples.

*Grey-Iron.*—High carbon hematite cast iron: 0.140 in. per ft.

Good quality engineering cast iron: 0.158 in. per ft.

*Steel.*—Light section ($\frac{1}{4}$ in. to $\frac{1}{2}$ in. thick): 0.25 in. to 0.27 in. per ft.

Heavy section: 0.20 in. per ft.

*Whiteheart Malleable Cast Iron.*—Average hard iron contraction: 0.255 in. per ft.

Average annealed contraction (net): 0.278 in. per ft.

*Blackheart Malleable Cast Iron.*—Average hard iron contraction: 0.230 in. per ft. ($\pm 0.007$).

Annealed contraction (net):

Total carbon 2.10 to 2.24 per cent.; average 0.141 in. per ft.

Total carbon 2.54 to 2.84 per cent.; average 0.127 in. per ft.

High temperature—short anneal; average 0.134 in. per ft.

Low temperature—long anneal; average 0.127 in. per ft.

*Non-ferrous.*—Non-ferrous metals vary considerably, but two extremes may be given:

Monel Metal: 0.25 in. per ft.

White metal: 0.067 in. per ft.

Unfortunately the amount of the contraction becomes inconstant immediately the conditions are changed. The above data refer to castings of standard section and unhindered contraction. If the section of the casting is less, the contraction is usually greater; with greater sections, the contraction is usually less.

Where special conditions intervene, such as heavy cores, or special shapes, a considerable reduction in the contraction is often found. Occasionally no contraction is to be observed, the casting being of the same dimensions as the mould in which it was cast.

A further variable may be introduced by subsequent heat-treatment or annealing, *i.e.*, in the cases of malleable cast iron, steel, certain of the non-ferrous metals, and some special cast irons. Even if there is a complete knowledge on the founder's part of the contraction characteristics of his metal, combined with a wealth of experience on the effects of shape and section upon the contraction, the latter factors will often produce variations which can be remedied only by "trial and error" methods. The location of runners, feeders and chills often have a profound effect upon the ultimate contraction exhibited by the casting.

### Variables Introduced by Production Methods

Assuming the contraction allowances made by the founder to be accurate, he is still faced with production difficulties in producing a casting which is "accurate to drawing." The three chief media employed for moulding are green sand, dry sand and loam. Oil sand moulding has some of the characteristics of both green and dry sand. The following remarks and data apply mainly to green sand, though most are equally applicable to dry sand or loam.

Systems of moulding differ chiefly in the method of ramming the sand and working the pattern. Ramming may be by hand with various shaped rammers; by jolting the pattern, moulding box and sand; by squeezing by hand or power; by throwing in the sand from an impeller; or by a combination of these methods. The method chosen depends upon numerous factors, such as the shape and size of the castings, the quantity to be produced, the equipment available and the general economics of the job. These diverse methods are naturally prone to give different strengths to the rammed sand and so affect the contraction by the varying resistance of the mould.

The extraction of the pattern from the mould is another potential source of trouble. Probably the most accurate method is that known as the "stripper." In this case the pattern is part of a rigid machine and works to and fro in guides. often drawing the pattern from the mould through an accurate template or "stripping plate." No rapping or vibration is used to release the pattern from the mould. Since the pattern equipment for stripper work is very expensive, this method of production is only warranted when very high outputs from one pattern are called for.

In other methods, the pattern is mechanically loosened in the mould before withdrawal. This may be performed by hand rapping or by power vibration. Either method results in the mould being enlarged beyond the pattern size, and in the first case this depends entirely on the individual judgment of the operator. The patterns after (or in some cases during) loosening, may be withdrawn by hand, depending entirely on individual skill: or may be stripped mechanically either by drawing the pattern from a stationary mould or by removing the mould from the pattern.

Other parts of moulding equipment have an effect on the accuracy of the mould to the pattern. For example, errors in box joints, pins, snug or dowel holes, etc., all affect the accuracy of the castings produced.

In the case of very straight-sided patterns moulded in strong, smooth sands, there is a constant risk of "ram-offs." This is caused by the ramming pressure of the higher layers of sand forcing the compacted sand away from the pattern at joint level, so forming a mould slightly larger at the joint than was the pattern.

Similar difficulties attend the making of an accurate core. In addition the insertion of the core is an operation attended with some difficulties. The mould must be so designed that the core may be accurately located and held firmly against the tendency of the molten metal to displace it. To ensure accuracy, it is frequently necessary to use gauges when placing the cores, and to prevent subsequent displacement by the use of metal studs, chaplets, or external mechanical means.

In addition to equipment, moulding materials such as sand have a great effect on accuracy. Great efforts are made to obtain uniform mixing from batch to batch, but it is necessary to alter the grade and type of sand used for various castings, and this may introduce variables.

Core sands also present problems, especially dried cores, since these are subject to expansions and contractions during the drying operation. It is frequently difficult to make a core strong enough to withstand handling and erosion by the molten metal, and which will yet yield readily to the contraction of the casting around it.

Apart from errors introduced in the mould itself, dimensional accuracy can be seriously affected by the pouring operation and other details attendant upon it. The mould may be strained, due to pouring too rapidly or to insufficient weighting of the mould. Variation in bulk of metal and its distribution in the mould; the situation of runners, feeders and chills, may all result in dimensional discrepancies by restricting contraction during cooling, or by setting up differential cooling rates in the casting. The "head of metal" initially used in pouring can also produce some variation in dimensions.

Certain of the factors discussed above may result in what might be termed "distortion" of the castings as opposed to ordinary linear discrepancies in size. For example, some castings (flat plates in particular) may show "camber," *i.e.*, a perfectly flat mould may yield a curved or twisted casting due to one face of the casting cooling quicker than the other. Restrained contraction in the mould and differential cooling in various parts of the casting due to any of a large number of causes will often result in serious distortion of the casting.

The "firing" of castings susceptible to cracks (spoked wheels, etc.), or heat treatment of castings, will frequently result in further considerable distortion.

It will be readily appreciated that in spite of all the founder's anticipation and his precautionary measures, there are few castings produced which do not exhibit some dimensional inaccuracy, large or small, attributable to one or more of the above-mentioned factors.

## Investigations Carried Out by the Technical Committee

When considering the data set out below, it should be borne in mind that all examples under consideration have been extracted from regular production in foundries, and not from special "laboratory type" tests. Moreover, every casting here considered is giving full satisfaction to customers, the majority of whom have a reputably high standard of requirements. Although the casting may show a large degree of change from pattern size, yet in most cases the individual variation between several castings from the same pattern is comparatively small.

The dimensional data on castings have been selected to illustrate the variables encountered in works practice, and should not be regarded necessarily as examples of the "best possible" accuracy obtainable on all castings. The metallurgical data were obtained as accurately as possible, and are, generally speaking, "accurate and typical" under the particular conditions existing.

The investigations of the Committee were divided into various groups, viz., malleable cast iron, steel, grey cast iron and non-ferrous metals, and the data obtained are set out below.

### Malleable Cast Iron

*(From data submitted by the Malleable Sub-Committee.)*

The following notes apply generally to both whiteheart and blackheart malleable cast iron, but the data are taken from tests on blackheart.

(1) Contraction of the hard iron is constant within wide ranges of chemical composition, casting temperatures and melting conditions. (See data given later.)

(2) Contraction of the annealed iron (*i.e.*, final contraction) is very varied and depends on many factors. (See separate data.)

(3) A standard contraction is used by patternmakers and may be $\frac{1}{8}$ in. or $\frac{3}{16}$ in. per ft.

(4) Castings show contraction which digresses from the contraction rule, due to particular shape and section.

(5) This digression from contraction rule can be covered by the patternmaker either from experience or by "trial and error."

(6) Thus it is advisable for a founder to produce his own pattern.

(7) A pattern supplied by a customer may not be suitable to produce an accurate casting because of lack of knowledge indicated under 3 and 5.

(8) It is thus possible for a founder to supply a casting from a customer's pattern which may not agree with the customer's requirements, but may be "true to pattern."

(9) Assuming the accuracy of a pattern according to 3 and 5, errors in dimensions can now arise because of moulding difficulties.

(10) Methods of moulding vary in intrinsic accuracy obtainable. This has already been dealt with.

(11) As mentioned under 2, the annealed contraction can vary considerably. The main factors affecting it are:—(*a*) Original total carbon content, and (*b*) extent of decarburisation, which is determined by: (1) packing material; (2) temperature and time of anneal; (3) composition of iron; (4) effectiveness of pot-luting, and (5) composition of oven gases. (See separate data given later.)

(12) It appears from the data just mentioned that the average contraction on blackheart after annealing (per Keep's bar) is 0.130 in. per ft. (approximately $\frac{1}{8}$ in.) and that variations compatible with good practice are from 0.112 in. to 0.151 in. (approximately [illegible] in. to $\frac{5}{32}$ in.).

(13) Assuming castings in the hard state to be exactly correct to pattern (*i.e.*, to have suffered the normal contraction only) then the errors introduced by annealing may be (per notes 3 and 12):—

Using $\frac{1}{8}$ in. contraction rule: from plus $\frac{1}{64}$ in. to minus $\frac{1}{32}$ in.

Using $\frac{3}{16}$ in. contraction rule: from plus $\frac{3}{64}$ in. to plus $\frac{1}{32}$ in.

## Data on Contraction of Blackheart Malleable

(*See notes*, 1, 2, 11 *and* 12.)

The following summary gives briefly the results obtained on tests carried out over a period of 12 years, using Keep's 12 in. bar cast in chills. During the period as many variables as possible have been examined. It may be taken for granted, however, that all test bars were free from primary graphite and that they were completely graphitised on annealing.

*Hard Iron Contraction.*—With total carbon 2.10 to 2.75 per cent.—average = 0.230 in. per ft. (±0.007). The highest contraction is usually associated with the lowest carbon and *vice versa*, but the variation is so slight that it may be assumed that the contraction is constant for all conditions which conform to normal practice.

*Annealed Iron Contraction* (hard contraction and soft expansion).—Average = 0.130 in. per ft. (plus 0.047 in., minus 0.030 in.). The highest contraction is associated with the lowest total carbon and *vice versa*, *e.g.*, original total carbon 2.10 to 2.24 per cent. = average contraction 0.141 in. per ft.; original total carbon 2.54 to 2.84 per cent. = 0.127 in. per ft.

Among the other factors noted under 12, time and temperature of anneal have a profound influence, *e.g.*,—

High temperature and long time—average contraction 0.134 in. per ft.

Low temperature and short time—average contraction 0.127 in. per ft.

From a careful examination of all data it would appear that within the limits of chemical composition, temperature, time and other annealing conditions compatible with good practice, the annealed iron contraction can vary:—

From 0.112 in. per ft. (approximately $\frac{7}{64}$ in. per ft.)

to 0.151 in. per ft. (approximately $\frac{5}{32}$ in. per ft.),

giving a total variation of a little over $\frac{1}{32}$ in. per ft.

*Effect of Re-heating Blackheart.*—(As for "setting.") Keep's 12-in. test bars cast in chills were used. After annealing the bars were heated to 700 deg. C. for 5 min. and cooled in air.

Average of five bars.—Annealed contraction = 0.106 in. per ft.

Average of five bars.—Re-heated contraction = 0.093 in. per ft.

*Note.*—The actual figures are lower than recorded in the previous data, and are probably due to these bars having higher total carbon contents (2.6 to 2.74 per cent.).

*Whiteheart Malleable.*—(Taken on Keep's 12-in. test bars cast in chills.)

Average hard contraction—0.255 in. per ft.

Average annealed contraction—0.278 in. per ft.

*Note.*—In the case of whiteheart appreciable differences in data obtained in different plants may be encountered, due to the wide range of chemical composition, annealing conditions, and types of structure produced for various classes of work.

### Data on Blackheart Castings from Regular Production

(*Note.*—These data cover all variables—mechanical and metallurgical.)

Since the primary object of this investigation was the determination of practical casting limits on dimensions of castings produced under normal works conditions, it was decided to collect the data from patterns already in production rather than from patterns made later with this investigation in mind.

A number of patterns were selected from several different foundries, all of which were producing castings acceptable to the customers concerned, and measurements were carried out on six castings taken at random from each pattern.

Table I given above shows particulars of measurements taken on a number of hard castings, mainly with the object of determining:—
(*a*) The variation exhibited between different castings from the same pattern (this, generally speaking, is found to be reasonably small), and
(*b*) the maximum contraction from the pattern size. This will be seen to vary over a wide range, not only as between different patterns, but also between different dimensions on the same casting.

On examining Table I, it will be noticed that in the great majority of cases the amount of variation between castings from the same pattern is reasonably small. In other words, it can be stated that under a given set of manufacturing conditions, reasonable uniformity of dimensions can be attained.

The amount of contraction from the pattern size exhibited in castings of different design is, however, seen to vary to a considerable extent. Extremes of change from pattern size, expressed in inches per foot, vary from an expansion of $\frac{3}{16}$ in. per ft. (example C, $1\frac{45}{64}$ in. dimension) to a contraction of $\frac{15}{32}$ in. per ft. (example D, $2\frac{3}{32}$ in. dimension). These are both taken on small dimensions, and are therefore somewhat exaggerated when expressed in terms of inches per foot.

Although the figures in Table I are self-explanatory, a few examples may be extracted and compared in terms of inches per foot contraction from pattern size.

*Examples A and B.*—All dimensions show a fairly uniform contraction of approximately $\frac{1}{4}$ in. to the foot.

***Example** C.*—$4\frac{63}{64}$ in. dimension shows approx. $\frac{3}{8}$ in. per ft. contraction, while $1\frac{45}{64}$ in. dimension actually shows $\frac{3}{16}$ in. per ft. expansion.

TABLE I.—*Dimensional Variations on Hard Castings.*

| Method of moulding. | Description of casting. | Dimension taken. | Pattern size, in in. | Casting dimensions, in in. Max. | Min. | Variation. | Max. contraction from pattern, in in. |
|---|---|---|---|---|---|---|---|
| (a) Stripper .. | Auto. differential carrier | Flange on joint .. .. | $11\frac{11}{64}$* | $10\frac{31}{32}$ | $10\frac{15}{16}$ | $\frac{1}{32}$ } $\frac{1}{16}$† | $\frac{13}{64}$ |
| | | At right angles to joint .. | $11\frac{11}{64}$* | 11 | $10\frac{31}{32}$ | $\frac{1}{32}$ } | $\frac{13}{64}$ |
| | | Between horns .. .. | $4\frac{39}{64}$* | $4\frac{19}{32}$ | $4\frac{17}{32}$ | $\frac{1}{16}$ | $\frac{5}{64}$ |
| | | Length .. .. .. | $14\frac{5}{8}$ | $14\frac{11}{32}$ | $14\frac{5}{16}$ | $\frac{1}{32}$ | $\frac{5}{16}$ |
| (b) Air machine | Auto. starter bracket | Length .. .. .. | $6\frac{7}{16}$ | $6\frac{11}{32}$ | $6\frac{11}{32}$ | Nil. | $\frac{3}{32}$ |
| | | Length to cored face .. | $5\frac{41}{64}$* | $5\frac{5}{8}$ | $5\frac{9}{16}$ | $\frac{1}{16}$ | $\frac{5}{64}$ |
| | | Flange on joint .. .. | $4\frac{41}{64}$* | $4\frac{19}{32}$ | $4\frac{17}{32}$ | $\frac{1}{16}$ | $\frac{7}{64}$ |
| | | At right angles to joint .. | $4\frac{41}{64}$* | $4\frac{9}{16}$ | $4\frac{35}{64}$ | $\frac{1}{64}$ | $\frac{3}{32}$ |
| (c) Jolt squeeze | Auto. differential case | Length .. .. .. | $4\frac{37}{64}$ | $4\frac{15}{32}$ | $4\frac{7}{16}$ | $\frac{1}{32}$ | $\frac{9}{64}$ |
| | | Diameter of flange .. | $10\frac{9}{64}$ | $9\frac{31}{32}$ | $9\frac{61}{64}$ | $\frac{1}{64}$ | $\frac{3}{16}$ |
| | | Depth .. .. .. | $1\frac{45}{64}$* | $1\frac{47}{64}$ | $1\frac{23}{32}$ | $\frac{1}{64}$ | $+\frac{1}{32}$ |
| | | Diameter of body .. | $7\frac{17}{64}$* | $7\frac{3}{16}$ | $7\frac{9}{64}$ | $\frac{3}{64}$ | $\frac{1}{8}$ |
| (d) Jolt squeeze | Auto. front hub | Diameter of flange .. | $9\frac{7}{8}$* | $9\frac{3}{4}$ | $9\frac{45}{64}$ | $\frac{3}{64}$ | $\frac{11}{64}$ |
| | | Distance between flanges | $2\frac{9}{32}$* | $2\frac{7}{32}$ | $2\frac{3}{16}$ | $\frac{1}{32}$ | $\frac{3}{32}$ |
| | | Diameter of small flange | $7\frac{1}{8}$* | $7\frac{1}{32}$ | $6\frac{31}{32}$ | $\frac{1}{16}$ | $\frac{5}{32}$ |
| | | Length .. .. .. | $5\frac{23}{32}$ | $5\frac{5}{8}$ | $5\frac{19}{32}$ | $\frac{1}{32}$ | $\frac{1}{8}$ |
| (e) Jolt .. | Auto. front hub | Diameter of flange on joint | $12\frac{29}{32}$* | $12\frac{5}{8}$ | $12\frac{19}{32}$ | $\frac{1}{32}$ | $\frac{5}{16}$ |
| | | At right angles to joint .. | $12\frac{21}{32}$* | $12\frac{19}{32}$ | $12\frac{35}{64}$ | $\frac{3}{64}$ | $\frac{7}{64}$ |
| | | Boss to flange .. .. | 2* | 2 | $1\frac{31}{32}$ | $\frac{1}{32}$ | $\frac{1}{32}$ |
| | | Length .. .. .. | $5\frac{43}{64}$ | $5\frac{21}{32}$ | $5\frac{19}{32}$ | $\frac{1}{16}$ | $\frac{5}{64}$ |
| (f) Floor .. | Flywheel .. | Diameter of plate .. | $16\frac{13}{32}$ | $16\frac{3}{64}$ | $16\frac{1}{32}$ | $\frac{1}{64}$ | $\frac{3}{8}$ |
| | | Depth of boss .. .. | $3\frac{1}{16}$ | $3\frac{1}{8}$ | $3\frac{7}{64}$ | $\frac{1}{64}$ | $+\frac{3}{64}$ |
| | | Thick plate .. .. | $\frac{3}{4}$ | $\frac{13}{16}$ | $\frac{25}{32}$ | $\frac{1}{32}$ | $+\frac{1}{32}$ |
| (g) Floor .. | Trough‡ .. | Length .. .. .. | $49\frac{1}{32}$ | — | $47\frac{29}{32}$ | — | $1\frac{1}{8}$ |

* Cored dimension. † Total variation. ‡ Measurements of one casting only.

*Example D and E.*—In each case contractions as high as $\frac{5}{16}$ in. per ft. are shown on several dimensions.

*Example F.*—$16\frac{13}{32}$ in. dimension shows a contraction of approx. $\frac{9}{32}$ in. per ft., but $3\frac{1}{16}$ in. dimension shows $\frac{3}{16}$ in. per ft. expansion.

*Example G.*—A contraction of $1\frac{1}{8}$ in. on a length of $49\frac{1}{32}$ in. represents a contraction of about $\frac{9}{32}$ in. per ft., in spite of the rapping which a floor moulded job may be assumed to have had.

It will thus be appreciated that a job calling for great accuracy may involve quite a large amount of experimental work before the pattern can be passed into production. The difficulty in producing accurate castings (bearing in mind this question of contraction as related to design and production methods used) is therefore emphasised when executing small quantities, or when working a customer's pattern, made to a contraction rule.

A further variable is introduced by the expansion of the castings in the annealing process. This is illustrated by the data in Table II.

### Extract from Blackheart Data Illustrating Inaccuracies Mentioned Above

In most cases six castings from each pattern were taken and measured before and after annealing. They are all production jobs, and are proving acceptable to the customers. Cored dimensions are indicated by an asterisk.

Col. A, in Table II, is pattern dimension.

Col. B is maximum variation in hard castings dimensions.

Col. C is maximum hard contraction from pattern.

Col. D is maximum variation in soft castings dimensions.

Col. E is maximum soft contraction from pattern.

On examination of the data in Table II, two facts will at once become apparent:—(*a*) The amount of final contraction shown by the

TABLE II.—*Dimensional Variations Due to Annealing.*

| Description of casting. | Method of moulding. | Dimension taken. | A. | B. | C. | D. | E. |
|---|---|---|---|---|---|---|---|
| | | Dimensions, in. | | | | | |
| (1) Auto. differential carrier | Stripper .. | Flange on joint .. .. .. | $11\frac{11}{64}$* | $\frac{1}{32}$ | $\frac{13}{64}$ | $\frac{1}{16}$ | $\frac{1}{8}$ |
| | | Flange at right angles to joint .. | $11\frac{11}{64}$ | $\frac{1}{32}$ | $\frac{13}{64}$ | $\frac{3}{64}$ | $\frac{3}{64}$ |
| | | Length .. .. .. .. | $14\frac{5}{8}$ | $\frac{1}{32}$ | $\frac{3}{16}$ | $\frac{3}{64}$ | $\frac{1}{8}$ |
| (2) Auto. starter bracket | Air machine | Length .. .. .. .. | $6\frac{7}{16}$ | Nil. | $\frac{3}{32}$ | $\frac{5}{64}$ | $\frac{5}{64}$ |
| | | Flange on joint .. .. .. | $4\frac{41}{64}$* | $\frac{1}{16}$ | $\frac{7}{64}$ | $\frac{1}{16}$ | $\frac{1}{16}$ |
| (3) Auto. front hub | Jolt .. | Flange on joint .. .. .. | $12\frac{11}{16}$* | $\frac{1}{32}$ | $\frac{1}{16}$ | $\frac{7}{64}$ | $\frac{1}{4}$ |
| | | Flange on joint at right angles | $12\frac{31}{32}$* | $\frac{5}{64}$ | $\frac{1}{64}$ | $\frac{3}{64}$ | $\frac{3}{64}$ |
| | | Length .. .. .. .. | $5\frac{43}{64}$ | $\frac{1}{16}$ | $\frac{3}{64}$ | $\frac{3}{64}$ | $\frac{1}{64}$ |
| (4) Rear brake drum | | Internal diameter .. .. | $14\frac{1}{16}$ | $\frac{1}{16}$ | $\frac{3}{8}$ | $\frac{1}{16}$ | $\frac{1}{4}$ |
| | | Top face diameter .. .. | $9\frac{1}{16}$ | Nil | $\frac{1}{8}$ | Nil | $\frac{1}{16}$ |
| | | Depth .. .. .. .. | $8\frac{1}{16}$ | $\frac{1}{32}$ | $\frac{3}{32}$ | $\frac{1}{64}$ | $\frac{1}{64}$ |
| (5) Channel section | | Length .. .. .. .. | $19\frac{1}{2}$ | — | — | $\frac{1}{8}$ | $\frac{9}{32}$ |

* Core dimensions.

annealed casting varies considerably. This is due partly to variations in hard contraction, and partly to variations in the subsequent expansion during annealing; and (*b*) the amount of variation between different castings produced from the same pattern will be found to have changed considerably after annealing. In the majority of cases the variation between annealed castings is greater than it was in the case of the identical castings, before annealing. This is clearly shown by comparing columns **B** and **D**.

A few examples of outstanding variations are set out below:—

*Example* 3.—$12\frac{21}{32}$ in. dimension. Variation between castings before annealing was $\frac{1}{32}$ in. after annealing was [illegible] in.

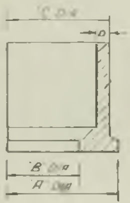
*Example* 2.—$6\frac{7}{16}$ in. dimension. Variation before annealing was nil, but after annealing was [illegible] in. (Note.—This represents a difference of approximately $\frac{1}{8}$ in. per ft.)

*Examples* 1 *and* 4.—Final annealed contraction on several dimensions varies considerably. Maximum contraction shown is approximately $\frac{13}{64}$ in. per ft., and minimum is approximately $\frac{1}{32}$ in. per ft.

Some further data were taken on ring castings shown on Tables III and IV relating to Series 1 and Series 2. Three different sizes of ring pattern of the same design were moulded (Series 1). The patterns were then thickened up and a further set of castings were moulded (Series 2). Both series were then cast from one ladle of metal. After careful measurement, all the castings were annealed in close proximity and under identical conditions. Finally, the castings were again carefully measured and the average contraction of the three diameters was calculated in each case.

The increasing amount of contraction exhibited by the larger diameter rings is of some interest, and it should also be noted that the heavier type (Series 2) exhibited a smaller range of variation. While not intended to prove any fixed relation between contraction and size or

TABLE III.—*Dimensional Changes in in., in Series 1, on Light Type of Ring.*




| Item. | Dimension. | Pattern size. | Hard casting. | Contraction. | Annealed casting.* | Expansion. | Net contraction. | Average net contraction, in. per ft. |
|---|---|---|---|---|---|---|---|---|
| Small ring | A | $5\frac{11}{32}$ | $5\frac{1}{4}$ | $\frac{3}{32}$ | $5\frac{19}{64}$ | $\frac{3}{64}$ | $\frac{3}{64}$ | 0.1237 |
| | B | $3\frac{5}{8}$ | $3\frac{35}{64}$ | $\frac{5}{64}$ | $3\frac{37}{64}$ | $\frac{1}{32}$ | $\frac{3}{64}$ | |
| | C | $4\frac{43}{64}$ | $4\frac{37}{64}$ | $\frac{3}{32}$ | $4\frac{5}{8}$ | $\frac{3}{64}$ | $\frac{3}{64}$ | |
| | D | $\frac{3}{16}$ | $\frac{3}{16}$ | — | $\frac{3}{16}$ | — | — | — |
| Medium ring | A | $6\frac{11}{32}$ | $6\frac{15}{64}$ | $\frac{7}{64}$ | $6\frac{9}{32}$ | $\frac{3}{64}$ | $\frac{1}{16}$ | 0.1574 |
| | B | $4\frac{21}{32}$ | $4\frac{35}{64}$ | $\frac{7}{64}$ | $4\frac{37}{64}$ | $\frac{1}{32}$ | $\frac{5}{64}$ | |
| | C | $5\frac{43}{64}$ | $5\frac{9}{16}$ | $\frac{7}{64}$ | $5\frac{19}{32}$ | $\frac{1}{32}$ | $\frac{5}{64}$ | |
| | D | $\frac{3}{16}$ | $\frac{3}{16}$ | — | $\frac{3}{16}$ | — | — | — |
| Large ring | A | $8\frac{11}{16}$ | $8\frac{33}{64}$ | $\frac{11}{64}$ | $8\frac{9}{16}$ | $\frac{3}{64}$ | $\frac{1}{8}$ | 0.2004 |
| | B | $6\frac{3}{4}$ | $6\frac{35}{64}$ | $\frac{13}{64}$ | $6\frac{19}{32}$ | $\frac{3}{64}$ | $\frac{5}{32}$ | |
| | C | $7\frac{61}{64}$ | $7\frac{25}{32}$ | $\frac{11}{64}$ | $7\frac{27}{32}$ | $\frac{1}{16}$ | $\frac{7}{64}$ | |
| | D | $\frac{7}{32}$ | $\frac{7}{32}$ | — | $\frac{7}{32}$ | — | — | — |

section, these figures do serve to indicate how size and section can influence dimensional changes from the pattern size.

### Practical Tolerances for Malleable Cast Iron

Any attempt to define tolerances acceptable to both founder and consumer is fraught with considerable difficulty. It has already been shown that castings can be produced which show comparatively small individual variations, but which may seriously digress from the contraction rule. Economic considerations are bound to limit the amount of experimental work done on any particular pattern, according to the quantity of castings to be produced and the equipment which is available.

It was felt, therefore, that although certain tolerances may be laid down for what might be termed "repetition" work, yet considerably wider tolerances should be allowed for small quantity orders, and also on patterns which are supplied by the customer.

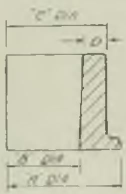
Even so, in both repetition and non-repetition classes, there are bound to be cases where special circumstances or peculiarities of design will result in exceptional amounts of variation from the pattern size. It is felt, however, that it would be impracticable to attempt to cover every possible variable, and that such cases, when they occur, must be subject to special consideration.

After very careful consideration of the whole subject, it is suggested that, except in special cases, the following are reasonable tolerances to cover the majority of variables:—

*Tolerances on Dimensions of Malleable Castings.*

| Dimensional range. | Repetition or "mounted" patterns. | Non-repetition and "loose" patterns. |
|---|---|---|
| Below 4 in. .. | + or − $\frac{1}{32}$ in. on dimension. | + or − $\frac{3}{64}$ in. on dimension. |
| 4 in. to 8 in. .. | + or − $\frac{3}{64}$ in. on dimension. | + or − $\frac{1}{16}$ in. on dimension. |
| Over 8 in. .. | + or − $\frac{1}{16}$ in. per ft. | + or − $\frac{3}{32}$ in. per ft. |

TABLE IV.—*Dimensional Changes in in., in Series 2, in Heavy Ring.*



| Item. | Dimension. | Pattern size. | Hard casting. | Contraction. | Annealed casting. | Expansion. | Net contraction. | Average net contraction in. per ft. |
|---|---|---|---|---|---|---|---|---|
| Small ring | A | $5\frac{11}{32}$ | $5\frac{1}{4}$ | $\frac{3}{32}$ | $5\frac{9}{32}$ | $\frac{1}{32}$ | $\frac{1}{16}$ | 0.1374 |
| | B | $3\frac{5}{8}$ | $3\frac{35}{64}$ | $\frac{5}{64}$ | $3\frac{9}{16}$ | $\frac{1}{64}$ | $\frac{1}{16}$ | |
| | C | $4\frac{45}{64}$ | $4\frac{39}{64}$ | $\frac{3}{32}$ | $4\frac{43}{64}$ | $\frac{1}{16}$ | $\frac{1}{32}$ | |
| | D | $\frac{5}{16}$ | $\frac{5}{16}$ | — | $\frac{5}{16}$ | — | — | — |
| Medium ring | A | $6\frac{11}{32}$ | $6\frac{7}{32}$ | $\frac{1}{8}$ | $6\frac{1}{4}$ | $\frac{1}{32}$ | $\frac{3}{32}$ | 0.1688 |
| | B | $4\frac{21}{32}$ | $4\frac{17}{32}$ | $\frac{1}{8}$ | $4\frac{9}{16}$ | $\frac{1}{32}$ | $\frac{3}{32}$ | |
| | C | $5\frac{43}{64}$ | $5\frac{37}{64}$ | $\frac{3}{32}$ | $5\frac{5}{8}$ | $\frac{3}{64}$ | $\frac{3}{64}$ | |
| | D | $\frac{3}{8}$ | $\frac{3}{8}$ | — | $\frac{3}{8}$ | — | — | — |
| Large ring | A | $8\frac{11}{16}$ | $8\frac{31}{64}$ | $\frac{13}{64}$ | $8\frac{9}{16}$ | $\frac{5}{64}$ | $\frac{1}{8}$ | 0.1844 |
| | B | $6\frac{3}{4}$ | $6\frac{9}{16}$ | $\frac{3}{16}$ | $6\frac{5}{8}$ | $\frac{1}{64}$ | $\frac{1}{8}$ | |
| | C | $7\frac{61}{64}$ | $7\frac{25}{32}$ | $\frac{11}{64}$ | $7\frac{27}{32}$ | $\frac{1}{64}$ | $\frac{7}{64}$ | |
| | D | $\frac{3}{8}$ | $\frac{3}{8}$ | — | $\frac{3}{8}$ | — | — | — |

The depth of the flange remained correct to pattern size, except the two large rings, which both showed $\frac{1}{64}$-in. gain.

## Dimensional Tolerances on Steel Castings

*(From Data submitted by Steel Castings Sub-Committee.)*

Considerable variation in contraction is experienced in the production of steel castings, due mainly to the following factors:—

(*a*) *Section of Casting.*—Castings of light and reasonably uniform section (say from $\frac{1}{8}$ to $\frac{1}{2}$ in. section) will usually show a net contraction from pattern size of 0.25 to 0.27 in. per. ft. Heavier sectioned castings with a metal section of 2 in. or over will, under the same production conditions, show a net contraction from pattern size of as low as 0.20 in. per ft.

*Note.*—In each case, no other variables are taken into account, and the above figures relate to the influence of section alone.

(*b*) *Hindered Contraction in Mould.*—Castings are frequently produced in which the design is such as to hinder the contraction of the casting in the mould, for example, heavy cored work, or frame castings with large projecting feet or brackets. In such cases the net contraction from pattern size may be as low as 0.12 in. per ft. This would give rise to very considerable discrepancies in size, especially on large castings.

(*c*) *Scaling Allowance.*—A scaling allowance of $\frac{1}{64}$ to $\frac{1}{32}$ in. is frequently necessary to cover dimensional variation due to heat treatment.

### Mechanical Factors

A large number of other factors, generally as listed for malleable cast iron, also have a profound influence on dimensional accuracy.

### Practical Tolerances

No comprehensive investigation has yet been undertaken to determine suitable tolerances for steel castings, but the following have been put forward as an indication of the order of accuracy obtainable:—

(*a*) *Jobbing Work.*—$\pm$ $\frac{1}{32}$ to $\frac{1}{16}$ in. for small castings.

$\pm$ $\frac{3}{16}$ to $\frac{1}{4}$ in. for large castings.

(*b*) *Repetition or Machine Work.*—$\pm \frac{1}{64}$ to $\frac{1}{32}$ in. on small sections.
$\pm \frac{1}{32}$ to $\frac{1}{16}$ in. on machined sections.

## Dimensional Tolerances on Cast Iron

(*From Data submitted by Cast Iron Sub-Committee.*)

(1) The variation in contraction experienced in the production of grey cast iron castings is also dependent on a very wide range of factors. Generally speaking, those variations which are due to mechanical rather than metallurgical causes, are similar to those previously discussed when considering malleable cast iron.

(2) On the other hand, cast irons vary over a very wide range of chemical compositions and physical structures, and the contraction figures directly attributable to metallurgical factors alone can therefore show considerable variation.

TABLE V.—*Shrinkage Data for Cast Iron.*

| Test yoke. | Average reading shrinkage on 12 in. | Limits of variation. | |
|---|---|---|---|
| | | Plus. | Minus. |
| 1 | 0.147 | 0.010 | 0.009 |
| 2 | 0.151 | 0.007 | 0.006 |
| 3 | 0.141 | 0.010 | 0.012 |
| 4 | 0.147 | 0.009 | 0.005 |
| 5 | 0.146 | 0.012 | 0.012 |
| 6 | 0.153 | 0.010 | 0.007 |
| 7 | 0.153 | 0.007 | 0.010 |
| 8 | 0.152 | 0.009 | 0.009 |

(3) Results taken on the Keep's test bar on different grey irons have given net contraction figures varying from 0.129 to 0.163 in. per ft. Individual results taken with particular irons on the Keep's test bar would appear to indicate that a limit of $\pm$ 0.010 on 12 in. is as close a limit as can normally be expected. The data are given in Table V.

Whilst it is appreciated that depth of chill is an important factor influencing results on the Keep's test bar, it must also be remembered that mechanical variations, such as unequal ramming, rapping of pattern, size of runner, etc., are practically non-existent.

### Working Tolerances for Cast Iron

Three investigations on dimensional accuracy of jobs in normal production were undertaken as follows:—

#### Example (1)

Tests on a number of bracket castings for textile machinery were taken, six castings being measured in each case, and the same quality grey iron being used throughout. (See Table VI.)

It will be seen from Table VI that the variations in length on a dry sand mould are very slight. The green sand mould gave the nearest width to drawing size (viz., $3\frac{3}{4}$ in.), the higher figures in the dry sand being accounted for by the sag of the mould during handling and drying when lying mould face upwards. This particularly applies to the hand-rammed moulds, which receive more handling before they reached the drying stoves than the jolt ram moulds. The castings observed showed contraction from the original pattern size ($21\frac{1}{16}$ in.), due to all causes (mechanical and metallurgical) by the following amounts:—

*Cast in green sand moulds*: $\frac{1}{8}$ in. to $\frac{3}{16}$ in. contraction from pattern size.

*Cast in dry sand moulds*: $\frac{11}{64}$ in. to $\frac{3}{16}$ in. contraction from pattern size.

The maximum variation in the case of green sand moulds was $\frac{1}{32}$ in. and in the case of the dry sand moulds from $+\frac{1}{64}$ in. to nil.

#### Example (2)

Sixteen rail chair castings from the daily production were selected at random and checked for variations on dimensions. (See Table VII.)

Quite apart from the contraction allowed on the pattern, the castings were found to vary individually as follow:—

11-in. hole centre: four castings only were within $\pm 0.010$ in.

TABLE VI.—*Dimensional Variations in in., on Grey Iron Bracket Castings.*

| Method of moulding. | | Pattern size. (Standard rule.) | Length along joint. | | | Width across joint. | | |
|---|---|---|---|---|---|---|---|---|
| | | | Average. | Variation. | | Average. | Variation. | |
| | | | | Plus. | Minus. | | Plus. | Minus. |
| Green sand. | Hand ram on turnover machine | $21\frac{1}{16}$ | $20\frac{29}{32}$ | $\frac{1}{32}$ | $\frac{1}{32}$ | $3\frac{23}{32}$ | Nil. | $\frac{1}{64}$* |
| Dry sand. | Hand ram on turnover machine .. | $21\frac{1}{16}$ | $20\frac{7}{8}$ | $\frac{1}{64}$ | Nil. | $3\frac{57}{64}$ | $\frac{1}{64}$ | $\frac{1}{64}$ |
| Dry sand. | Jolt ram on turnover machine .. | $21\frac{1}{16}$ | $20\frac{7}{8}$ | $\frac{1}{64}$ | Nil. | $3\frac{13}{16}$ | Nil. | Nil. |

* On one sample only

o

Maximum variations were +0.055 in. to −0.053 in.

$2\frac{15}{16}$ in. jaw width: eight castings only were within ±0.010 in.

The maximum variations were +0.020 in. to −0.049 in.

TABLE VII.—*Variations in Grey Castings.*

*Standard Rail Chair.* 95 *lbs. B.S. Rail Section. Hand rammed on turnover machine, gravity draw.* 1 *in. round holes at* 11 *in. centres, stripped with plungers. Jaws formed on pattern with loose slips, two for rail jaw, and one for key.*

The Variations are given in Thousandths of an in.

| Chair number. | Hole centres 11-in. std. drawing. | Jaw width $2\frac{15}{16}$-in. std. drawing. |
|---|---|---|
| 1 | 11 + 0 | $2\frac{15}{16}$ + 0 |
| 2 | 11 + 10 | $2\frac{15}{16}$ − 2 |
| 3 | 11 + 13 | $2\frac{15}{16}$ − 21 |
| 4 | 11 + 23 | $2\frac{15}{16}$ − 8 |
| 5 | 11 − 53 | $2\frac{15}{16}$ − 49 |
| 6 | 11 − 12 | $2\frac{15}{16}$ + 17 |
| 7 | 11 + 38 | $2\frac{15}{16}$ − 2 |
| 8 | 11 − 3 | $2\frac{15}{16}$ + 17 |
| 9 | 11 + 15 | $2\frac{15}{16}$ + 2 |
| 10 | 11 + 29 | $2\frac{15}{16}$ − 8 |
| 11 | 11 − 38 | $2\frac{15}{16}$ − 2 |
| 12 | 11 − 17 | $2\frac{15}{16}$ − 23 |
| 13 | 11 − 3 | $2\frac{15}{16}$ − 9 |
| 14 | 11 − 14 | $2\frac{15}{16}$ + 20 |
| 15 | 11 + 1 | $2\frac{15}{16}$ + 17 |
| 16 | 11 + 55 | $2\frac{15}{16}$ + 20 |

Hole centres max. + variation + 55 } = Extremes of 108
" " " − " − 53 }

Jaw width max. + variation + 20 } = Extremes of 69.
" " " − " − 49 }

In terms of inches per foot, these figures represent extremes in size between the largest and smallest castings of:—

0.118 in. per ft. on hole centres.

0.210 in. per ft. on jaw width.

Nevertheless, as it is important to realise, these castings were taken from production and were giving no cause for complaint with the consumer.

The actual tolerances specified by the consumer were :—

$\pm \frac{1}{32}$ in. on $2\frac{15}{16}$-in. jaw width.

$\pm \frac{1}{64}$ in. on width of 4-ft. $8\frac{1}{2}$-in. road.

(This tolerance affects the bolt centres on which measurements were taken.)

### Example (3)

Tests for dimensional accuracy were taken on numbers of drum type castings in regular production. Some four or five different methods of gating were experimented with, in the endeavour to obtain maximum accuracy. The method finally selected for works production yielded the following data :—

(A) *Hand Rammed.*—Maximum contraction on 11.784 in. dia. = 0.160 in.

Minimum contraction on 11.784 in. dia. = 0.102 in.

Eccentricity varied from 0.020 in. to 0.045 in.

(B) *Machine Rammed.*—Maximum contraction on 10.621 in. dia. = 0.157 in.

Minimum contraction on 10.621 in. dia. = 0.112 in.

Eccentricity varied from 0.020 in. to 0.060 in.

In the light of the above investigations, it would appear more latitude on dimensional accuracy is necessary than is generally appreciated.

### Non-Ferrous Metals

*(From Data compiled by the Non-Ferrous Castings Sub-Committee.)*

Since the term " non-ferrous " covers an extremely wide range of metals in which castings are produced, any considerations on dimensional tolerances must be on a very general footing. As with the other metals previously discussed, the dimensions of castings produced from any given pattern will depend on three primary factors, viz. :—

(1) The amount of contraction normally exhibited by the particular metal being worked.

(2) Hindered contraction (or in some cases expansion) due to restriction in the mould, or to the size-mass or design of the particular casting to be produced. This also includes variables attributable to runner and feeder location and the use of chills.

(3) Variables introduced in moulding, *i.e.*, variation of mould size from pattern size.

Since the many alloys in use have widely differing physical properties, the relative importance of any one factor will vary according to the alloy being worked. For example, certain alloys will exhibit much greater strength and rigidity at elevated temperatures, and will therefore not be so susceptible to dimensional variation due to restriction offered by the mould during the cooling period.

Examples of contraction (determined on round bars cast in green sand between yokes) are given below for a few of the commonly cast alloys:—

Aluminium casting alloys: $\frac{1}{8}$ in. per ft.
Aluminium silicon alloys: $\frac{1}{16}$ in. per ft.
Aluminium and manganese bronzes: $\frac{3}{16}$ in. per ft.
Mond metal: $\frac{1}{4}$ in. per ft.
Yellow brass and German silver: $\frac{3}{16}$ in. per ft.
Tin-base white metal: $\frac{1}{16}$ in. per ft.
Lead-base white metal: $\frac{1}{16}$ in. per ft.
Phosphor-bronze: $\frac{3}{16}$ in. per ft.

It should be realised, however, that, so far as foundry practice is concerned, these are purely empirical figures, and will vary greatly with the design of the casting and with the production technique adopted.

The varying allowances made in a particular foundry when producing phosphor-bronze castings are cited below as an example:—

(1) Normal sand-cast work up to about 2 ft. dia.: $\frac{3}{16}$ in. per ft.

(2) Wheels of about 5 ft. or 6 ft. dia.: $\frac{1}{2}$ in. per ft.

(3) Wheels with arms 10 ft. to 14 ft.: $\frac{1}{16}$ in. per ft.

(4) Centrifugally-cast wheels, say $4\frac{1}{2}$ ft. dia.: $\frac{3}{16}$ in. per ft.

These figures, of course, are probably dependent largely on the particular design of the example given, and cannot be considered as a guide to general practice. They do serve, however, to emphasise the difficulties involved in producing castings which are "accurate to drawing."

### American Investigations on Casting Tolerances

Although none of the work on tolerances, carried out by the Technical Committee of the Institute of British Foundrymen during the last three years, has been previously made public, it is of interest to note that the American Foundrymen's Association also undertook a completely independent investigation during 1935 on this same subject. Some correspondence has since been exchanged between the two Committees concerned, and the Committee is greatly indebted to the American Foundrymen's Association for their kind permission to refer to this work.

It may be of interest to remark at this stage, that whereas in this country the subject has been mainly developed by the malleable section of the industry, in America it was the grey iron section which was mainly interested.

The Grey Iron Division of The American Foundrymen's Association circulated privately in May, 1935, a set of tentative tolerances for grey iron castings, which was intended to serve as a basis for discussion on the subject. The suggested range of tolerances is set out below, and it is of interest to note that the figures suggested by these would appear to indicate that they are producing castings to limits very similar to those indicated by the Institute's investigations. The notes given below the table are also extracted from the A.F.A. circular of the same date.

"The schedule of castings size tolerances listed above is proposed for review and criticism of A.F.A. members interested in the production of jobbing castings. The proposed schedule is intended to apply to *quantity production of jobbing castings* and not to very special cases where extremely close tolerances are required or to the few piece orders where tolerances are not ordinarily specified.

"*Specified Tolerances* (see Table VIII) are critical geometrical relations specially required and fully specified on drawings or specifications. These specified tolerances are to be used as a guide by the designer in identifying his construction media limitations.

"*Note.*—When closer limits are required, special casting practice technique may be employed to attain the desired results on certain types of castings. This exacting dimensional requirement is, however, when found practical to attain, accompanied by an increase in the manufacturing cost.

"*Unspecified Tolerances* (see Table VIII) are to be understood as the limits that bound general satisfactory casting practice expected without special designation on drawing or specification."

In view of the fact that these figures have not yet been published in America, it is desirable that they should not be used as a basis for discussion.

### Competitive Position of Castings

Although first impressions on studying the data submitted in this report may tend towards a feeling that dimensional variations on castings are somewhat wide, this is not the case. It should be remembered that a very large tonnage of castings is produced annually which meets very exacting dimensional requirements. If small quantity orders are excepted, then it is usually possible for a foundry to produce castings to any reasonable *specified* tolerance. Most of the founder's present difficulties lie in the fact that reasonable practical tolerances on important dimensions are rarely specified on the drawing, with the result that unimportant dimensions (from the consumer's view-point) may be held within close limits, sometimes at the expense of accuracy on a dimension which is important.

The inclusion of defined limits in a dimensions clause would protect the founder against unreasonable demands and unwarranted rejections,

Table VIII.—*A.F.A. Tentative Proposal for Grey Iron Castings Size Tolerances.*

(Notes extracted from A.F.A. circular of May 2, 1935.)

| Dimensional range in in. | Suggested tolerances in in. for cast iron. | |
|---|---|---|
| | Specified tolerances. | Unspecified tolerances. |
| Up to 2 .. .. | + or − $\frac{1}{64}$ | + or − $\frac{1}{32}$ |
| 2 to 4 .. .. | + or − $\frac{1}{32}$ | + or − $\frac{3}{64}$ |
| 4 to 7 .. .. | + or − $\frac{3}{64}$ | + or − $\frac{1}{16}$ |
| 7 to 12 .. .. | + or − $\frac{1}{16}$ | + or − $\frac{3}{32}$ |
| 12 to 24 .. .. | + or − $\frac{3}{32}$ | + or − $\frac{1}{8}$ |
| 24 to 40 .. .. | + or − $\frac{1}{8}$ | + or − $\frac{5}{32}$ |
| 40 to 60 .. .. | + or − $\frac{5}{32}$ | + or − $\frac{3}{16}$ |
| 60 to 100 .. | + or − $\frac{3}{16}$ | + or − $\frac{1}{4}$ |
| 100 up .. .. | + or − $\frac{1}{4}$ | + or − $\frac{1}{2}$ |

and would safeguard the buyer from undesirable inaccuracies. It would encourage the consumer to seek the help of the founder in obtaining greater precision; it would prevent disagreements and improve the relations between the castings producer and consumer. The attainment of greater accuracy than that specified would in no way be prejudiced; rather would the reverse be the case. It would provide a "yard stick" by which the founder could measure his efficiency, and this would encourage the raising of the standard of precision.

It is hoped that the publication of this Report will serve more purposes than was intended originally. It should be understood that the founder desires to make castings with greater precision and is continually studying ways and means to that end. There is, however, need for greater appreciation by the designer and engineer of the founder's difficulties, and much could be done to produce better and cheaper castings by the proper kind of co-operation. So many castings are badly designed that it is impossible to make them reasonably accurate, whereas the founder's expert knowledge would enable him to suggest alterations which would facilitate the achievement of a high degree of accuracy. Too often the proffered help of the castings manufacturer receives no welcome from the designer. Much assistance would be afforded by the inclusion of more information on drawings. For example, the dimensions where the greatest precision is required, and points where the castings will be jigged could be marked on the drawing and the sequence and nature of machining operations could be stated.

It is realised that the subject is contentious and the tentative proposals here put forward are likely to be received with much criticism. This is what is required, as, before continuing this activity, it is necessary that these recommendations should truly represent the foundry viewpoint and that they should be such as will meet with the approval of the engineering industry. Co-operation of the foundry and engineering trades is therefore most necessary before further progress can be made.

Thanks are expressed to the many organisations, foundries and individuals who assisted in collecting the data for this publication. The list is so great that the names are not mentioned, but special note is made of the American Foundrymen's Association, who so kindly permitted the inclusion of a reference to their unpublished work upon "Grey Iron Castings Size Tolerances."

# Scottish Branch

## METAL MOULDS FOR CAST IRON

By J. McGrandle (Associate Member)

The castings here dealt with, cast in cast-iron moulds, are all of one type, all being air turbine rotors as illustrated in Fig. 1. The castings for these rotors vary in weight from 23 lbs. to 290 lbs. as cast. There are six different sizes, all in the form of hollow cylinders. The thickness of section of the castings varies from $1\frac{1}{2}$ in.

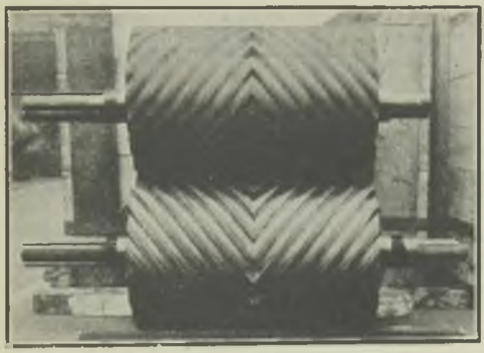


Fig. 1.—Air Turbine Rotor Castings made in Cast-Iron Moulds.

in the smallest size casting to $4\frac{1}{2}$ in. in the largest size, the outside diameters of the smallest and largest being $5\frac{1}{2}$ in. and $13\frac{1}{2}$ in. respectively, and the inside bores from $2\frac{1}{2}$ in. to $4\frac{1}{2}$ in.

These castings were made in drysand, with the exception of the two smallest sizes of $1\frac{1}{2}$ in. and $2\frac{1}{8}$ in. thickness which were made in greensand, before the casting of them was undertaken in cast-iron moulds. The larger sizes required, when made in sand moulds, a lower silicon content than is normally used for this class of castings. The ordinary run of castings made contain 2 per cent. silicon and these large rotor castings required a 1 per cent. silicon iron. The syphon brick method of tapping metal is used in the foundry necessitating a large well of metal being kept in the furnace. When a charge is changed this well must be emptied at the correct time. This emptying the well of the cupola causes a great deal of time and trouble.

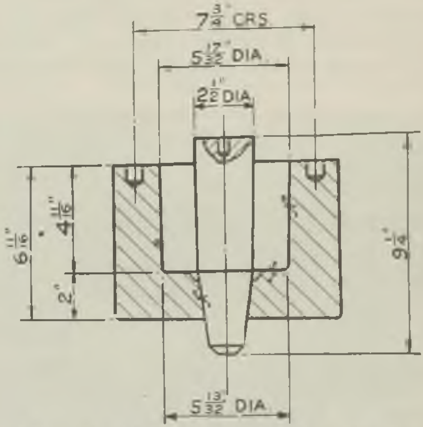



FIG. 2.—DESIGN OF MOULD USED.

The castings now made in cast-iron moulds are run from the ordinary 2 per cent. silicon metal, thus obviating the changing of charges. These castings when made in sand moulds suffered occasionally from shrinkage cavities, etc., which were not always apparent before the castings left for the machine shop.

## Metal Mould Design

The design of metal moulds are seen in Figs. 2 and 3. The centre chills are of plain medium carbon steel and fit into a tapered hole in the bottom of the mould, the end of steel centres protruding through the bottom of the mould. In the smaller and medium size moulds, a guide plate is used to keep centre chill vertical, after the bottom end of the centre has become distorted. The draw or taper on steel centres is, in larger sizes $\frac{1}{8}$ in. on 12 in., *i.e.*, the diameter of the top of the steel centre is $\frac{1}{4}$ in. more than the diameter at the bottom of the centre in contact with the casting. The taper on the smaller sizes is $\frac{1}{16}$ in. on 6 or 7 in. The taper on mould is similar to taper on centres.

The moulds as shown are open at the top and with the exception of the two largest sizes of

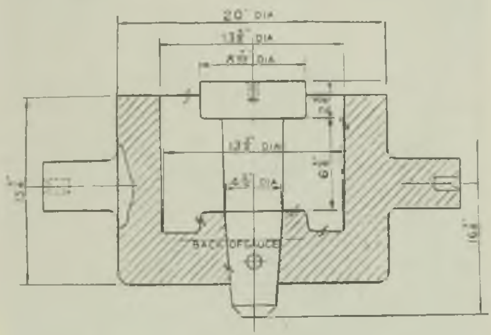


FIG. 3. DESIGN FOR THE LARGEST TYPE OF MOULD.

castings, regular in section. In the case of the largest mould (Fig. 3) a recess is formed at the top and bottom of the casting about $1\frac{3}{4}$ in. deep, and increasing the internal diameter from $4\frac{1}{2}$ in. to $8\frac{1}{4}$ in. The bottom fin which is shown in Figs. 2, 3 and 4, etc., was found to be a satisfactory method of preventing difficulty in the machining of the bottom of the inside bore of the casting, any chill effect at this corner being transferred to the fin which is dressed off before leaving for the machine shop. This fin removal is the only dressing necessary for these castings when made in metal moulds.

When the moulds are properly used, at a fairly definite length of time after casting and solidification, the mould is inverted and the casting removed easily by a few light blows with a hammer, on the protruding end of the steel centre. The casting is then lifted on to an iron block, still inverted, and the centre piece is knocked out with slightly more hammering. The time to knock out the casting is gauged by watching the top surface of the casting, and after some ex-

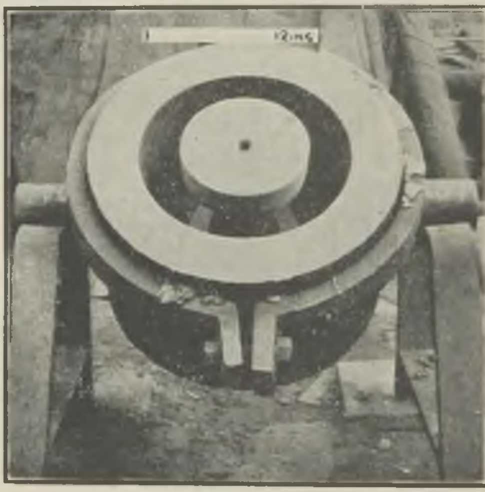


FIG. 4.—SHOWING THE TYPE OF MOULD USED.

perience, keeping within certain limits of time and temperature, it is reasonably easy. If the removal of the casting be attempted too early, the centre piece may come out and leave the casting in the mould with no ready means of removing it.

Consequently, by the time the casting is removed the mould has received no benefit, and the length of time before another can be cast is consequently prolonged.

If too great a length of time be allowed to lapse before knocking out, the casting is easily removed (except in the case of castings having a recess at the bottom), but the mould has been heated more than is necessary, and consequently involves delay before another cast can be made. The centre piece requires more power to be removed than if knocked out at the correct time, because of its continued expansion, and the contraction of casting round it, with the result that the centre is apt to become distorted and strains set up in casting. In the case of recessed castings, the casting contracts on the collar of the mould, and the mould and casting may have to be cooled overnight in order to affect removal.

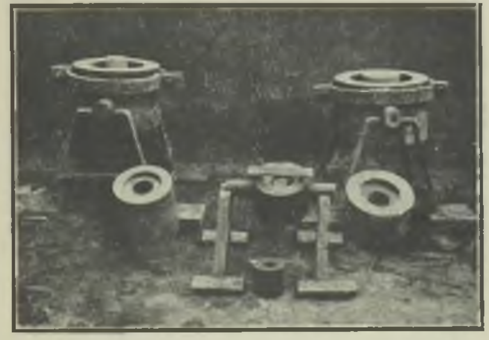


FIG. 5.—GROUP OF MOULDS, AND CASTINGS MADE FROM THEM.

## Nature of Moulds

The moulds are made from an ordinary 2 per cent. silicon iron of the following approximate analysis:—Total carbon, 3.5 to 3.6; manganese, 0.6 to 0.8; sulphur, 0.05 to 0.06, and phosphorus, 0.4 to 0.6 per cent. This analysis is also used for the rotor castings. In the making of the metal mould, the inside surface is formed by a steel core used cold or nearly so and the mould made in drysand with chills or denseners, around the outside surface of the casting of the mould. The casting of the mould is afterwards machined on the inside surface and top to finished sizes.

## Life of Moulds

The life of a mould depends mainly on the casting temperature; the length of time the casting is in the mould; the temperature of the mould during casting and the coating used on the mould surface. If care be not taken while casting, of course, the life of mould is seriously shortened and the casting may fuse to the mould at one or more points. The casting is effected as quickly as possible, the metal, being well skimmed, is practically thrown into the

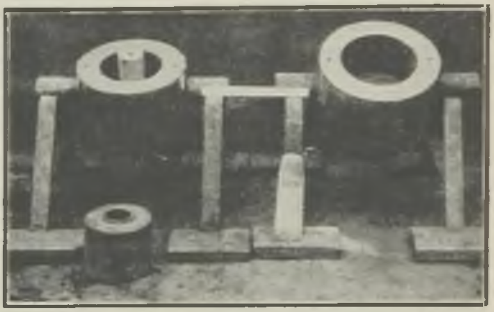


Fig. 6.—A Pair of Moulds, one carrying the Core, together with the Finished Casting.

mould, allowing the steel centre to take the rush of metal.

The larger the mould or casting the shorter usually is the life of the mould. The large recessed mould has shortest life, averaging from 90 to 100 castings per mould. This life could be materially increased by not forming the bottom recess in the casting. The bottom collars develop fire cracks, since the temperature to which they rise, whilst the casting is in the mould, is considerably higher, and cooling faster when the casting removed, than the adjacent mould metal. The casting metal eats into these fire cracks and prevents the easy removal of castings. It is proposed when next the moulds are being made or when the present moulds give trouble to replace this collar by a detachable steel ring or collar. The next largest sizes give about 200 to 250 castings before the mould is declared scrap. In the medium size, that is those having a mould thickness of $2\frac{1}{2}$ in., a thickness of casting of $2\frac{3}{8}$ in., and the centre diameter of 3 in., about 250 to 350 castings are made before the mould is scrapped. In smaller sizes about 500 castings are made before the mould gives out.

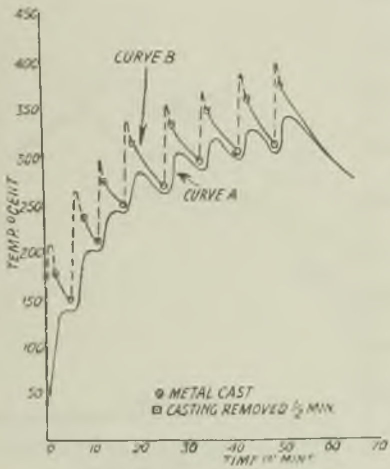



Fig. 7 (Smallest Mould).

The moulds are scrapped when difficulty is experienced in the removal of the castings, due to fire cracks running parallel with the length of the mould. These fire cracks are apparent long before the mould is finished or scrapped. The three largest moulds usually crack through on the vertical sides when the third or fourth casting is made. A steel collar is bolted round the mould in case of accidents which however are very remote. This crack opens up to about $\frac{1}{32}$ in. after the casting has just solidified on the top surface, but when the casting is removed the crack becomes practically invisible. This crack in no way seems to shorten the life of the mould, since any fire cracks formed have no relationship to the position of these first mould cracks.

### Coatings of Moulds

The coatings tried out on the surface of these moulds have been of various materials, such as clay washed and dried; thin coatings of ganister

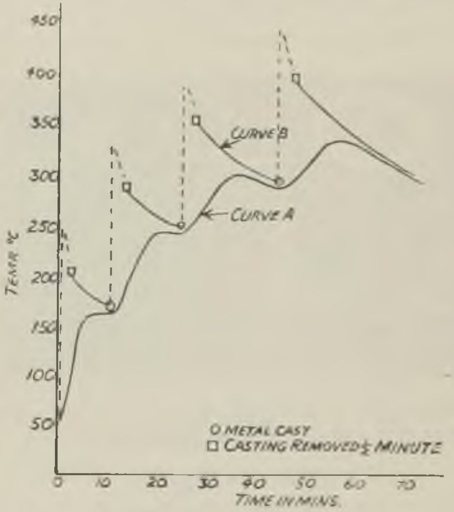



Fig. 8.

washed and dried, with and without frequent coatings of oil, and oil and graphite, etc. The claywashed moulds were not satisfactory above a certain temperature, about 300 deg. C., the coating being apt to flake off. When a light coating of oil and plumbago was applied after each casting was removed, the life of the coating was increased, but was still unsatisfactory. In applying oil or oil and graphite, the oil was made to flash and a coating of soot was formed on the surface of the mould. Two types of ganister were tried, one type causing small blowholes on the surface of the casting irrespective of the mould temperature, etc. This coating flaked off easily. Another type of ganister gave very satisfactory results, the coating staying on for several days with oil and graphite coated lightly on the surface after the removal of each casting. This coating when properly dried gave no trouble in respect to blowholes and a good surface was obtained on the casting.

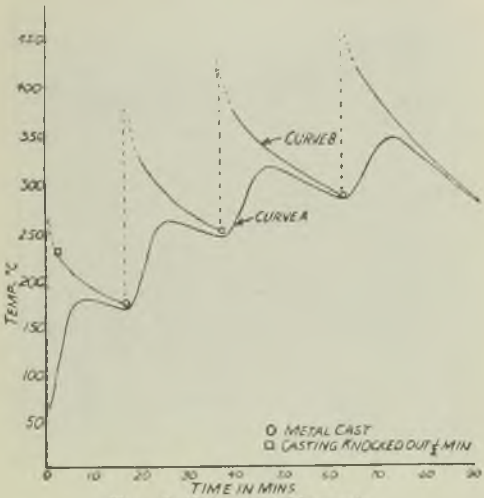



Fig. 9 (Largest Mould).

Figs. 7 to 9.—Three Typical Time-Temperature Curves of the Moulds used.

At the present moment a thin ordinary blackwash coating is used which, whether necessary or not, is removed, and the mould is recoated each day. This coating gives no trouble; it is easily applied, and if the mould temperature is kept below 400 deg. C. when casting, the coating stays on well.

A piece of hot metal heated in a nearby stove to redness is placed in the mould just before the midday break. After lunch time the now warm mould is coated with blackwash and again a piece of red-hot metal placed inside, until ready for casting. Casting usually commences about 3.30 p.m., and continues until about 5.20 p.m.

A coating of kaolin and sodium silicate was tried, but the difficulty of obtaining this coating without blistering and the time necessary to do so properly was found to be not worth while,

Fig. 10.

although for small classes of castings where a good surface is necessary on casting, and not machined all over as these castings are, there is every indication that it would be the best coating.

### Time Temperature Readings

The time and temperature readings taken of moulds during casting are shown in Figs. 7, 8 and 9. The outside temperatures were taken in a small hole, $\frac{1}{4}$ in. deep, on the outside of the mould, halfway up the mould wall. The inside temperatures were taken on a small hole, $\frac{1}{8}$ in. to $\frac{3}{16}$ in. deep, on the bottom inside surface of the mould. The thermocouple on the outside was kept in the hole all the time; on the inside, the thermocouple was removed when casting and replaced immediately the casting was knocked out, 30 sec. being allowed to elapse before a true reading could be taken. The thermocouple was of the nickel-chrome type, with a diameter of $\frac{3}{16}$ in. at the hot junction. The dotted lines on the graphs are only hypothetical.

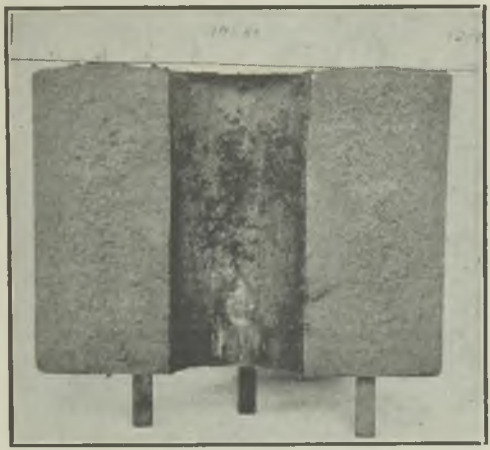


Fig. 11.

Figs. 10 and 11.—A Typical Fracture exhibited by Castings made in Cast-Iron Moulds.

### Nickel Used

The first casting from each size, except in the smallest, has nickel additions added to the ladle, giving a nickel percentage of 0.3 to 0.6 per cent. nickel, which overcomes any tendency for chilling of the bottom corners of the casting. In the smallest size, the first casting is scrapped, being used solely as a means of heating the mould, the rest having 0.4 to 0.5 per cent.

nickel present. In the next size, *i.e.*, $2\frac{1}{8}$-in. thickness of casting, 0.2 per cent. nickel is all that is required to keep casting machinable; in other sizes no nickel is added, unless it be the first casting of the day.

The mould keeps heating up, as can be seen from Figs. 7 to 9, for the first hour, after which

Fig. 12.—Near Surface of Casting. × 50. Unetched.

a greater time-lapse must be allowed between each casting. Usually, metal after the first hour is not so easily procurable, as the larger sizes of castings in the foundry are then being cast, and there is a lapse of 20 to 25 min., when no castings may be made in the metal mould, and this allows the mould to cool down sufficiently to continue casting at a rate approximately to the centre of graphs shown.

These moulds were not designed for fast production work, but the cost of these castings now as against the former method of moulding is reduced some 50 to 75 per cent. Two moulds of the same type are usually run in conjunction with one another, one man effecting casting, knocking out, etc., in the case of the smallest

FIG. 13.—NEAR SURFACE OF CASTING. × 200. ETCHED.

size, and one man and a boy in the case of larger sizes. The larger sizes are cast by labourers. The time chargeable against the castings is therefore only casting time plus the short time necessary to prepare the moulds.

The time for the dressing of the castings is practically nil, as all that is done is to remove the chilled fin at the bottom of the casting. The floor space occupied by the mould and equipment is considerably less than that taken up by boxes and the necessary moulding sand for the same job. The cost of making a new metal mould

FIG. 14.—CENTRE OF CASTING. × 50. UNETCHED.

is little more than that of making two of the rotor castings in sand.

### Soundness of Castings

From the point of view of cavities of any description the soundness is practically 100 per cent. perfect. The only cases where holes have been formed have been in the form of gasholes, which apparently are evolved from the mould or coating. In one of the types of ganister used fairly large blowholes were formed up the side of the casting just below the skin. If the mould be used above a temperature of 400 deg. C. small long blowholes, which run into the casting nearly at right-angles to the mould surface, are found. These blowholes may attain a length of 1 in. to $1\frac{1}{2}$ in. with a thickness of $\frac{1}{16}$ in. to $\frac{1}{4}$ in.

FIG. 15.—CENTRE OF CASTING. × 200. ETCHED.

Trouble was experienced due to small hard pellets near the surface of castings. These were small splashes of metal during casting which stuck to the sides of the mould, and were rendered white or chilled. When the rising metal reaches these pellets, in most cases it does not remove them. With the present coating any splashes which strike the mould side fall back into the main body of metal immediately and are redissolved. The fracture of two sizes of castings are shown in Figs. 10 and 11.

### Hardness and Machinability

The hardnesses of the various sizes do not differ very much from each other, the smaller sizes varying from 207 to 240 Brinell

FIG. 16.—SHOWS BOTH TYPES OF THE EXTRUSION. × 200. ETCHED.

between different castings, but the maximum variations in any one casting is 10 to 15 Brinell points. The hardness when no nickel is present is more variable than when nickel is present. When nickel is present the hardness through the section is more uniform, being hardest about $\frac{1}{4}$ in. below surface of casting and softest at outside face. This softness at outside face is due to ferrite-fine graphite eutectic at surface of castings.

The machinability of these nickel castings is much superior to that of nickel-free castings with even lower hardness. A Brinell number above 240 is to be avoided as expensive cutters are used to machine the helical grooves in the castings.

## Physical Properties

The microstructures of these castings are shown in Figs. 12, 13, 14 and 15. The analyses of drillings from the centre of these rotors show combined carbon of 0.7 to 0.8 per cent. on the small sizes, and 0.5 to 0.7 per cent. on the larger sizes. The amount of fine graphite-fine ferrite structure at the surface of the castings seems to depend to a great extent on casting temperatures and mould temperatures. The minimum amount of ferrite-fine graphite is obtained by casting at a low temperature and using a very warm mould. The maximum amount—sometimes extending to almost ⅛ in. in thickness—is arrived at by casting hot with a relatively cool mould. But the main point, however, is the casting temperature, for which no figures are available. The metal is allowed to cool, with the addition of cast-iron scrap until just past the "breaking" stage, when it is cast; this gives the minimum thickness of ferrite/fine-graphite eutectic. This ferrite/fine-graphite is not desirable, in so far as its wearing properties are inferior to coarse graphite-pearlite structure. Under normal circumstances the ferrite/fine-graphite skin is removed in machining, leaving the coarser graphite-pearlite structure at the surface of the finished rotor.

## Extrusions

A point worth mentioning is the extrusions formed on the open surface of the casting. These are of two types: (1) Large extrusions attaining as much as 1 oz. in weight are sometimes formed, almost immediately after the top surface of casting has solidified. This extrusion takes place at no more than two or three places on the open-cast surface; and (2) at temperatures near 950 deg. C. small globules force their way through the solid top open surface; these globules are about $\frac{1}{16}$ in. to $\frac{1}{8}$ in. in diameter.

The first extrusion, on examination, was found to be of fine-ferrite/graphite eutectic with little more phosphorus than normal in casting, but the second type of extrusion is of a high-phosphorus iron. Fig. 16 shows the structure of both types, the ferrite/fine-graphite eutectic extrusion forming first and then after a certain period the small high-phosphorus globule made its appearance inside the first extrusion. The large nodules or extrusions almost always go hand in hand with a large thickness of ferrite/fine graphite at surfaces of castings, although immediately below the extrusion the metal is usually coarse graphite and pearlite.

## DISCUSSION

Mr. E. J. Ross, who opened the discussion, asked how Mr. McGrandle determined the thickness of the mould; was it by trial and error? It seemed to him there were three factors to be dealt with or overcome, viz., heat transmission, heat absorption, and radiation. The last was the most difficult to control, and it occurred to him whether it would not be better to have a fluted mould. The first two factors, transmission and absorption, could be calculated, but to get the three working in harmony would give considerable trouble.

Mr. McGrandle said that the real purpose of using metal moulds was to get better castings and make them cheaper. They did not cast all day so they did not have to take such great precautions to prevent overheating of the moulds. Various methods such as pins at the outside or back of the moulds where air could be blown on, would increase the rapidity of cooling. In his case rapidity was not a factor. They made the thickness of the casting the same as the thickness of the chill. If the moulds were made thicker they kept hotter, due to greater mass, although giving better radiation. If they were made thinner they would heat up too rapidly.

Mr. R. D. Lawrie congratulated Mr. McGrandle on his Paper and on having adopted such unorthodox methods to obtain sound castings. He stated that the average foundryman was inclined to try out various dodges in the shape of gates, risers, and denseners, and few had the courage to go to such unorthodox methods as had Mr. McGrandle. He was surprised to see that the moulds were cast open, as a covered mould would have given a much more solid casting.

He noticed that the metal contained 0.5 per cent. P, and thought that with this amount there must be a considerable amount of extrusion, firstly due to graphite separation, and secondly to phosphorus. Had there been a top on, this extrusion would have been put to better account, for if the walls of a permanent mould are unable to give, a denser casting must be the result. Regarding mould dressings for permanent moulds, he had tried many and found that ordinary machine oil poured from an oil-can gave quite satisfactory results.

The oil ignites on coming into contact with the heated mould, leaving a sooty deposit on the face. He could not understand why cracks should form vertically, and suggested that they might have originated from a small blowhole or other surface defect causing a lump on the casting which scores the mould when the casting is being withdrawn.

In his opinion surface cracking was caused by the disintegration of crystals due to repeated heating and cooling. Mr. McGrandle referred to a small projection on the bottom of the casting for the purpose of removing chill, but he (Mr. Lawrie) was surprised to learn that there was any chilling present with an iron containing so much silicon and nickel.

Mr. McGrandle replied to Mr. Lawrie that they coated with lampblack; they could do without a coating, but in that case the mould did not last so long. Referring to cracks, as a matter of fact there are some at the bottom of the mould radiating from the centre hole. The most troublesome were the longitudinal cracks. With repeated heating and cooling of the mould two or three things could happen. Combined carbon could decompose with deposition of graphite. Expansion of the mould face was apt to accentuate the main cracks always up and down. There was a slight oxidation on the surface after two or three heatings. By allowing a quarter of an inch for machining they got a fine surface on the moulds. He did not agree with the idea of a top on the mould as it would mean having a gate and dropping the metal which would be liable to burn-on or cause local erosion.

The Chairman (Mr. D. Sharpe) made the suggestion that hematite iron might be tried with advantage. He also suggested the use of a cheese type of mould as was used in the making of tyres. He proposed a vote of thanks to Mr. McGrandle for the Paper, which had given them something to think over and had been definitely helpful.

# Lancashire Branch

## SOME POINTS IN THE MODERN PRODUCTION OF CASTINGS

By A. Phillips (Member)

Expressed in the simplest terms, the manufacture of satisfactory castings consists of pouring "correctly prepared metal" into "correctly made moulds" that have been produced from "patterns suitably designed." The modern tendency to cut down the weight of castings combined with increasing intricacy in design, closer chemical specifications, and increased physical properties, calls for the best of every unit of personnel, equipment and material concerned in the production of castings. During the last twenty years, foundry metallurgy, sand preparation, moulding machines, foundry technique and plant have advanced considerably, all of which have assisted the foundryman to improve his products and maintain their place in the modern world.

### Moulding and Sand Preparation

To assist in the production of correctly made moulds that will give correct clean castings the modern foundryman has made considerable improvement in the preparation of the sands used for them. There has also been much improvement in sand mixing machinery. It is safe to say that it would be difficult to produce many of the intricate castings now demanded without the use of the recently developed artificially-bonded sands, commonly known as oil sand.

To maintain and improve the sand used in the making of the moulds, it is essential for the foundryman to have a knowledge of the sands he employs. He can then manufacture moulds and cores from day to day with a reasonable guarantee that similar conditions in the sands are being produced. Attempts are now being made completely to standardise the testing of moulding sands, and so control the essential properties. The apparatus now used by the B.C.I.R.A., and The Sands Committee of the

Fig. 1.—Mansfield Sand. × 30.

Institute of British Foundrymen is well known and is of great advantage in sand control. As sand is essential in the manufacture of castings, it will probably be of interest if a few of the properties of moulding sand are described, with a number of tests used in their control.

TABLE I.—*Physical Properties of Moulding Sands Currently Used in Lancashire.*

| | Analysis. | | | | | | |
|---|---|---|---|---|---|---|---|
| | $SiO_2$. | $Fe_2O_3$. | $Al_2O_3$. | CaO. | MgO. | Loss on ignition. | Alkalis. |
| Mansfield | 83.5 | 2.74 | 8.31 | 1.5 | 0.47 | 1.95 | 1.53 |
| Bury road | 81.7 | 3.00 | 10.20 | 1.2 | 0.39 | 3.10 | 0.41 |
| Manchester red | 85.15 | 2.61 | 7.77 | 0.66 | 0.63 | 1.90 | 1.28 |
| Sea sand | 90.70 | 2.61 | 2.53 | 1.56 | 0.71 | 1.35 | 0.54 |

| *Sieve tests* :— | 30–20. | 60–30. | 90–60. | 120–90. | 150–120. |
|---|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Mansfield | 3 | 10 | 25 | 52 | 10 |
| Bury road | 34 | 30 | 13 | 6 | 15 |
| Manchester red | 0.5 | 29.5 | 47 | 7.0 | 6 |
| Sea sand | 5 | 60 | 27 | 5 | 3 |

| *Refractory tests* :— | | Deg. C. | Deg. F. |
|---|---|---|---|
| Mansfield | Seger Cone No. 28 | 1,630 | 2,966 |
| Bury road | ,, ,, ,, 20 | 1,530 | 2,786 |
| Manchester red | ,, ,, ,, 33 | 1,730 | 3,146 |
| Sea sand | ,, ,, ,, 30 | 1,670 | 3,038 |

**Sands**

Chemical and physical properties of moulding sands have been determined and given specific names, thus:—(*a*) chemical analysis and mineral

Fig. 2.—Manchester Coarse Red. × 30

analysis; (*b*) fineness; (*c*) strength; (*d*) permeability; (*e*) durability.

Table I shows the analysis, fineness by the sieve test, and the refractory tests on sands used in the Lancashire district. It will be seen that sea sand has a high silica content, 90.70 per cent., but is a very coarse sand when looking at the sieve test, which shows that 60 per cent.

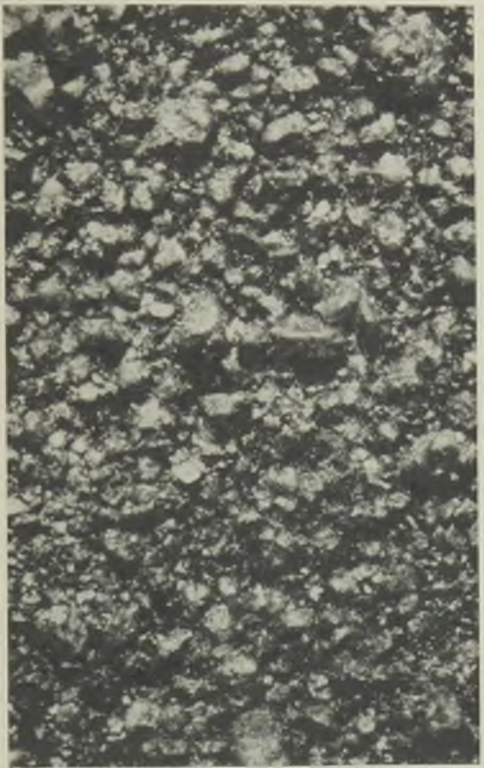


Fig. 3.—Manchester Fine Red. × 30.

is between the 30 and 60 mesh. Mansfield sand, which has 83.5 per cent. silica, is a very fine sand as shown by the sieve test, as 52 per cent. is finer than a 90 mesh. Tests of this character assist the founder in grading his moulding sands.

### Fineness or Grain Size

This goes to distinguish between open and close sands, and calls for little explanation.

Figs. 1 to 4 show photomicrographs of Mansfield sand; Manchester coarse sand (red); Manchester fine sand (red); and Bury road sand. The first is a fine grained sand, having rounded grains; the second exhibits a difference in grain size; the third has angular grains which carry a very good bond. Finally, Fig. 4 shows a sand containing a large percentage of fine bonding material, with very large grains of gravel.

TABLE II.—*Strength and Permeability of Sands.*

| *New sands.* | Average permea-bility. | Length after fracture. | Bond. Per cent. | Ratio of water to sand. |
|---|---|---|---|---|
| | Sec. | In. | | |
| Mansfield .. | 36.75 | 3.83 | 52.55 | |
| Manchester fine (red) .. | 34.91 | 3.33 | 58.25 | 1 : 10 |
| Manchester coarse (red) | 28.90 | 5.20 | 35.0 | |
| Bury road sand .. | 28.37 | 4.50 | 42.5 | |

### Green Bond

The next consideration is strength or bond, and this is of very great importance. This property is due to the amount of clay ($Al_2O_3$) and ferric oxide present, and the ideal condition of their presence is in the form of thin films surrounding each grain and in this condition it is at its maximum efficiency, as it retains in contact a certain amount of water. Moulders sometimes take a handful of sand, compress it and break it for a green bond, which for general purposes is sufficiently reliable, but tests of a quantitive nature can be usefully carried out from time to time, and are a more reliable control.

Fig. 4.—Bury Road Sand. × 30.

### Tests for Cohesiveness

These are taken by pushing a standard-size green core over the edge of a horizontal glass surface until fracture occurs. Measurement is then taken of the unbroken piece, and in Table II are shown the green-bond strengths of a few of the sands commonly used in Lancashire foundries.

### Permeability

Permeability is the facility with which a body allows the free passage of air or gas. One of the greatest considerations in obtaining this is pore space evenly arranged. Rounded sand grains are a further consideration, but the one for which the moulder is responsible is the manner in which his ramming is performed, and

TABLE III.—*Varying Ramming and Percentage of Water.*

| Test no. | Percentage of water. | Ramming. | Time to pass 100 c.c. of air through a dried core. |
|---|---|---|---|
| | | | Sec. |
| No. 1 .. | 12.0 | Light rammed | 47.5 |
| ,, 2 .. | ,, | Normal ,, | 53.0 |
| ,, 3 .. | ,, | Heavy ,, | 82.5 |
| ,, 4 .. | 16.0 | Light ,, | 79.0 |
| ,, 5 .. | ,, | Normal ,, | 263.0 |
| ,, 6 .. | ,, | Heavy ,, | 449.0 |

the condition of the sand when this ramming takes place, also the amount of water with which some moulders swab.

The permeability figures obtained as a result of experiments are most interesting, and go to show that too much care cannot be given to the proper and equal tempering of sand, and that the moulder must exercise every possible care in seeing he does not add too great a quantity of water either as a result of his facing sand drying or by swab-pot methods. One is too apt to say that as it is a dry-sand mould it does not matter to what extent water is added. It matters very largely, particularly previous to ramming or finishing, as wet sand rams much more closely than a dryer sand.

Table III shows the necessity for keeping a close control on the initial moisture content. If

FIG. 5.—SEA SAND. × 30.

No. 2 core is compared with No. 5, they demonstrate the effects of different degrees of ramming, especially when the sand contains a large percentage of water.

### Addition of Water to the Face of a Core

Table IV shows an attempt that was made to produce similar conditions as a dried-sand mould. The sand used in these tests was taken from the coremaker's bench. It demonstrates, when comparing Nos. 1 and 3 against Nos. 2 and 4, that the amount of water sprayed on the face of a core, or mould, should be kept to a minimum, although the mould is subsequently to be dried.

TABLE IV.—*The Effects of the Addition of Water to the Face of a Core made from Core Sand.*

| Test no. | Condition of green core. | Time to pass 100 c.c. of air through a dried core. |
|---|---|---|
| | | Sec. |
| No. 1 | Light rammed .. .. | 28.0 |
| ,, 2 | Light rammed ; face of core moistened with water .. .. | 35.5 |
| ,, 3 | Normal rammed .. | 32.0 |
| ,, 4 | Normal rammed ; face of core moistened with water .. .. | 49.25 |

### Durability

One of the points of at least equal importance to the previous ones is that of durability, by which is meant the ability with which sand can be used and re-used. A sand which has a low degree of durability may not be profitably used even though the analysis, fineness, permeability and cohesiveness tests may indicate its suitability. Natural bonded sands possess the presence of colloidal matter, and it is these which determine to a very great extent the durability of the sand. The problem is distinct from the problem of refractoriness, or the resistance to fluxing, as it is conceivable that even refractory sand might have a short life.

The behaviour of much colloidal matter is distinguished by its independence upon water, the

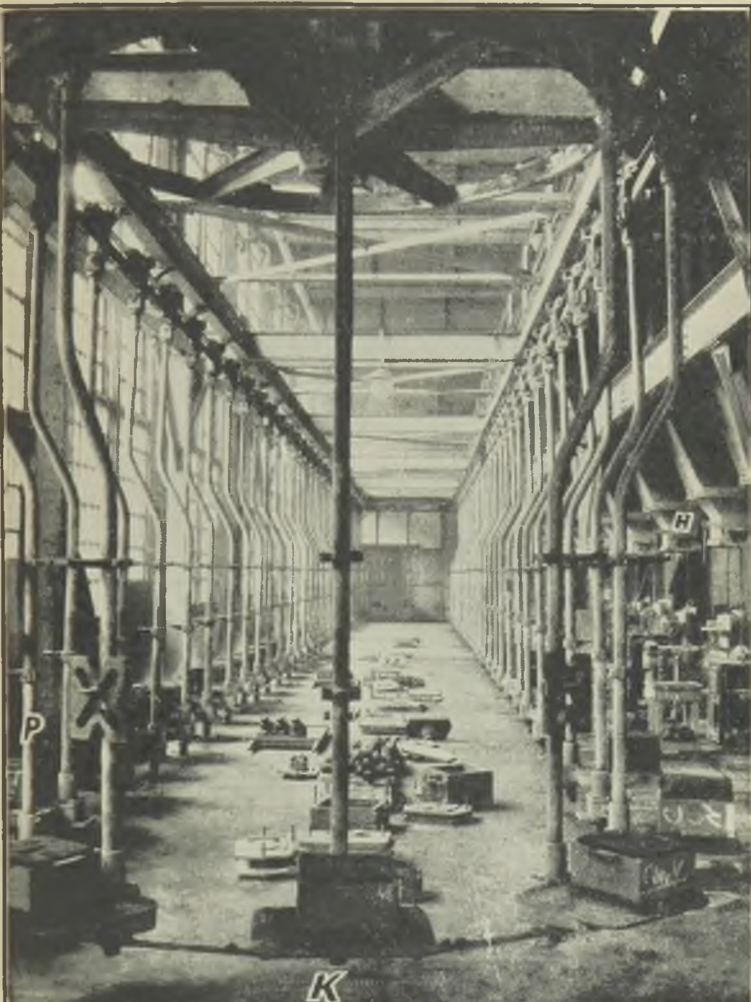



FIG. 6.—THE MOULD CONVEYOR OF THE PENDULUM TYPE.

content of which varies both with temperatures and the neighbouring vapour pressure. Upon subjection to sufficient heat these colloids are destroyed. Their ability to take up water and again become possessed of a bond is lost, and the sand becomes dead. If it is not subject to too great a heat it will rehydrate and can be used for further work. The life of a bond is controlled by this critical temperature. Many clay bonds will stand a high temperature without breaking down, but are unfortunately subject to sintering, and in this condition they lose the

TABLE V.—*Relation of Green Bond to Heat-Treatment.*

| *Sand.* | Heating temperature. Deg. C. | Length in inches after fracture. | Green bond. Per cent. | Percentage of water. |
|---|---|---|---|---|
| Mansfield .. | 110 | 3.9 | 51.2 | 10.0 |
| | 400 | 4.11 | 48.7 | 10.0 |
| | 700 | 5.64 | 29.5 | 10.0 |
| Manchester coarse (red) | 110 | 5.30 | 33.7 | 10.0 |
| | 400 | 5.70 | 28.7 | 10.0 |
| | 700 | nil | nil | |
| | 700 | 5.80 | 27.5 | 26.0 |
| Bury Road sand | 110 | 4.45 | 40.6 | 10.0 |
| | 400 | 5.97 | 25.3 | 10.0 |
| | 700 | — | — | 10.0 |
| | 700 | 5.66 | 29.2 | 18.0 |

colloidal property of again taking up water, and consequently will not again take up bond.

A combination of hydrated colloidal iron oxide and clay will give a long-life bond, and one that will readily rehydrate. From heating curves taken on various sands it has been found that there is a flat on the curve at 110 deg. C., and another flat between 480 deg. C. and 580 deg. C., on the majority of them, which points out that practically all the water in the clay is driven off between these temperatures. In Table V are shown three sands which were chosen for this test—fine, coarse and open grains. They were heated uniformly with thermocouples embedded in the sand, allowed to cool, then the required percentage of water added. The green-bond tests were carried out as previously described.

A cursory examination of the results shows the fact that road sand decreases in strength very rapidly, the loss in bond strength being 15.3 per cent. at 400 deg. C.

If it is assumed that the life or durability of a moulding sand depends entirely upon the amount of bonding material it can retain after being subjected to high temperatures, it would be reasonable to tabulate the three sands as follows:—*Mansfield No.* 1, having the longest life with only 2.5 per cent. loss in bond strength at 400 deg. C.; *Manchester coarse No.* 2, with a loss in bond strength of 5 per cent., and *Road sand No.* 3, with a loss in bond strength of 15.3 per cent.

Sands were heated to the desired temperatures and weighed. Afterwards they were entirely covered by water and allowed to soak for 24 hours. At the end of this period the samples were heated to 110 deg. C. to constant weight, and the increase in weight taken as the water of rehydration.

An interesting point of the results of Table V is that two of the sands subjected to a temperature of 700 deg. C. required more water to obtain a medium bond strength. This points out that the heap sand containing a large amount of burnt sand which will not rehydrate is not suitable for use in sand mixtures, as excess water is necessary to obtain a working bond.

### Oil Sand Cores

A recent improvement in foundry technique is the use of oil sand cores. In order to obtain good oil sand cores it is essential that the raw materials employed should be of good quality. The sand should be refractory, clean and free from clayey and organic matter. The grains should be well rounded and of smaller size. Fig. 5 shows the large rounded grains, with absence of fine bonding material characteristic of sea sand. The oil used must be of sufficient

TABLE VI.—*Tests Carried Out on 36-in. dia. Cupola.*

| | Wagon No. 20. | Wagon No. 3. |
|---|---|---|
| *Time in blast* | 4 hrs. 5 min. | 4 hrs. 40 min. |
| *Iron melted* | Pig 25,690, Scrap 21,521 } 47,211 lbs. | Pig 25,300, Scrap 20,590 } 45,890 lbs. |
| Iron melted per hr. | 11,530 lbs. | 9,820 lbs. |
| ,, ,, ,, min. | 192 ,, | 164 ,, |
| Coke used, bed | 1,186 ,, | 1,136 ,, |
| ,, ,, charges | 5,195 ,, | 5 001 ,, |
| Ratio coke to iron, including bed | 1 : 7.4 | 1 : 7.5 |
| Do. without bed | 1 : 9.1 | 1 : 9.18 |
| Ratio carbon to iron without bed | 1 : 10.9 | 1 : 10.7 |
| Carbon content of coke | 83.10 per cent. | 85.76 per cent. |
| *Without bed.* | | |
| Coke consumed per hr. | 1,270 lbs. | 1,070 lbs. |
| ,, ,, ,, min. | 21.16 ,, | 17.85 ,, |
| Assuming (1) | 30,000 cub. ft. of air required per ton of iron. | |
| (2) | 151.2 ,, ,, ,, lb. of carbon. | |
| *Blast required by iron as per No. 1 above* | 2,670 cub. ft. of air per min. | 2,200 cub. ft. of air per min. |
| *Blast required by coke without bed* | 2,659 ,, ,, ,, | 2,313 ,, ,, ,, |
| *Vol. of air per min. as registered by Pitot tube* | 2,577.5 cub. ft. per min. | 2,180 cub. ft. per min. |
| *Average pressure in "U" tube* | 9.01 ozs. | 9.776 ozs. |
| *Temperature of iron* | Maximum, 1,400 deg. C. | Maximum, 1,320 deg. C. |
| | Minimum, 1,374 ,, | Minimum, 1,300 ,, |
| 14 readings | Average, 1,384 ,, | Average, 1,310 ,, |
| *Condition of coke* | Fair size, good structure | Soft and spongy. |
| Direction of wind | S.W. | S.W. |
| *Velocity* | 12.15 m.p.h. | 12.0 m.p.h. |

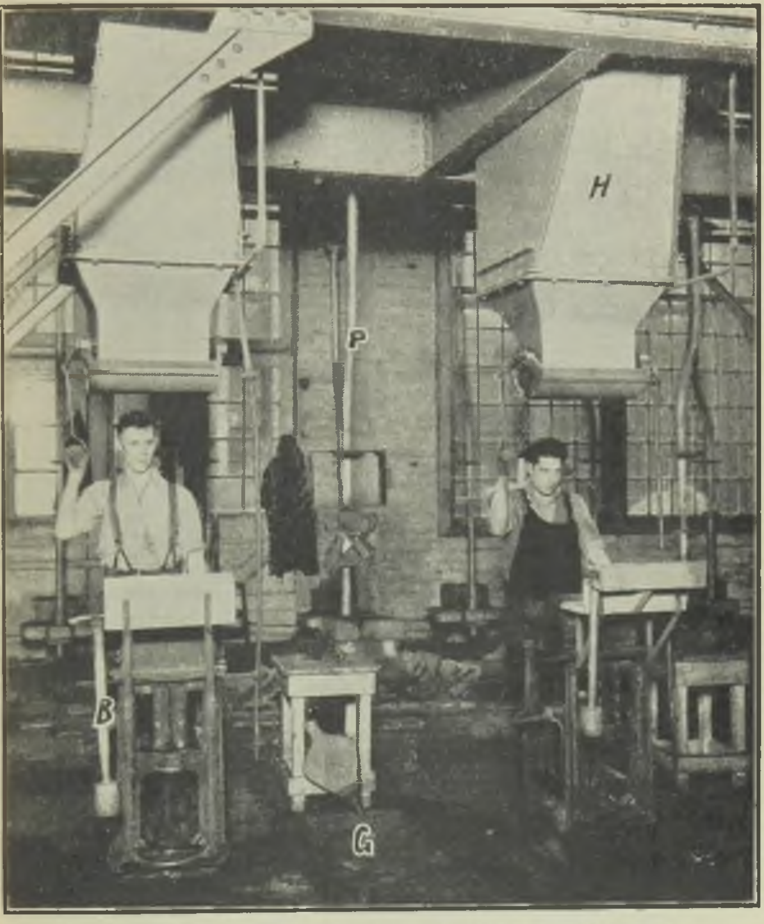



FIG. 7.—SAND HOPPERS AND SPECIAL RAMMING FACILITIES.

strength to enable the core to retain its form in the green state, its viscosity must be low to permit of its mixing with the sand and the film value must be high in order that it may bind a large quantity of sand. The oil must oxidise at such a rate that the core breaks readily, and in the oxidised condition should enable the core to withstand the wash of molten metal. When properly baked and dried the core should not be susceptible to atmospheric moisture.

For certain binding oils the operations of mixing the sand, water and oil are best carried out by emulsifying the oil and water, then adding the emulsion to the sand immediately before entering the mixer. The viscosity of this emulsion should be low and the interfacial tension between the emulsion and the surface of the grains of sand must be low to permit the grains to be wetted.

The process termed "drying" consists of two distinct operations:—(*a*) drying—which removes all the moisture, and (*b*) baking—which oxidises the oil and gives strength and hardness to the core.

**Mechanised Plant**

Recent additions to the modern foundry are the continuous mechanised plants. These are very varied and every installation is a special and complete problem in itself. The one to be briefly described is of the pendulum type. Fig. 6 shows a view of the pendulums "P" used for conveying the moulds to the pouring station and then to the knock-out grid "K." The knock-out grid is in the front foreground, and the pouring station is out of sight at the extreme right background. The sand hoppers "H" and moulding machines can be seen on the right.

Fig. 7 shows a closer view of the sand hoppers and pattern draw moulding machines with grating "G" under machines for the spilt sand to fall through on to the sand conveyor for return to the sand mill. It will be noted the machines are of the portable type. This allows for the production of small quantity orders as duplicate machines can be previously assembled with their necessary pattern plates and held in readiness to be placed under the hoppers. This change-over does not take many minutes and has a considerable advantage over the method of fixing stationary moulding machines under the sand hoppers.

At the side of each machine will be seen a dual pegging and flat rammer " R." This is made the exact weight of a spade. In the moulding practice away from the conveyor the men used their spades to fill the sand in the boxes, and the handle to ram with. This tool allows them to have something they are familiar with and have the necessary " feel " when ramming. As it is made of wood, the patterns do not receive heavy damage, also it is a very useful tool to ram sand to the desired consistency around projecting pieces on the patterns.

From this view the pendulum conveyor " P " can be seen behind the operator, and it is evident that the moulders spend the majority of their time making moulds, as they have only to pull the lever for sand and turn round to place the moulds on the mould conveyor. Coal dust is added in minute regular quantities on the spilt sand conveyor by means of a jarring action on a coal dust container arranged over the grating.

Fig. 8 shows on the right-hand side, the sand elevator " E " for conveying the sand from the knock-out up to the magnetic separator and sand riddle seen on the left. On the top can be seen the sand scrapers (or push plates) " P " which feed the sand to the magnetic belt " M." After the pieces of iron have been separated, the sand falls on a flat riddle " R," through this into the sand mill " M.L.," then it is discharged on to the sand conveyor belt " C " for the hoppers " H."

The sand conveyor " C " to feed the hoppers is seen in the left foreground, whilst the knock-out end of the pendulum conveyor is seen in the right foreground. Both here and at various places on the plant are placed emergency stop-

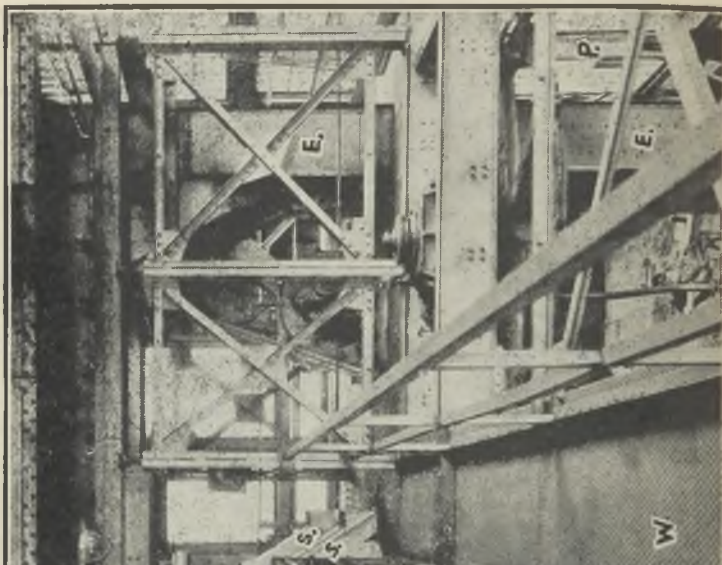



FIG. 8.—VIEW OF THE UPPER LEVEL OF THE MECHANISED PLANT.

ping button switches " E.S." These immediately stop the whole plant if desired.

Fig. 9 shows a closer view of the push plates " P " on the sand conveyor with upper gangway " W " and emergency switches " E.S."

Outstanding advantages of mechanised plants are that all moulds are poured at one point, and all castings are collected at one point. The metal is conveyed to the pouring station by means of an overhead monorail runway.

Fig. 10 shows a modern Telpher arrangement for conveying the metal from the various cupolas to the different pouring stations. It will be seen that the branch lines run at right angles to the main rail, also note the various by-passes " B " to avoid congestion, and to allow free conveyance of metal in any direction. The rail on the left side is to feed the pendulum conveyor pouring station " C."

## Alloy Cast Irons

Cast iron, brasses, bronzes and aluminium alloys are the metals the founding of which chiefly concerns the general foundryman. Ordinary cast iron can be regarded as a complex alloy, which in the past has been considerably misunderstood and in some instances condemned by engineers and designers. This condemnation has been in some instances due to the fact that engineers have formerly experienced failures at certain parts of cast-iron castings which they considered had been designed with sufficient safety margin. These failures were due to both foundrymen's and engineers' complete lack of information on the different strength of cast iron at varying sections.

The test shown in Fig. 11 was prepared to demonstrate the existing difference between shear-test specimens taken from varying thicknesses of cast iron from one casting, and illustrates the physical difference, although the chemical composition is the same. The casting was made of 8-in. cube with varying wall thicknesses. Test-pieces when taken from different

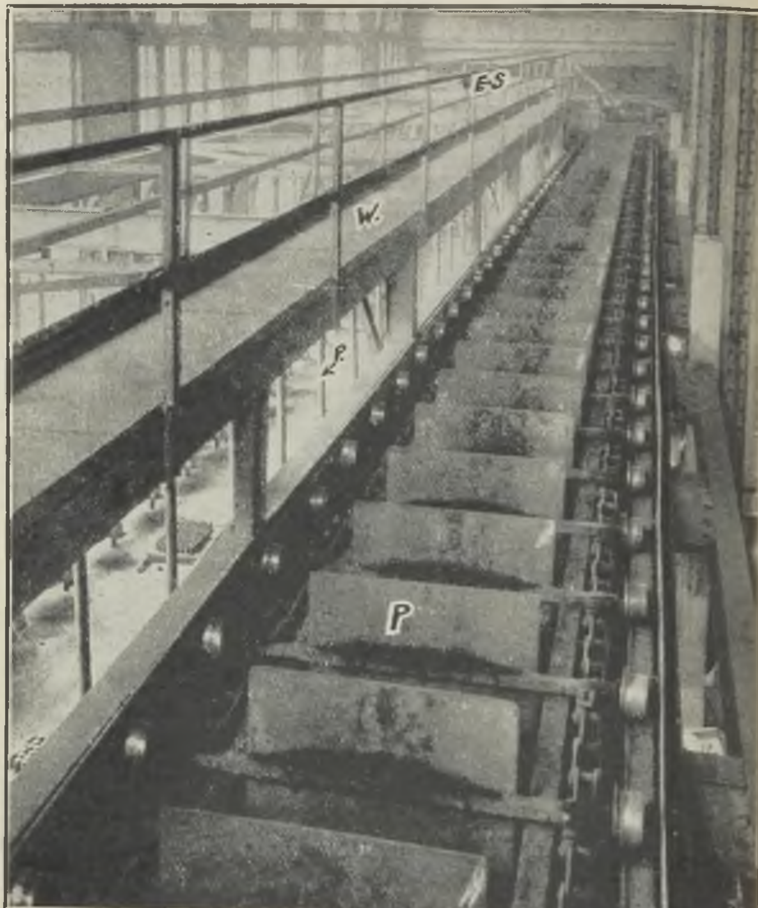



FIG. 9.—PUSH-PLATE CONVEYOR SUPPLYING THE HOPPERS.

parts gave entirely different results as will be seen. On each side is shown an unetched microstructure of the graphite formation corresponding to the wall thickness, from which will be clearly seen the large difference in the structure of varying sections of metal.

The following figures show the difference in physical properties of ordinary cast iron with varying sections:—Three bars of 3 in., 2.2 in. and 1.2 in. dia. poured with the metal used for a large casting gave 10.18, 12.05 and 15.65 tons per sq. in. respectively.

The change in the electrical properties is clearly shown in cast iron of varying sections from the same melt by the following statement:—Bars $\frac{3}{16}$ in. sq. gave 94.3 microhms per C. sq.; bars $\frac{3}{8}$ in. sq. gave 105.3 microhms per C. sq.; bars $\frac{3}{4}$ in. sq. gave 109.5 microhms per C. sq.

This shows the difference in specific resistance of different sections of cast iron of the same chemical composition. Recently-developed alloy cast irons are now being manufactured which give physical properties thought unattainable a few years ago. Tensile tests of 18 to 20 tons are now regularly produced, also alloy cast irons have been developed for special purposes, such as non-magnetic cast iron and special heat-resisting iron.

In the alloy cast-irons group there are:—(1) Mixtures with varying steel additions, (2) mixtures with varying nickel additions, (3) mixtures with varying nickel and chromium additions, (4) liquid white cast iron treated with calcium silicide, (5) liquid white cast iron treated with ferro-silicon and (6) liquid white cast iron treated with nickel.

In the special cast irons there are:—(1) Cast iron, with addition of Ni and Mn, which gives machinable non-magnetic cast iron; (2) specially-produced alloy cast irons, such as Silal and Nicro-Silal for heat-resisting purposes; (3) close-grained cast iron poured into preheated moulds and called Perlit.

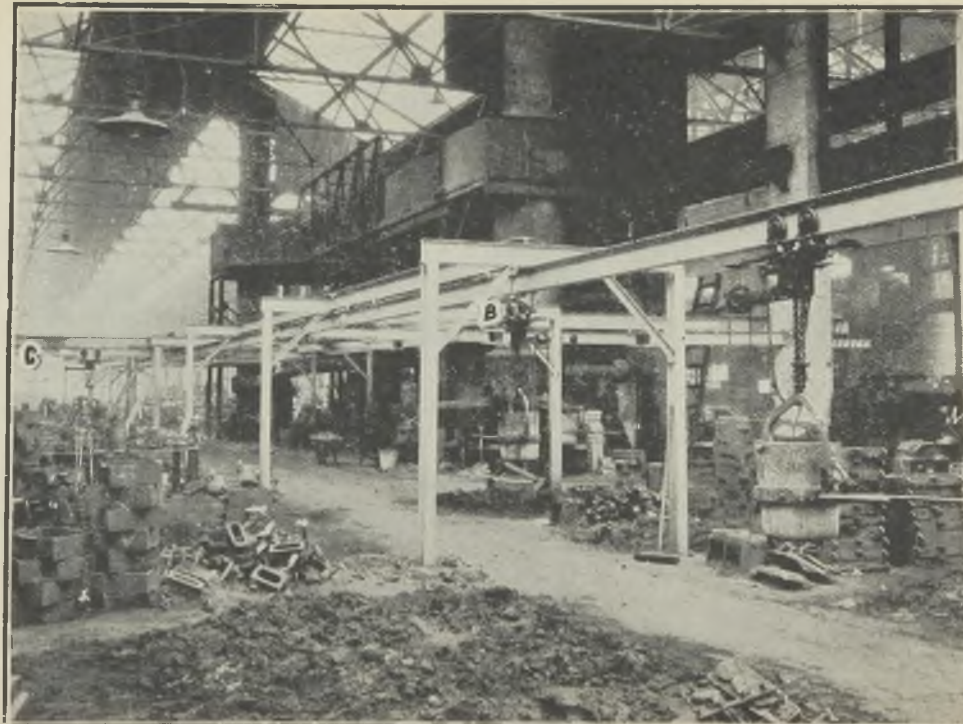



FIG. 10.—METAL DISTRIBUTING IN A MECHANISED FOUNDRY.

Fully to describe all the characteristics of any one of these recently-developed alloy cast irons would take up excessive space, but there is one important point which must not be overlooked. All these special alloy irons have their limitations, and with some the production of complicated-shaped castings must be viewed with caution owing to their high-contraction values at critical temperatures during the cooling down in the mould.

Fig. 12 shows two test-blocks of Association goal-post shape. Around them will be seen castings following the same contour. This was an experiment to test the liability to cracking of different alloy cast irons and their suitability for complicated-shaped castings. These tests were carried out under similar conditions as to dimensions and the like. The different metals were poured round the cast-iron shapes and allowed to cool in the moulds. The one on the left was poured from an ordinary cast iron and gave 11.5 tons per sq. in. tensile on a separately cast " M " bar and was of the following composition:—G.C. 2.85, C.C. 0.60, Si 1.75, Mn 0.86, S 0.08 and P 0.62 per cent.

As will be seen, this did not exhibit any fracture. The one on the right was poured from an inoculated alloy cast iron which gave 20 tons per sq. in. tensile on an " M " bar, and fractured at the corner. From this and other tests, it appears that the full characteristics of high-tensile alloy cast irons must be fully understood before they are used for castings of complicated shapes which require a " breathing time " during the cooling-down period in the mould. One of the claims for the majority of these alloy cast irons is the uniform structure throughout the different sections of a casting. An example is the uniform Brinell hardness taken through a section of a flanged bush casting made in Perlit cast iron, an iron produced by the control of the two elements, carbon and silicon, together with a correct mould temperature. This example is shown in Fig. 13 against the irregular Brinell numbers of an ordinary cast iron taken on a similar section of a casting.

Associated with the recent development of alloy cast iron has been the extended use of sodium carbonate as a de-sulphurising agent. This is another addition to the improvements made in the quality of cast iron.


FIG. 11.—INFLUENCE OF SECTION THICKNESS ON GRAPHITIC STRUCTURE.

### Drying, Venting and Pouring Moulds

Among the chief points in the successful production of large castings are:—(*a*) The mould and cores to be completely dry; and (*b*) full freedom for the gases and air to escape from the cores and mould. During recent years, considerable improvements have been made in the methods for drying moulds and cores. In all modern foundries the temperature in the latest type of core stoves is equal in all parts. This is a great asset in drying moulds and cores.

A recent type of mould dryer which is very successfully used is one which ejects hot air into the mould from a coke fire and can be operated by the compressed air from the shop mains. An excellent feature about this type of drying is the passing of hot gases through the down runners and ingates. This ensures that they are completely dry, especially if the ingates are long and the down gates a good distance away from the mould. Many a casting has been scabbed on parts adjacent to the ingates, which

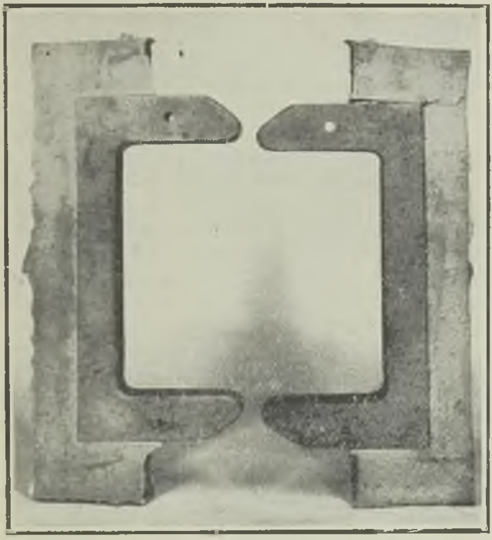


Fig. 12.—The "Soccer" Goal-Post Test to show up liability to Crack.

has been due to incorrectly-dried runners, when the old method for drying moulds was used.

Full freedom for the escape of the gases from the cores is best taken care of by arranging, wherever possible, for each core to have a separate vent to the outside, and not to have a number of cores with their vents escaping into one common cinder bed.

Instances have been found where the escape of the gases from smaller cores has been restricted owing to the heavier pressure exerted by larger cores, when all the vents are allowed to escape in one common outlet. Another instance of defects caused by the air being trapped is sometimes evident by a series of small blowholes on the face of the castings along the flash line where draw-backs have been used. To prevent this air, which increases in volume when heated, becoming trapped, channels are cut up the joint faces of the drawbacks, and the air is allowed to escape out through the top part. An example of this is shown in Fig. 14, which shows a mould partly closed with one drawback to fit in. Along the vertical wall can be seen the air channels at X, which allow full freedom for the escape of any air accumulated in the drawback joints. The calculation of the size and number of runners for large castings is mainly based on previous experience, and varies with the size and shape of the casting. The range will probably vary from 1.5 to 1.85 sq. in. of ingate per ton of casting.

The amount of ingate for a casting is very important, as it must be sufficient to allow the mould to be filled at all points and not too large to prevent the metal in the runner basis being kept up during pouring. Fig. 15 shows the pouring of a 54½-ton turbine casing in a modern foundry. Over 70 tons of metal were poured from five ladles with 25, 18, 15, 10 and 8 tons capacity. Three supplementary runner channels can be seen joining into two large basins. Here is the result of over 5,000 moulding hours. The resultant casting showed that the mould and cores had been fully dried, the vents and air channels satisfactorily cleared, and also the calculations of the ingates were correct, together with the temperature and condition of the molten metal.

### Cupola Operation

To produce satisfactory castings in either ordinary or alloy cast iron, the molten metal must not be produced indifferently. The most common form of melting cast iron in the foundry is by the cupola, and recent developments have been made to cupola melting by the introduction

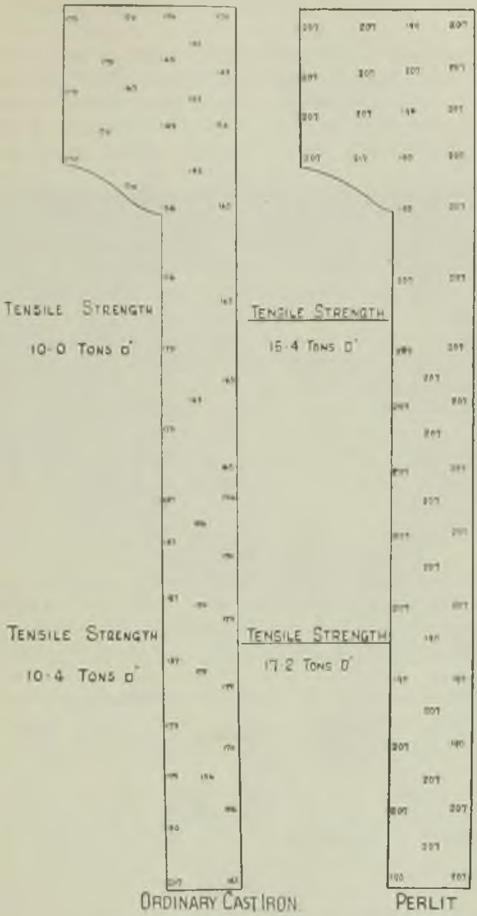



FIG. 13.—BRINELL HARDNESS TESTS ON ORDINARY AND PERLIT CAST IRON.

of the Poumay and balanced-blast cupolas. The design and type of a cupola are not the only considerations, as a correctly-designed cupola incorrectly operated will not give satisfactory results.

Assuming the tuyeres and tuyere area are in line with modern cupola practice, the condition of the lining is satisfactory, the brickwork and holes are patched up, and the tapping holes and bottom are correctly made; then, after the fire is started and well burned up, there is the question of the coke bed—an important factor in the melting of iron satisfactorily. It must be made and maintained at a sufficient height above the tuyeres to prevent the iron coming in contact with the blast. The size of the coke bed should not be determined by weight; the safest plan is to have an iron rod cut to the required length, then, by inserting it through the charging door, the depth of the bed may be ascertained. The height of the bed, usually 18 to 24 in. above the tuyeres, should not be measured until the bed charge is burned through thoroughly, and it is preferable to use large coke for the bed charge.

## Coke Charges

All materials should be preferably weighed on the cupola platform. The coke and iron charges must be kept level at all times, as the melting zone is limited in height, and if material reaches this zone, irregular, poor iron is to be expected. If all material is charged indifferently, indifferent metal will result. The cupola spout and all ladles should be well heated before using —a very important factor.

When coke and air have been fixed in calculated proportion, the iron charges may be determined by experiment, and will be found to vary, according to the cupola characteristics, metal composition and section of castings, from 7.5 to as much as 12.0 ratio. Changes should be only gradual, and each change should be given several days' trial before proceeding with any further alteration. In this way there is little danger of such experiments causing any serious loss of castings.

Having decided on the coke charges and air supply, which is generally stated as 6-in. deep coke charge, and 30,000 cub. ft. of air per ton of iron melted for the complete combustion of 225.5 lbs. of coke with 88 per cent. carbon content, the only fluctuation that sound practice allows is in the weights of the iron charges.

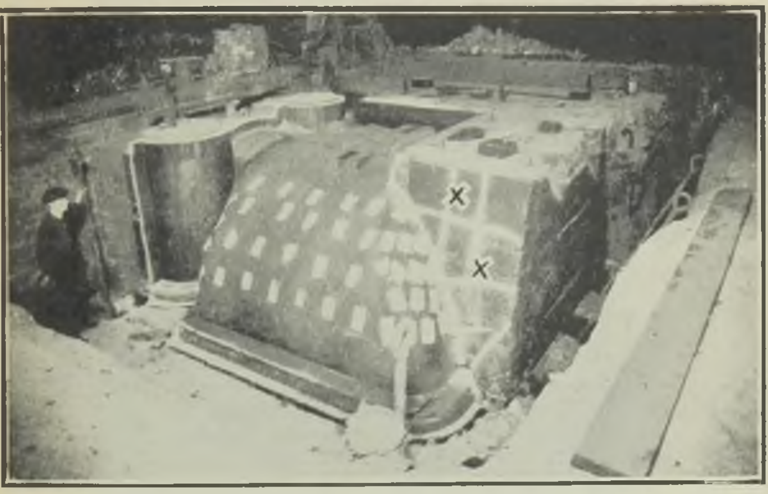



Fig. 14.—Air Channels shown at X X for Venting Drawbacks.

The combustion factors, coke and air, should be left unaltered. Although this has been proved to be sound and is quite logical, it is seldom found in operation. The influences of the properties of coke on cupola practice shown in Table VI indicate that it is always necessary to use good-class foundry coke. It embraces a summary of two tests that were carried out in a 36-in. dia. cupola under conditions similar to these obtainable in general practice. The coke from wagon No. 20 was used for the first day and coke from wagon No. 3 for the next day. The hours in blast and pounds of metal melted are comparable, but there is a distinct difference between metal melted per hr., 11,530 lbs. against 9,820 lbs., coke ratios are comparable 1:7.4 and 1:7.5. The carbon content of the coke is slightly higher from wagon No. 3—85.76 against 83.10 per cent. It will be seen that the blast pressure for the second day is higher, but the cubic feet of air per minute is lower than that of the first day, the size of the coke on the bed charges being as near equal as possible. From this it appears that the soft spongy coke used from wagon No. 3 crushed under the weight of the charges, forming a mass of solidified material, slag and iron just above the tuyeres. This resistance caused an increase in the blast pressure and reduction in the volume of air supplied. The temperature condition of the metal on the second day was very low, an average of only 1,310 deg. C., taken with an optical pyrometer on the stream of metal leaving the spout. The same instrument was used for both tests as the temperature readings would be comparable. The direction and velocity of the wind was taken so that all variable factors could be included.

### Changes in the Metal after Melting

As long as the molten metal is in contact with the fuel, it is not likely that any direct control can be exercised with a definite analysis specification in view. However, some control can be obtained in the melting of cast iron if the changes taking place during melting are clearly understood, and steps taken to obtain definite melting conditions. The greatest difficulty in melting iron in the cupola is the carbon control, and in a large percentage of special work the quantity and condition of the carbon is the deciding factor between a good and bad casting. To explain this the cupola can be usefully divided up into three zones:—

*Zone* 1.—Extending from the charging door

FIG. 15.—CASTING 70 TONS OF METAL FOR A TURBINE CASING.

sill down to the beginning of the melting zone. For practical purposes, cast iron and steel mixtures in this zone absorb very little extra carbon until actual melting begins, although steel does carburise a little.

*Zone 2, or the Actual Melting Zone.*—Cast iron and steel melt just above the hottest zone at their respective melting temperatures, and fall through the hottest zone in small drops. This hottest zone has a temperature of at least 1,650 deg. C. These drops absorb carbon rapidly,

TABLE VII.—*Steel Charges Melted in a 36-in. dia. Cupola.*

| Time. | Volume of air. | Pressure. | |
|---|---|---|---|
| | Cub. ft. | In. $H_2O$. | |
| 11.20 | 2,600 | 15 | *Analysis "C."* |
| 11.25 | 2,700 | 17 | 2.61 T.C. |
| 11.50 | 2,700 | 16.8 | 0.120 Si. |
| 11.55 | 2,600 | 16.2 Tapped | 1.58 Mn. |
| 12.00 | 2,550 | 17.0 | 0.131 S. |
| 12.5 | 2,600 | 16.8 | 0.115 P. |
| 12.10 | 2,600 | 17.4 Tapped | |
| 12.15 | 2,300 | 13.8 | *Analysis "D."* |
| 12.20 | 2,300 | 13.6 | 2.94 T.C. |
| 12.25 | 2,300 | 13.4 | 0.13 Si. |
| 12.30 | 2,250 | 14.0 Tapped | 1.61 Mn. |
| 12.35 | 2,200 | 13.8 | 0.128 S. |
| 12.40 | 2,200 | 15.6 Tapped | 0.125 P. |

due to their high temperature and being in intimate contact with incandescent coke, more carbon is absorbed in this zone than in any other part of the furnace.

*Zone* 3.—This extends from the melting zone to the well. The molten metal lying in the well gradually falls in temperature; sulphur is absorbed in this zone and in the second zone. From these points one can draw conclusions that for high total-carbon irons, melt hot, but slowly, and for low total-carbon metal, melt hot and rapidly. Cast iron, including material with a range of total carbon from 2.8 to 3.5 per cent. when melted in the cupola, will tend to absorb the maximum amount of carbon that can go into solution, at the temperature attained in the melting zone. At any rate, if the maximum amount of carbon is not absorbed in the melting zone, it is very probable that sufficient is absorbed to preclude any further addition by the bed coke.

The three main points for carbon absorption in cupola operations are temperatures in the melting zone, time in the melting zone, and the initial analysis of the material melted. This is borne out by slow-melted hot iron, as it is much higher in carbon than quick-melted hot iron.

Table VII shows an all-steel mixture melted in a cupola with varying blast and volume of air supplied. For the metals C and D, 1,000-lb. charges of steel, plus 25 lbs. of FeMn (80 per cent.) were used, and melted under conditions similar to those obtained in general practice for the coke charges, etc. It will be seen, when the high volume of air and high blast pressure is noted, that in metal C a total carbon content of 2.61 per cent. was obtained, but in metal D, with a lower volume of air and lower blast pressure, 2.94 per cent. total carbon content results.

The author wishes to thank Mr. Jolley, foundry and patternshop superintendent, for his advice in preparing the Paper; and Messrs. Metropolitan-Vickers Electrical Company, Limited, for permission to present this Paper.

## DISCUSSION

The Chairman of the Section, Mr. Lawson Wharton, said he was sure they had all heard Mr. Phillips give a very interesting Paper, on what he would call a combination of technical and practical knowledge of the foundry.

### Vote of Thanks

Mr. Alec Jackson, proposed a vote of thanks to the lecturer, and said they had had, as expected, a very fine address on various points of foundry work, well worth coming some distance to listen to. Even if members had a fair amount of practical experience, when it came to such lectures, which took them out of their practice, they felt rather small.

Mr. J. Hogg, seconding, said that although Mr. Phillips was a metallurgist, he had made himself clear to every foundryman present. It had been said sometimes that those men spoke over their heads, but it could not be said that evening.

The vote of thanks was heartily carried.

### The Silt Question

Mr. J. Pell said that there was one thing the lecturer had omitted to mention. That was the silt in sand bogey. One sent a sample of sand away to be analysed, and it came back with a detrimental report, to say that there was too much silt in it. That was his experience, but at the same time they were producing high-grade castings. He would like to know why the lecturer had not mentioned the matter of silt in sand.

The Lecturer replied that he only just touched upon the subject of sands. He had not explained everything that was in sands and silt. Some people, especially in America, washed the silt out, because they had artificially bonded sands there, and the grains became so broken with constant reheating that they were reduced to a very fine dust. Silt was the useless constituent of sand, but could be removed, similarly to coal and like material, by flotation. For medium-grade castings, however, a silt was not disadvantageous. Nevertheless, it would be detrimental in core sand, where mixed in the round-grained sea sand, since it would collect between the grains, thus reducing its permeability.

### Analytical Reports

Mr. Hogg said he thought Mr. Pell was really questioning the competence of the analyst. Everybody knew that sometimes. for instance, plumbago was analysed. After the analyst had ascertained the fixed carbon, and one or two minor constituents, such as moisture, he described the residue as ash. He, himself, had blacked a mould with plumbago, which consisted of the ash that had been left after fixed carbon had been removed, and had had perfectly good results, as long as it was not gritty. He did not think that the analyst Mr. Pell had in mind understood the functions of what he was analysing.

### More About Silt

Mr. Phillips said that probably it would be of interest to describe a little bit more about the silt. One of the tests to which sand was submitted was the sedimentation process. They placed an inch of sand in a tube, filled it with water, and violently agitated it. On being left to stand, one would find that all the large grains immediately settled at the bottom, and then the other grains in layers superimposed themselves, whilst the clay matter remained suspended. Finally, there was the uppermost layer, containing a milk-like material in suspension, which was termed a colloid. If some sand core or sea sand that had been used for a long time and had had rough treatment was shaken up in a bottle, it would be found that the large grains were settling down rapidly, while the other material formed stayed in suspension, but finally it settled. There was no bond, but there was a fine, silty material, which remained at the top. That was the silt that they had in sand.

As for Mr. Hogg's reference to plumbago, he certainly agreed with him that, when the fixed carbon had been separated from the ash, there remained material sufficiently highly refractory to be the equal to carbon itself. This question of refractoriness of ash in plumbago was one bound up with the sulphur content.

### Speed of Pouring

Mr. Jones said, with regard to the speed of pouring metal, 1.55 sq. in. per ton was found to be quite satisfactory for dry moulds, but he would like to know whether it was adequate for steep castings, with ½-in. thickness, ranging from 10 cwts. to 3 tons, as he found that the best speed was about 2.5 sq. in. per ton.

Mr. Phillips said he should have made some qualification about that. He was meaning castings round about 4 ft. to 6 ft. deep made in dry-sand moulds. He agreed with Mr. Jones that they had to vary their runners in some cases. There were certain castings where they would probably have a ratio of 3 sq. in. per ton of castings, but he mentioned that, when he was talking about castings which were 6 ft. deep and 12 ft. wide. Sometimes it was quite difficult to know what size of runners to use, if one used too much runner area one would not be able to keep the runner full. If one did not put sufficient runner on the metal would not reach to the top of the job. That was why he just gave an illustration of what was about the average to work upon. But, he certainly agreed with Mr. Jones that, for example, in green-sand moulds, one reached as much as 3 sq. in.

## Runner Area Ratios

Mr. John Jackson (Lancashire Branch-President) asked if it were wise to enunciate an amount of ratio of runner area for castings. For instance, the lecturer had said that a certain area of runner size for a certain weight of casting varied according to whether the mould was of dry or green sand. He did not think it mattered so much, but asked himself how they would fare with jobs of the description of long channel rails such as were used on spinning frames. Such a job was a rail from 14 ft. to 16 ft. long, to be run at one end, with a wall-section thickness of ¾ in., with mid-feather arms round about ½ in. across. They found there that they had to swill the metal through as large a runner as they dare possibly use—a runner would take the metal without bursting, though, in order to get the metal to the end of the mould, and yet due to what might be termed the filtration shape of the ingate, they did get clean castings with it. He would imagine that these castings were something of the order of 4 cwts. or even less. The runner size would be double the size the lecturer had given for a casting of that weight. Much depended on the nature of the job, and no hard-and-fast rule could be made.

Mr. Phillips said that it was a question, as he had said before, of previous experience on the particular job, in fixing the runner area. He agreed with Mr. Jackson that the question of runner size was very arbitrary. But he gave a job of the type that one had only once to try out. There were many jobs, indeed hundreds, where they had arranged for runners in some cases up to six sq. in. to a ton, because they were only just little bits of arches. But the reason why he mentioned that was, if they took large castings, anything say round about from 12 to 40 or 50 tons, and they took the runner ratio of what he had said, he did not think they would be very far wrong. On smaller castings he would not talk about runner ratio because one could not definitely say anything, as each casting was a problem in itself.

### Mould Drying

Mr. F. Harris raised the question of drying by means of a mould dryer, as the lecturer had mentioned that the hot gases were passed down the downgates, through the ingates, into the mould, and up to the riser. That was as far as he understood it. Was that sufficient to dry the whole of the mould thoroughly, or did he recommend some other special methods in order to get satisfactory results by placing a special downgate for the gases to pass down, and another for them to pass out of the mould cavity?

Mr. Phillips said if he had inferred that in his remarks, he was mistaken. A mould after receiving its top part, dryers were installed on the latter. The hot gases entered through openings in the top part, and into the mould cavity, and came out through the end runners of the two gates at both ends. He said that an excellent feature about that type of drying was the passing of hot gases through the runner and the ingates. In the old method as compared with the new, if one used coke fires one sent moisture to the face, and this did not effectually dry the runners. With a large mould such as one for a heavy turbine casing, or a big base tank, with down runners, and one placed a modern dryer on the top of the runner, and operated for a couple of hours, they would be surprised at the results they would get in all the part adjacent to the corner.

### A Novel Sand-Drying Process

Mr. Harris asked whether Mr. Phillips when he was mixing sand, used the sand dry, or not.

The Lecturer said that they used dried sand. They had various methods of drying; one was the utilisation of stoves. Another method incorporated the use of two parallel railway lines, over which ran a roller carrying a series of pig-patterns all over the surface. Men filled in the area in between with sea sand, and after levelling it off, rolled it, and so formed a series of moulds like the ordinary pig bed in blast-furnace practice. Any spare metal made during the course of the day was poured into these moulds, and in doing so dried the sand adjacent, and that was how they dried the sand.

### Bury Road Sand

Mr. Hogg said he did not think Bury road sand was clearly understood locally. Bury road sand was one of the finest sands, in his opinion, that they had in the country, as far as it went, but it should not be milled.

Mr. Phillips said he fully agreed with what Mr. Hogg had said. He had been unable to find any sand the equivalent of Bury road sand, either in this country or on the Continent, but there was one thing about Bury road sand,

and, as Mr. Hogg said, they destroyed a lot of its characteristics if they milled it. Also Bury road sand was used in making cases adjacent to runners where they got a very hard scouring action of the metal. If one mixed Bury road sand with a handful or bucketful of iron turnings, or iron filings, and used it adjacent to the runners on a heavy casting, one had in this region a facing which would stand any of the scouring action of the passing of probably 50 or 60 tons of metal off that runner point.

# Lancashire Branch

## DIE CASTING

By A. H. MUNDEY (Member)

Die casting is generally understood in our own country as that method of production by pouring or by forcing metal into highly finished moulds or dies, the result being a casting true to dimension and form, with holes and inserts as may be required, and frequently with internal and external screw threads complete, so that apart from a small amount of trimming and also polishing and plating the casting is ready for service or for assembling into machine parts, without subsequent machining operations.

In the United States the term die casting is reserved for that process which we usually describe as pressure die casting, whilst the method known to us as gravity die casting—that is by pouring from a ladle or crucible into the die, depending upon the head and runner for filling the mould completely—is variously spoken of as permanent mould casting, single purpose and multiple purpose mould casting.

In 1923-24, Anderson and Boyd classified the methods of casting then in use. Mortimer in 1926 adopted this, and Cartland and the author expanded this in a lecture to this Institute in 1929. Now, as at that time it is proposed to divide the art into two main divisions—gravity die casting and pressure die casting.

It is quite impossible to state when castings in metal were first produced, and, interesting as this subject may be, it is out of place to attempt researches in this direction, but it is permissible to point out that bronze spear heads and axe heads were produced by casting in long-life moulds carved out of stone or made in baked clay, by prehistoric craftsmen of several thousands of years ago. It is thus evident that the desire to avoid the destruction of the beautifully finished work of the moulder after each cast was very strong in the minds of the ancient foundryman.

Coming to comparatively recent times the application of die casting started either with the type caster or the bullet caster, the latter being developed during the American Civil War.

## Type Casting

It is perhaps hardly realised that at the present time the greatest users of die castings and in fact the largest and most numerous die casters are the printers. Every type is die cast. In the old days type was die cast by pouring molten metal into a three-part mould held in the hand, or it was gravity die cast; now it is all pressure die cast. Founders' type, or as it is sometimes called case type, is cast in special machines, the metal being injected by a plunger pump into the mould, the character being formed by the matrix.

Composing machines, such as the linotype and intertype, cast slugs or plates with a line of type faces cast along its edge. The monotype casts single letters. These machines are pressure-casting machines of marvellous accuracy. Every day and still more every night hundreds of tons of metal are cast into stereo-plates for the production of newspapers, the moulds being of a papier mache material called flong, an example of gravity die casting of outstanding interest and importance.

The accuracy and high finish of the die-cast type is such a commonplace of life that it is hardly appreciated. [Here the author invited members to inspect a few specimens.] It must be remembered that these types are not hand finished in any way whatever.

## Slush Castings

Probably the simplest and best known castings produced in permanent two-part moulds is the toy soldier; this is not only a die casting, but it embodies another feature of considerable economic importance, it is a hollow casting produced without "coring." The metal is poured into the mould, allowed to cool sufficiently to form a solidified lining to the form of the interior of the mould whilst the centre is still fluid, the mould is quickly inverted, the still fluid metal poured out, and the mould is now opened and the hollow casting ejected. Small statuettes and art castings are produced, and the process is called "slush casting."

### The Corthias Process

Another process which has some application in art work is the Corthias method, used for shallow casting. A permanent and well finished mould is prepared and provided with a core corresponding to the form of the interior of the vessel to be cast. A measured quantity of metal is poured into the mould, and immediately the core is pressed by mechanical means into the molten mass. Centrifugal casting is so well understood by the present day foundryman that any description would be superfluous. But it is successfully applied to the production of die castings, particularly die-cast bearing-liners, but the utility of centrifugal casting is not confined to cylindrical or even to symmetrical castings.

### Gravity and Pressure Die Castings

Gravity die castings are not as a general rule so highly finished, as to surface, nor are they so accurate and fine in dimension as pressure die castings; the reason is obvious, the weight of the fluid head and gate is the only pressure applied.

The metallurgical structure of a die casting is generally superior to that of a sand or loam mould casting, and it is claimed that a gravity die casting is in turn superior as to structure and solidity to a pressure casting. This is hotly disputed by the modern pressure die casters, who claim with well established reason that in the cast of high pressures now employed a degree of soundness and density is obtained which cannot be reached by any other method. It is, however, held that when a well regulated thermal balance between the mould and the fluid metal is maintained the metal freezes layer by layer, each succeeding portion feeding that below, until the gate is reached which should solidify last. The core is removed as quickly as possible to avoid setting up strains due to contraction stresses. In fact, one of the most important factors in the technique of the operators is the removal of cores and the rapid stripping and dismantling of the mould.

The displacement of the air contained in the mould is in gravity die casting a relatively simple operation and only a limited provision for venting is necessary, but that depends upon the form of the casting to be produced and naturally that of the die. Another factor sometimes overlooked in die casting as in general foundry work is the dissolved or occluded gases, which are largely released as the metal approaches the solidifying point; provision must be made for the elimination of the gases, or the collection of them in the heads and risers, or unsound castings will be produced. Yet another cause of disappointment is the formation of cavities which on close inspection are found to differ in form from air or gas holes. These are shrinkage cavities. They are seen under a magnifying glass to be angular in form, and are caused by the metal crystallising in its natural way whilst solidifying. Meanwhile, the still fluid portion drains away, leaving small holes or spaces.

Gravity die casting is all important in industry, and as stated, the principle is very old. Present day practice entitles it to the greatest respect both for the amount of work produced in permanent moulds with gravity feeding only, but for the excellence of the product in design and material.

All the metals and alloys used in the industry can be and are regularly die-cast, although there are many designs placed before the producers which are so intricate, that the use of gravity methods would be courting failure.

## Alloys Utilised Commercially

The number of articles now produced by gravity die casting is enormous. Bearings and liners are made in lead-base and tin-base metals, battery plates and grids—a very important and rather difficult job in lead-antimony alloy or in lead hardened with calcium and the alkali metals. Numberless small jobs are made in zinc-base alloy, but pressure casting is much to be preferred in this type of work. Aluminium and other light alloys, both gravity and pressure casting receive favour according to circumstances. A notable job for gravity casting in aluminium alloy is the piston for automobile engines. The ease and rapidity of casting depends greatly on the variation in design, thus some pistons are so contrived that in order to withdraw the cores, from small pockets, a central three or four part core is required, and this is withdrawn in sections. Portions have to rotate through a part of a circle before they are free. This sort of thing emphasises the desirability of a conference between the designer of the casting and the die designer; much time, energy and money are wasted by neglect of this simple and obvious course.

## Aluminium Gear Boxes

A splendid example of high efficiency in design and organisation is given in the production of an aluminium gear box by the engineers of Messrs. Leyland Motors. The finished weight of the casting was 52 lbs. The alloy was copper $7\frac{1}{2}$ per cent., silicon $3\frac{1}{2}$ per cent., the remainder being aluminium. The contraction allowance was 0.008 per in. The die weighed 1 ton, and was made of cast iron in two main sections, but contained twenty-eight working parts. The temperature of pouring was 750 deg. C., and the mould heated to 400 deg. C.

A comparison of time of production was kindly furnished:—For sand castings, $3\frac{3}{4}$ hrs. per box; die casting, 12 mins.

Four men were engaged in the operation, and

2,000 castings had been made up to the time of report without replacement of mould parts. There was a saving of 10 lbs. of metal in the die casting over the sand casting.

### Aluminium Bronze

For the casting in aluminium bronze, gravity die casting is employed almost exclusively, and

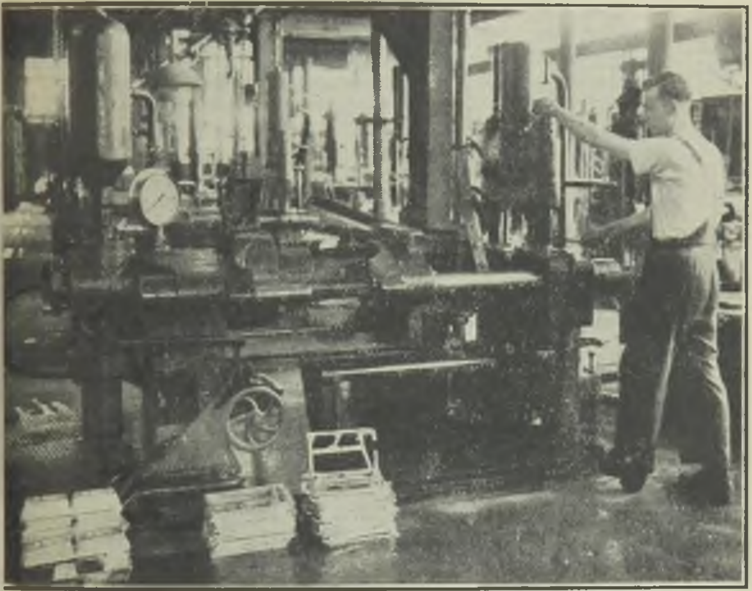


FIG. 1.—MEDIUM HYDRAULIC MACHINE FOR DIE CASTING—ONE OPERATOR.

most successfully. [Examples were then shown of castings thus produced.] Pressure casting can be employed, but having regard to the wear and tear upon the die, it cannot be regarded as an economic success. High-tensile brass, is gravity die cast, with success, as is also aluminium brass. The 60 copper, 40 zinc, brass is cast with success by either gravity or pressure process, but the methods and technique used in the latter is of the greatest interest.

### Nickel Alloys and the Holley Process

Nickel alloys, that is so-called nickel-silver, and also nickel additions with or without iron and manganese to the aluminium bronzes, are capable of gravity die casting. They can be pressure die cast also, but the effect on the dies is so severe that the proposition is, though full of interest, not an economic one. Finally in reviewing the possibilities of gravity die casting, there is the Holley process, successful means of casting in iron. The walls of the dies are relatively thin, and the exterior is furnished with vanes for air cooling similar to an air-cooled engine. The interior parts are carefully coated with a very thin wash by spraying, leaving a refractory lining. This is further protected by a coating of soot produced by an acetelyne flame. The moulds are arranged upon a rotating table or a moving platform, and brought under the ladle. The moulds are stripped very rapidly. This method, together with very carefully selected iron for the charge, results in castings which are dense and strong, yet capable of machining, and are not chilled as would have been expected in early days from an iron charge cast in a chill or metal mould.

### Machines

Pressure die casting. This is so closely associated with the methods employed that it will be interesting to refer to the machines and their products in direct relationship. The author repeated the analogy of the teapot to the early combination of metal pot and pressure machine. Imagine a metal pot, shaped essentially like a teapot, the lid is removed and replaced by a plunger, the die is fastened to the spout, molten metal is maintained in the pot or vessel. A sharp blow on a wooden knob at the top of the plunger ejects a charge of molten metal from the spout into the die. An apparatus patented in 1872 was in actual operation. Throughout the past sixty years and particularly during the last fifteen years, the machines and apparatus have been elaborated and improved, yet throughout in the case of plunger machines the same general principle has obtained. Let it not be thought that because the process is simple in principle that it is an easy operation, for that is not the case, the illustrations will serve to indicate something of the progress which has taken place in recent times.

### The Doehler Machine

The Doehler hand-operated machine which was introduced nearly thirty years ago is still in use, and a more excellent apparatus for studying the fundamental principles of pressure die casting can hardly be imagined. The plunger is operated by a long arm connected by a bell-crank lever to the plunger, and moves in the cylinder which terminates in the nozzle, the axis of which is at right angles to that of the plunger, the cylinder being either a part of or immersed in the well containing the molten metal. The die is held on a hinged plate, the two parts being held together by a toggle joint. The cylinder is filled by withdrawing the plunger a stated distance sufficient to uncover a port. The die is locked down so that the aperture or sprue is in close contact with the nozzle. The forward motion of the piston closes the port and forces the contained molten metal through the nozzle into the die. The die plate is unfastened, swung away on its hinge and the die opened by the toggle, the cores if present are withdrawn, the casting ejected by ejection pins, and the whole cycle of operations repeated.

It is not the mechanical operations, although they are of the utmost importance, to which special attention is directed. It is of special interest to watch the man at work operating the lever. The experienced operator varies the speed and character of the pull according to the size and form of the casting. A short sharp pull is sometimes needed, whilst a long pull with a decided " follow-through " is advisable in another case. The success of these variations is quite marked. The lesson to be learned is that a simple mechanical operation cannot copy faithfully the human skill. But when an air-operated system is interposed the resilience of the compressed air accomplishes the slightly prolonged action.

The positive action of the toggle is also a good lesson for the designer of the more modern and high-powered machine, for in these cases the tendency is to force the dies apart, due to the inrush of metal at high pressure, and this has to be counteracted by powerful devices, out of all proportion to the apparent needs of the operation.

Out of this simple machine has evolved mechanically-operated casting apparatus which is turning out thousands of small castings daily, in various establishments. The temperature, consistency, and general character of the lower melting point alloys, that is, zinc base, lead base and tin base metals, can be studied and standardised.

The difficulty in managing the plunger and cylinder as devised in the Doehler machine and others of this type at the temperature necessary for aluminium, and the action of molten aluminium on a well-fitting plunger and pump cylinder which is constantly submerged in the metal, brought about the use of air pressure to squirt the fluid metal into the die.

Vessels made on the principle of the chemists' wash bottle or the ladies' scent-spray were devised. These had obvious disadvantages which were overcome gradually by arranging that the air from high-pressure cylinders should be cunningly admitted into an annular space in the upper part of the metal container, the pressure on the surface of the alloy being suddenly raised and the metal squirted out of the nozzle communicating with the bottom of the vessel without spraying, but in a full stream or jet.

Pressures as high as 600 lbs. per sq. in. are used with success.

### Goose-Neck Machine

The principle of the U-shaped tube was also introduced, care being taken that the metal should not pass beyond the lower part of bend;

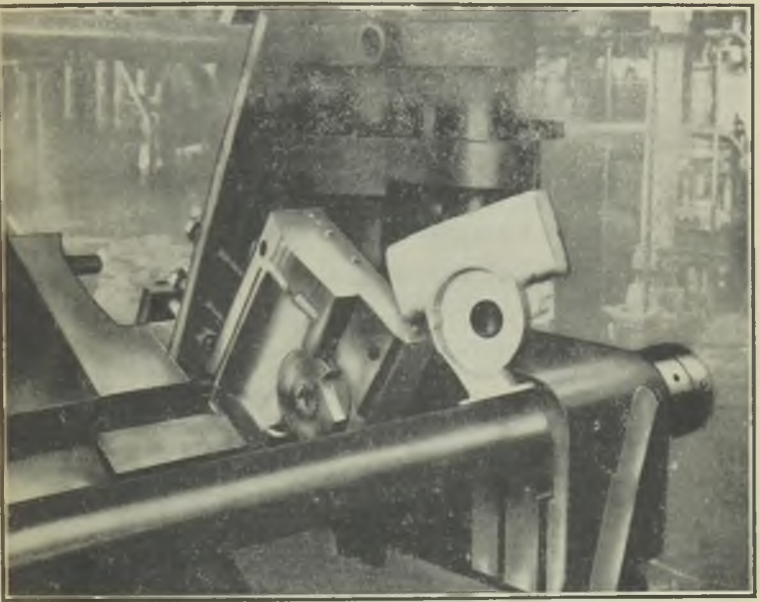


FIG. 2.—LARGE MACHINE. CLOSE-UP OF DIE IN PLACE WITH CASTING JUST EJECTED.

in some cases a fluid plunger of molten lead was introduced. From this, it would appear, was evolved the goose-neck machine, one of the most favoured type of machines in general use.

The goose-neck machine is so designed that after each casting operation the nozzle of the metal pot shall dip into a well of metal and take up a fresh charge, which is in turn forced into the die immediately the nozzle has been brought into intimate contact with the sprue or entry in the die. The die is held together with great firmness and the contact of the nozzle with the sprue passage is adjusted with care, any looseness or bad fitting in these positions give rise to bad castings, thick fins, splashing, etc. The operations are automatic and the sequence of the stages is carefully guarded and controlled.

The ejection of the sprue or tail piece has been a problem, and so a split sprue arrangement which facilitates the ejection of the casting has been devised. The cover die remains stationary over the melting pot, and the ejector die is pulled back through a camshaft operated by a worm and worm wheel. Cores are removed automatically.

Mr. Marc Stern describes in his book a further modification; the ejector die is stationary and the cover die is movable. An air cylinder operates a plunger, which forces the metal through the centre of the cover die. This unit and the furnace are supported up a saddle, and with it are movable. This arrangement protects the die from excessive heat by radiation. These machines are adapted for use with all the alloys up to and including the aluminium alloys, that is, those operating up to temperatures not exceeding 700 deg. C.; actually the working temperature is usually well below 650 deg. C.

The introduction of the use of the plunger type of machine so arranged that it shall not be constantly immersed in the molten metal and with a different mechanism owes much to Josef Polak and several of his contemporaries.

## Polak Machine

The Polak type of machine uses hydraulic power for operating a plunger acting directly upon the metal, as illustrated in Figs. 1-3. As hydraulic power does not furnish that resilience which is so desirable, the inventors added high-pressure air to the hydraulic fluid, thus a pressure of upwards of 3 tons per sq. in. can be obtained, and at the same time the plunger is actuated in a fashion which is a greatly augmented copy of the human pull on a sensitive lever.

The great advantages which accrue to these modern machines are immense power and pressure, producing sound, dense castings, great stability, capacity for production of very large castings of high finish.

The valve mechanism and intensifiers are very complex and ingenious. A clever device for the removal of the excess of the metal after the casting operation is a special feature, and beyond this the machine is capable of and designed for the production of die castings in 60:40 brass at a temperature of about 950 deg. C. to 970 deg. C.

Modifications of the type of machine which has been illustrated consist chiefly of that known as the "parting line device." The features were described in an article* by Dr. Ladislav Jenicick. The machine is operated in such a manner that the metal container is a part of the die, a measured portion of the metal in a semi-solid or plastic condition is introduced, and the plunger injects it into the form of the die, which when parted allows the casting with the gate and surplus of metal attached to be removed as a whole.

Another system* also described and illustrated in the same article is the Buhler machine, which operates in the horizontal direction. In this case the die parts and leaves the casting with gate and surplus attached.

The Pack machine working in a vertical plane is yet another example of the same character of making the die a part of the machine, or rather it embodies the metal container as a part of the die, and delivers the casting gate and surplus attached.

* "Metal Industry."

Yet another machine by Ekart has the plunger working vertically but from underneath. The metal is temporarily contained in a thin asbestos cup. This is also a parting line machine.

It is not possible to describe or even to refer to every machine which has been invented during the past few years. The engineers have been very busy in devising methods of overcoming the difficulties which have been encountered and also in avoiding the special features of machines of competitors.

### Metals and Alloys

The alloys employed in the industry of die casting are of necessity very numerous. It is fair to say that practically the whole family of white metals, that is, those combinations of lead, tin and antimony with or without small amounts of copper, and even cadmium and bismuth can be and are employed to a greater or less extent. Thus there are the Printers' metals, of which the following are representative:—

| | Sn. Per cent. | Sb. Per cent. | Pb. | Cu. |
|---|---|---|---|---|
| Founder's type | 12 to 25 | 20 to 30 | Remainder | 1 per cent. (max.) |
| Linotype .. | 3 to 4 | 10 to 12 | ,, | ,, |
| Intertype .. | 3 to 4 | 10 to 12 | ,, | ,, |
| Monotype .. | 5 to 10 | 15 to 19 | ,, | ,, |
| Stereotype .. | 5 to 10 | 14 to 17 | ,, | ,, |

### Lead Base Alloys for Bearings

These vary from 5 to 10 per cent. tin, 12 to 15 per cent. antimony and the remainder lead. Sometimes copper and other metals are added for special features, and include many important brands, such as Magnolia, Eyre, Tandem, Atlas, etc. Lead-base alloys, consisting of lead hardened by the addition of calcium, barium, sodium may be die cast. Battery plates and fittings for accumulators are of lead hardened by antimony of from 5 to 10 per cent., and also lead hardened by the alkaline earths. Regulus alloys of special purity for chemical engineering are also die cast.

Tin-base alloys as used for anti-friction metals are all capable of being die cast. These range

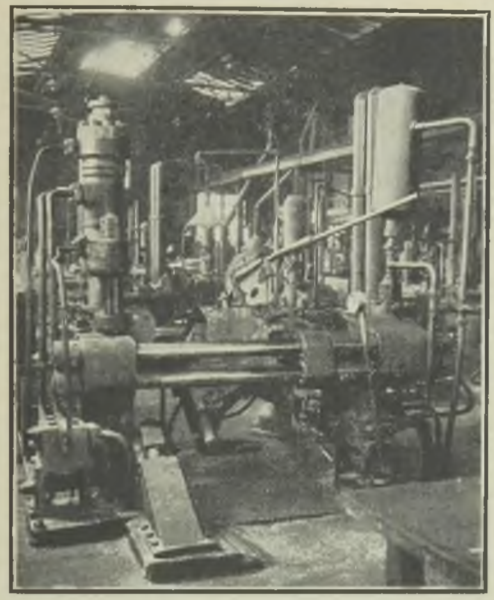


Fig. 3.—Large Hydraulic Die-Casting Machine with Air Reinforcement capable of exerting pressure of 350 tons.

from 93 per cent. tin down to 5 per cent. tin. The high grades are lead-free, and special additions of the rare metals are added to give special resistance to fatigue stresses; all of these are die cast if required.

Special tin-antimony alloys are used for certain parts of gas meters, they contain upwards of 70 per cent. of tin; they resist the action of hydrocarbon gases to a remarkable extent. They are capable of being die cast with remarkable accuracy. All the pewters and so-called Brittania metals lend themselves to die casting.

### Zinc-Base Alloys

This is probably the most important family of die-casting alloys, a distinction which it may be said to share with the aluminium alloys. The reports in a Paper to the Institute of Metals, Vol. XL, No. 2, by Russell, Goodrich, Cross and Allen, gave numerous figures which were the basis of those given to this Institute in 1929. The alloys in this series are divided into two distinct groups:—(1) the older-fashioned composition, in which zinc is hardened by the addition of tin and copper, with a small proportion of aluminium, and (2) the alloy which is in most general use at the present time, zinc hardened by aluminium and copper, with a small addition of magnesium.

Under (1) the alloy consisted of tin 7 to 10 per cent.; copper, 4 to 7 per cent. and zinc balance, while about 0.2 to 0.5 per cent. of aluminium is added for a double purpose—as a deoxidiser and to prevent the tendency to galvanise the dies and machine parts into which it comes into contact at a high temperature. This alloy gives fine finish, great accuracy as to dimension, but it is accused of being liable to age-hardening and cracking, with subsequent internal corrosion and distortion. Impurities are apt to produce these effects. The strength of these alloys is found to be about 9 tons per sq. in., as a practical maximum. They are not ductile.

(2) The second type of zinc-base alloy contains about 4 per cent. aluminium, 3 per cent. copper, and about 0.1 per cent. magnesium, with occasionally small traces of rarer elements, the remainder being zinc. It is essential that the constituent metals shall be of the highest purity possible. Tensile tests give 18 to 20 tons per sq. in., with a reasonable amount of ductility. This is shown more definitely in a twist or torsion

test than by a marked elongation in a tensile test.

### Aluminium Alloys

For gravity die casting, aluminium with 8 to 12 per cent. of copper is used for pistons for internal combustion engines. Manganese up to 1 per cent. is sometimes added, but it decreases the thermal conductivity.

Y alloy 4, which consists of: Magnesium, 1.2 to 1.7; nickel, 1.8 to 2.3; copper, 3.5 to 4.5 per cent., and aluminium remainder, is an excellent material, capable of heat treatment for the improvement of its physical properties. For pressure die castings, the alloy of 11 to 13 per cent. silicon, remainder aluminium, is undoubtedly first favourite.

There are many special alloys which have high properties, and are highly recommended in view of their strength ductility and resistance to corrosion. The most recent is that developed by Mr. A. J. Murphy, of Messrs. Stone & Company, called Ceralumin. [Some specimens were then exhibited.]

### Aluminium Bronze

Gravity die castings in aluminium bronze are of the greatest importance. They are as strong as a medium grade steel, have a beautiful skin and colour, whilst the machined surface is like gold. They resist corrosion to a marked degree, and are very reliable. A whole section of the industry is devoted to the production of this work, the value of which cannot be over estimated.

### Brass Die Castings

Both gravity and pressure work are successfully carried out in brasses of approximately copper 60 per cent., zinc 40 per cent. It is this alloy which is the basis of brass pressure die castings. Here a feature of the work is the production of the castings at a temperature between the solidus and liquidus, the consistency of the metal being that of melting snow, and the production of the casting under high pressure. Excellent results are obtained, and the process which is past the experimental stage is full of promising possibilities. Tensile strengths of over 25 tons to the sq. in. are obtained, and this would no doubt be increased, but there is one handicap. The high stresses upon the surface of the die, coupled with the high temperature and the speed of the metal travelling over the die face, produces a crazy pattern of hair-like lines upon it; these gradually deepen, thus in most cases the die-life is short. It is possible that this may be overcome in time, and researches into various kinds of alloy steels and heat treatments are going forward. The problem is a difficult one, but it is hoped that it is not an insoluble one. It has a distinct bearing upon the economic position of pressure die casting in the alloys of the higher class.

## Die Design

Die design is the most important factor in the whole industry. The engineer must see in imagination the finished casting, then reverse the whole conception, as in the case of general foundry practice, but with this cardinal difference, the material of his mould and in almost all cases his cores is of hard steel, difficult and expensive to fashion into shape. The mould or die must fit together with extreme accuracy, admit of being opened to deliver the casting without distortion or damage, and provide for crystalline and thermal contraction and permit the expulsion of air contained in the die and of gases dissolved or occluded in the molten metal. There are many more factors, but these serve to show the scope of the problem set the die designer. The dies are water cooled by water passing through closely placed channels.

The material of the die is of great importance. As a rule the base is of good cast iron, the body of the die, both upper and lower parts, of high-grade steel forging, frequently of chrome-vanadium steel. After forging, the steel must be normalised, and after a certain amount of machining a further annealing is given. The cores and special working parts are of high-tungsten steel. The dies are, after finishing and testing, generally heat-treated and hardened and tempered under strict pyrometric control.

The die making is carried out by craftsmen—engineer-mechanics who are artists. The machining and fitting operations are of the highest order; in fact it would be difficult to describe the excellence of both design and workmanship without superlatives. When a die is nearing completion wax or plaster casts are taken, and after necessary adjustments it is tested by placing in the machine for trial casting before the hardening and tempering operations.

In the production of aluminium bronze and of brass castings in the gravity process, aluminium-bronze dies are sometimes used and sand or loam cores for intricate interiors. It is suggested that an inspection of the specimens [exhibited] indicate to some extent the scope of the present-day application of die castings. The references already made should reinforce this mental picture. As to its future, who knows? One thing is certain; die casting is not a process which sometimes provokes a comment on mass-production methods as something unworthy, cheap and nasty. It has not destroyed any industry or trade, but has created and fostered its own and other markets. The fact that pressure casting cannot be considered as a means of production unless numbers of, say, 10,000 can be ordered, makes it clear that there is no real competition with general foundry work of the best grade. This apart from the limitation of size.

It is useless to ask for a quotation for die castings at a price per pound, for the more intricate and valuable products are often too light to be valued in this fashion. Yet, in considering very large numbers it is a very inexpensive method of production and the only way that the articles [exhibited] could possibly have been made. As a mass-production job die casting does not destroy the ingenuity or initiative of any of the operatives, but encourages skill and concentrated application. The finishing, polishing and plating of die casting constitute a section which involves much technical skill and which repays genuine study. It is fair to claim the whole industry of die casting as a valuable addition to the engineering and manufacturing world.

### Vote of Thanks

Upon the motion of Mr. J. Hogg, seconded by Mr. A. Phillips, a hearty vote of thanks was unanimously accorded to Mr. Mundey for his extremely instructive and interesting Paper.

## DISCUSSION

Mr. A. Phillips mentioned that Mr. Mundey had not described the " Soag " machine. Did this machine compare favourably with the " Polak " machine in regard to the " push through?" He would also like to be informed as to what method Mr. Mundey adopted for heating up dies, as this was of great importance to the steels.

Mr. Mundey replied that he was not very familiar with the " Soag " machine, but he did not know that any machines other than the " Polak " were working hydraulically on the air principle. There was no reason why they should not; but there would have to be a re-designing of the valves, etc. He did not think there was any patent to prevent this being done.

Mr. A. Phillips said that the " Soag " machine functioned with air and water.

Mr. Mundey replied that, in that case, the " Soag " machine should function in a similar manner to the " Polak." As a general rule, before work started in the morning the dies were heated up by means of gas jets, and extreme care was used by the casters in doing so. He had a great admiration for the casters, who worked very hard and tended their machines as though they were babies. The dies were heated for a few minutes, sometimes for as long as a quarter of an hour, and then a few castings were made. No water was run through until everything was ready. Then the water was turned on very carefully. All the dies were water-cooled, the die designer being very careful to keep his water channels well back so that the cooling was only done by conduction and absorption.

Mr. A. Phillips asked what annealing temperature was used in the production of dies made from forged chrome-vanadium steel.

Mr. Mundey said for chrome-vanadium steel a temperature of something like 950 deg. C. was required. For the heat-treatment of the higher-grade steels 1,300 deg. C. was necessary, because they were very hard. The time depended upon the mass. Quarter of an hour would be sufficient for a small die casting, but a large one might required a prolonged period.

Mr. A. Sutcliffe (Bolton) asked whether Mr. Mundey could cast gun-metal, because if he could then he knew of a firm who would at once dispense with the services of two moulders. He had brought a number of samples of gun-metal castings with him which were typical of about 4,000 now lying useless at the foundry simply because a correct copper alloy was not obtainable. He would be pleased to receive some information from Mr. Mundey with regard to a way out of the difficulty.

Mr. Mundey said gun-metal was very difficult to die cast. He did not say that it could not be die cast, but he did not think it would be worth it. He had referred to the work of the craftsmen of ancient Greece and Rome in the production of gun-metal castings of axe and spear heads in permanent moulds. But these were simple castings. Gun-metal has a very short plastic range; that is, there is a very short gap between the solidus and liquidus. The early worker was able in the cases mentioned, working on an alloy very near the eutectic, to make good castings, but this is not easy if the casting be of complex design.

Mr. Moreland, who was present, had experimented with the making of die castings in gun-metal; perhaps he would say if it were a reasonable operation.

Mr. Moreland here stated that gun-metal is not an appropriate alloy for die castings as a commercial job.

Mr. Mundey further remarked that when all was said and done die casters generally did not care to undertake jobs which were not paying propositions. There would be too many wasters in the case of gun-metal. The specimens exhibited by Mr. Sutcliffe had a zinc base.

Mr. A. Sutcliffe replied that that was so. He had been informed that the casting could be made in gun-metal. He was pleased to learn from Mr. Mundey that that was not possible.

Mr. Mundey said that castings could be made in 60/40 brass, commonly known as "Muntz" metal, which was practically the same as manganese bronze, except that the latter had a few small additions. Those small additions were somewhat of a nuisance for die casting. There was one small point he would like to bring out in connection with one of the exhibits produced by Mr. Sutcliffe, which was a zinc-base casting. It was broken. There was a great deal in the psychology of a user. If the user was driving his car out of the garage and just touched the handle of the door on the side of the garage so that it broke off, then, if it was made of brass, he would say, "What a nuisance; I must have given it a really good biff!" If when it was broken it showed up as white metal, he would say, "Well, that's rotten stuff," though it might have been equally as strong as brass. He would not blame himself as a driver; he would blame the handle.

Mr. A. Phillips asked why was a large sweeper casting, which had been described, made of 13 per cent. silicon-aluminium alloy.

Mr. Mundey said it was the only alloy it would cast in. The idea was that if it was not possible to cast a casting of aluminium with 13 per cent. silicon alloy it was not possible to cast at all. It was the best alloy for casting aluminium alloy.

Mr. Sutcliffe asked whether it was possible to die cast a pressure gauge for a boiler. He had to sand-cast hundreds of them each week. Was there any difficulty concerning contraction or cracking if cast in a die?

Mr. Mundey said they would not contract or crack if made properly.

Mr. E. Sutcliffe said he was machine moulding them in yellow brass, and not making them from zinc-base or aluminium alloys.

Mr. Mundey said he did not like yellow brass for die casting. The difficulty was that brass die castings were cast at a temperature of 950 to 1,000 deg. C. At that temperature the metal rushed into the die, and set up stresses upon its face. The heat was conducted away by the mass of the die. This went on time after time until presently hair-like lines appeared on the face of the die very similar to crazy pavement pattern. These lines became deeper, and as a rule it was only possible to get about 1,000 castings from the die. This amount of production was not sufficient in the case of an expensive die. Therefore in a general way it was not a practical commercial proposition to make pressure castings in yellow brass. This is not a universal rule for as many as 15,000 castings had been produced, but they were of suitable form and thickness. Of course, it could be done in other cases if one was prepared to pay for it.

Mr. A. Phillips asked if any dressing was put on the face of the die.

Mr. Mundey said that a little china clay was used, and sometimes a little graphite mixed with a white French chalk. It was not sprayed on, but put on very quickly by means of a rod. Sometimes they were smoked.

In further reply to Mr. Phillips, Mr. Mundey said that deep dies were sometimes sprayed. He was speaking of pressure casting. For gravity casting spraying was quite a different matter and was good.

The proceedings then concluded.

# East Midlands Branch

## SOME PROPERTIES OF MOULD AND CORE MATERIALS AT ELEVATED TEMPERATURES*

By F. Hudson (Member)

Now that the routine testing of mould and core materials is rapidly becoming established in many foundries there is a great need for research relative to the properties of these materials at elevated temperatures. It is obvious that the properties of sand in a mould at room temperature will not be the same when it is heated by the casting of the metal into that mould. For instance, one of the major problems of the steel founder is that of contraction cracks and there is no doubt that some reliable information relative to the question of sand expansion in conjunction with the strength of the sand at elevated temperatures will be helpful in the elimination of these defects. It is known that the additions of such substances as coal dust, sawdust, old crucibles, crushed fire-bricks, horse dung, oils, etc., profoundly effect the production of castings, but the technique of their action is quite another story. Perhaps some knowledge of the true function of these substances will be obtained by high temperature study. The need of information on the properties of mould and core materials at elevated temperatures is not alone to the steel-founder, although perhaps his need comes first. The iron-founder does succeed in producing a few cracked, scabbed and other sorry looking objects which could have undoubtedly been used for the services of man, instead of being given an ignominious grave, if the text of this Paper had been in evidence. Even the non-ferrous founder can conjure innocent objects of his own production back into the melting pot in a most mysterious manner yet perforce have to suffer seeing the worst casting ever produced occupying a most

* See also page 155.

conspicuous place in the machine shop. It is hoped that the results published in this Paper may in some measure lead to a more peaceful life in the non-ferrous foundry notwithstanding a saving in fuel.

A review of previous work conducted relative to the study of mould and core materials at

Table I.—*Materials used in the Investigations.*

| Designation. | Mixture. |
| --- | --- |
| Steel foundry "Compo." | Proprietory. |
| Iron foundry green sand | 98.9 per cent. green sand floor sand.<br>0.7 per cent. Scottish rotten rock.<br>0.3 per cent. coal dust.<br>0.1 per cent. wood extract.<br>(Milled for 2 min.) |
| Iron foundry dry sand .. | 98.9 per cent dry sand floor sand.<br>1.1 per cent. Bentonite.<br>(Milled for 10 min.) |
| Oil sand . .. .. | 87.0 per cent. Irvine sea sand.<br>10.0 per cent. Scottish rotten rock.<br>3.0 per cent. Semi-solid core oil.<br>(Mixed for 5 min.) |
| Brass foundry green sand | Wormit red sand.<br>(Milled for 5 min.) |

elevated temperatures is not a difficult task. Apart from some investigations upon the refractoriness of foundry sands, the effect of heat upon permeability and expansion tests, one can find little else of value. Much of the present knowledge of high temperature effects in the foundry is due to workers in the refractory field and there is definitely room for original investigations from the foundry viewpoint. During the past few years work of this nature has been forthcoming from the United States of America through the efforts of D. W. Trainer Junr., W. M. Saunders, H. W. Dietert, and A. H. Dierker. From Sweden, by Sixten O. V. Nilsson and from Germany by F. Maske and E. Piwowarsky. The available foundry literature in this country, however, does not contain

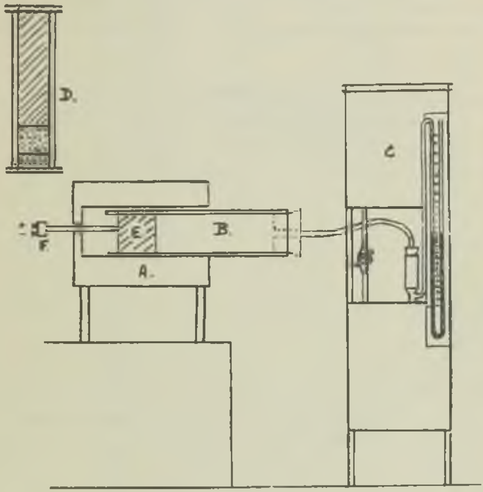



Fig. 1.—Apparatus for determining the Effect of Heat on Permeability.

A. Electric furnace. B. 2-in. bore vitreosil. C. Richardson's permeability apparatus. D. Method of ramming test-piece. E. Sand test-piece. F. Pyrometer.

records of any British investigation directly connected with the properties of mould and core materials at elevated temperatures and it is hoped that this present work will help to correct this omission and at the same time contribute in a small way to the progress of the trade as a whole.

The effect of heat on the properties of five samples of mould and core materials has been investigated, the designation of these samples being given in Table I. The normal physical properties of the sands at room temperature are indicated in Tables II and III.

### The Effect of Heat on Permeability

The apparatus used for determining the effect of heat on permeability is illustrated in Fig. 1.

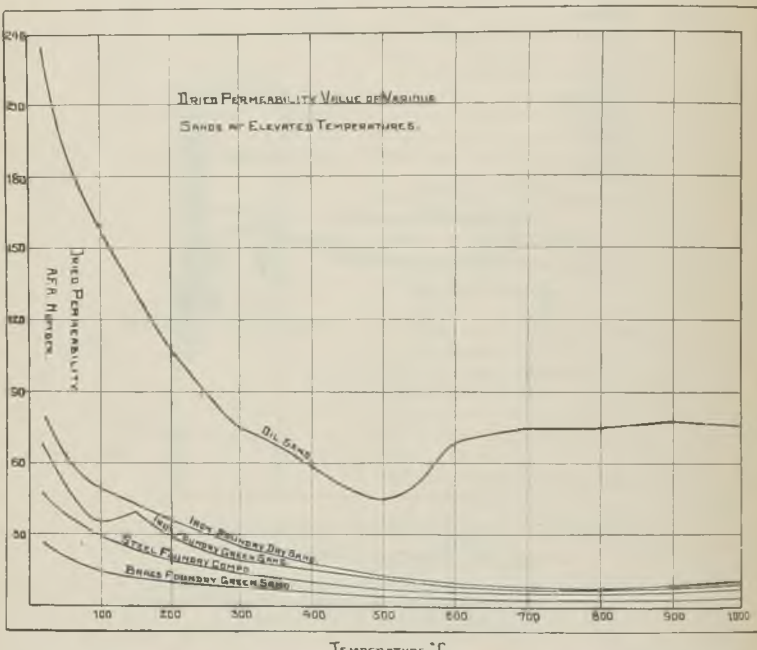



Fig. 2.—Dried Permeability Value of Various Sands at Elevated Temperatures.

The sand sample E under test is rammed by double-compression, as shown at D, in a vitreosil tube B. To minimise the chance of gas leakage between the sand and the vitreosil tube, the surface of the tube in contact with the sand is coated with plaster of Paris and the test section rammed into place before the plaster has com-

TABLE II.—*Properties of Materials Used.*

| Designation. | App. density. | Per cent. moisture. | Compression A.F.A. lbs. per sq. in. | | Permeability. A.F.A. No. | | Per cent. loss on ignition. |
|---|---|---|---|---|---|---|---|
| | | | Green. | Dried. | Green. | Dried. | |
| Steel foundry " compo." .. .. .. | 1.78 | 7.8 | 7.5 | 143.0 | — | 49 | 4.42 |
| Iron foundry green sand .. .. .. | 1.51 | 6.7 | 5.2 | 46.4 | 77 | — | 16.13 |
| Iron foundry dry sand .. .. .. | 1.74 | 9.1 | 7.0 | 155.5 | — | 69 | 4.60 |
| Oil sand .. .. .. .. .. | 1.46 | — | 1.4 | 336.0 | — | 223 | 3.88 |
| Brass foundry green sand .. .. .. | 1.75 | 7.3 | 6.5 | 133.4 | 22 | — | 8.51 |

pletely set. The tube is next placed in the electric furnace A, having temperature controlled by pyrometer F, and connected to Richardson's permeability apparatus C. The first permeability determination is conducted at room temperature, and then the furnace is switched

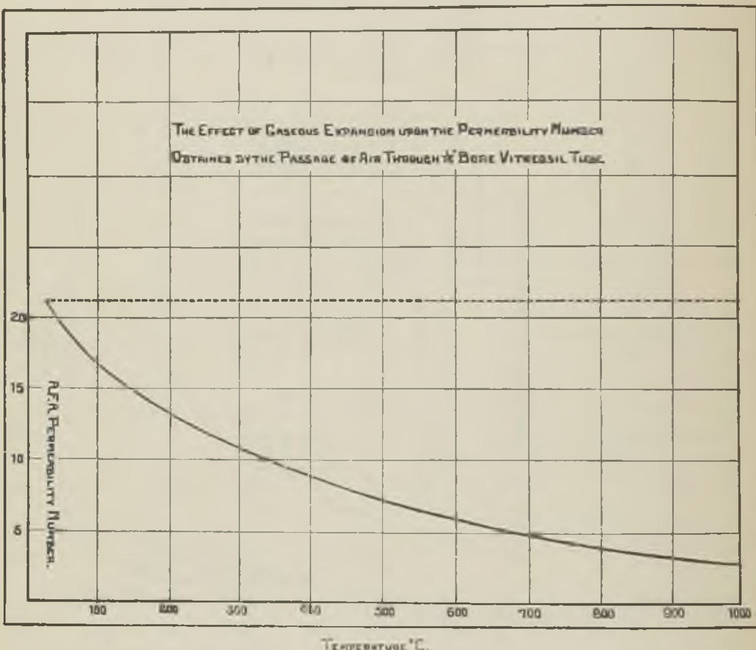



Fig. 3.—The Effect of Gaseous Expansion upon the Permeability Number obtained by the Passage of air through $\frac{1}{16}$-in. Bore Vitreosil Tube.

on and determinations conducted at every 50 deg. C. rise in temperature up to 200 deg. C., and every 100 deg. C. thereafter. At every test point the furnace temperature was maintained for 10 min. to ensure the penetration of heat to the centre of the specimen. It should be

TABLE III.—*Sieve Test on Materials Used.*

| Designation. | Per cent. clay. | Sieve test. Per cent. passing mesh. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 20 | 30 | 40 | 60 | 80 | 90 | 100 | 120 |
| Steel foundry "compo" .. | 17.1 | 69.1 | 61.4 | 42.4 | 38.3 | 29.3 | 24.3 | 17.2 | 15.0 |
| Iron foundry green sand .. | 13.9 | 96.3 | 92.6 | 87.1 | 45.6 | 22.8 | 18.2 | 15.8 | 13.4 |
| Iron foundry dry sand .. | 17.5 | 89.3 | 83.7 | 77.8 | 43.5 | 24.8 | 20.1 | 15.6 | 14.4 |
| Oil sand .. .. .. | 3.1 | 97.7 | 89.1 | 60.6 | 18.9 | 4.0 | 2.2 | 1.3 | 1.0 |
| Brass foundry green sand .. | 13.8 | 96.8 | 95.7 | 92.8 | 71.5 | 50.4 | 44.7 | 38.1 | 35.3 |

pointed out that the size of test-piece employed is 2 in. dia. × 2 in. long, and the permeability number determined by the passage of 2,000 ccs. of air exactly similar to the standard method recommended for the testing of sand at normal temperatures. Attention is particularly drawn to this latter statement in view of the work conducted in the United States on this question by Saunders.[1,2]

Saunders employed a test-piece 1 in. dia. × 2 in. long and measured the permeability by momentary pressure readings. Apart from these modifications the tests conducted by the present author are on similar lines to those done by Saunders, but it was felt that by using the standard size of test-piece the results obtained would be directly comparable with recommended practice. Furthermore, Saunders measured the permeability by momentary pressure readings, as he considered that the passage of 2,000 ccs. of moist air through the silica tube would tend to complicate the determination of the pressure, especially at the higher temperatures employed. In view of the enormous effect of gaseous expansion when the cold air comes in contact with the heated sand sample, it was considered that the measurement of permeability by pressure alone was inaccurate, and it would be advisable to conduct the test in the usual way. Accordingly in all the tests conducted the permeability number was obtained by passing 2,000 ccs. of air through the silica tube and noting the pressure after half the air had passed. It was found that this amount of air had little or no cooling effect on the test-piece when the $\frac{1}{16}$-in. jet was employed in the permeability apparatus.

Fig. 2 illustrates the effect of heat on the permeability of the various sands tested as previously described. These results are similar to those obtained by Saunders. At first sight one might naturally conclude that the effect of heat markedly decreases the permeability value of mould and core materials. Saunders puts forward this conclusion, and also tenders the suggestion that the breaks shown in the continuity of the curves obtained are due to the effects of other gas forming substances such as moisture or oil binders, whilst the decrease in permeability is due to the expansion of sand grains cutting down the flow of air. In these tests, however, the greatest factor of all has not

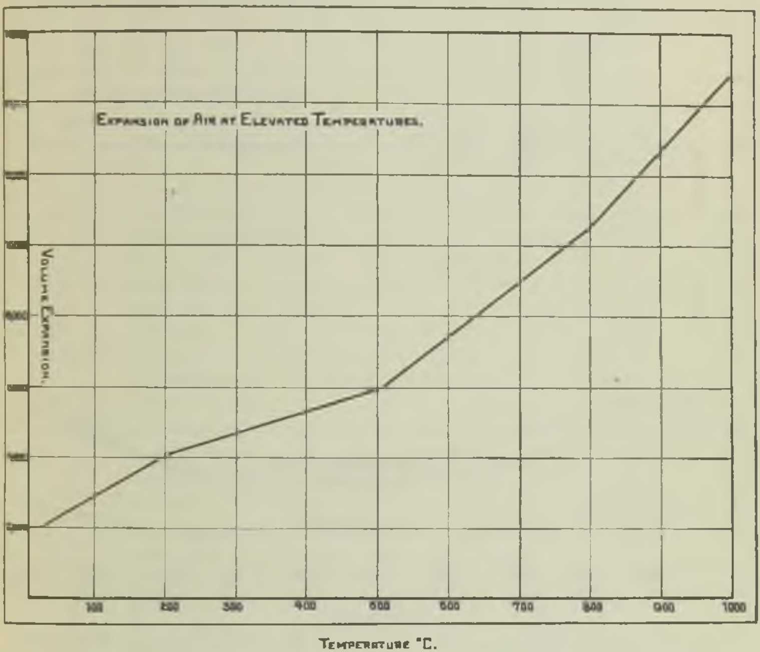



Fig. 4.—Expansion of Air at Elevated Temperatures.

yet been taken into account—namely the expansion of the air due to heat as it passes through the sand test-piece. Very few founders fully appreciate the enormous effect of this change. If instead of using the large 2-in. bore silica tube and its sand test-piece, a $\frac{1}{16}$-in. tube is substituted and the foregoing experiments repeated, some interesting results are obtained, as shown in Fig. 3. It will be observed that a $\frac{1}{16}$-in. vitreosil tube has a permeability number at room temperature of about 22, which decreases down to about 3 at 1,000 deg. C., as shown by the full line curve. Vitreosil, however, is not affected by heat of the degree shown,

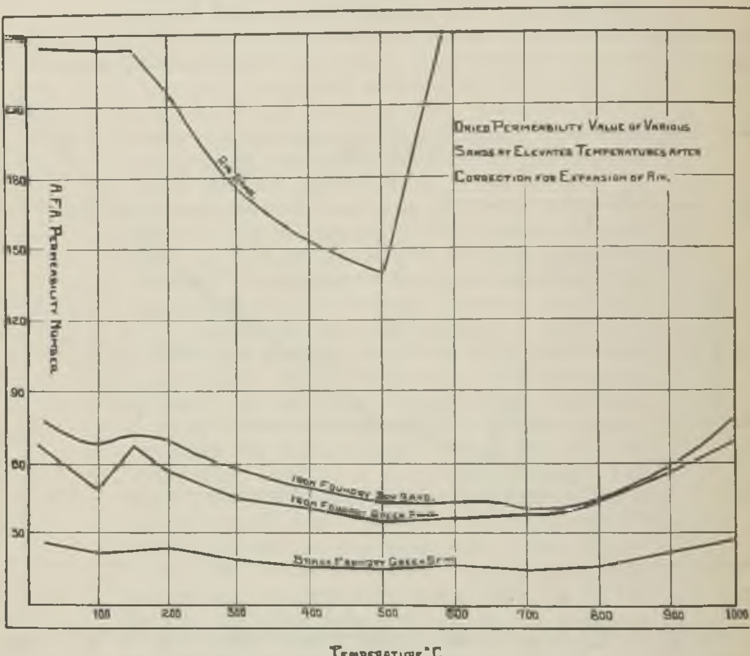



Fig. 5.—Dried Permeability Value of Various Sands at Elevated Temperatures after Correction for Expansion of Air.

and, practically speaking, does not contract or expand. Consequently it can be very positively stated that the bore of the tube has not altered, and consequently neither has the true permeability, which must still be the same, namely 22, at 1,000 deg. C., as shown by the broken line. The reason why the test method indicates a decrease in the permeability is due to the fact that whilst one employs 2,000 ccs. of air at normal temperature and pressure, at 100 deg. C. the 2,000 ccs. has expanded to 2,900 ccs., at 500 deg. C. to nearly 6,000 ccs., and at 1,000 deg. C. to nearly 15,000 ccs. These figures can be easily arrived at by employing the results obtained in Fig. 3 in conjunction with the usual permeability formula, and are plotted in Fig. 4. Now if the original permeability values, as indicated in Fig. 2, are corrected for the degree of air expansion at various temperatures, the true effect of heat on the permeability of mould and core materials can be indicated, as shown in Fig. 5. The corrected figures clearly indicate that the true permeability is not affected by heat. Theoretically this statement requires that the curves indicated in Fig. 5 should exist as straight lines, but it should not be forgotten that only the effect of heat on the expansion of the air used in the test has been taken into present account. All foundry sands contain either moisture or carbonaceous matter, and through the effects of heat these elements are turned into steam or gas, which goes to increase the degree of expansion already occasioned by the air. Furthermore, the volume of gas evolved should be corrected for pressure, as shown in Table IV. It was not found possible to allow for these additional factors in the present calculations, and this causes the curve to depart from the theoretical straight line. Once the majority of the gas-forming substances have been removed by heat the permeability figure rises and at 1,000 deg. C. the present tests clearly indicate that the permeability of mould and core materials is greater than at room temperature. A fairly accurate idea of the effects of heat on the permeability should be obtained from Fig. 5 by joining the result at room temperature with that at 1,000 deg. C. The increase in permeability is probably due to the expansion of the individual sand grains, in conjunction with the promotion of extra voids through the removal of gas-forming elements. This conflicts with the conclusions reached by Saunders, but, quite apart from the experimental evidence, one cannot see how the expansion of sand grains will reduce permeability, and it would appear that unless the very important effect of gaseous expansion be clearly taken in account there is a grave risk of inaccurate conclusions being reached.

Proof that expansion of the sand has little effect on permeability is given in Fig. 6. This

TABLE IV.—*Pressure Correction Data.*

| Manometer pressure (cms.). | To obtain volume at atmospheric pressure X by |
|---|---|
| 0 | 1.0 |
| 10 | 1.01 |
| 20 | 1.02 |
| 30 | 1.03 |
| 40 | 1.04 |
| 50 | 1.05 |
| 60 | 1.06 |

graph illustrates the effect of heat on the permeability of a specimen of graded Sillimanite bonded with 5 per cent. sodium silicate. Accurate expansion tests conducted on separate samples indicated that this material, as anticipated, did not appreciably expand or contract when heated. The permeability value, however. is still considerably reduced .by the effect of heat. Obviously, it cannot be due to any change in the grain size of the test-specimen itself, as this could not alter. (The actual expansion tests conducted to determine the extent of volume change in the material are illustrated in the section dealing with expansion.)

## Conclusions

It can be concluded from these tests that the permeability value for mould and core materials is decreased with increase of temperature. This decrease is principally due to the effect of gaseous expansion and not due to any pronounced structural change, such as expansion or contraction of the materials themselves. The ideal material for foundry requirements would be one that becomes more permeable with increase in temperature in order automatically to allow for the removal of the increasing volume of mould

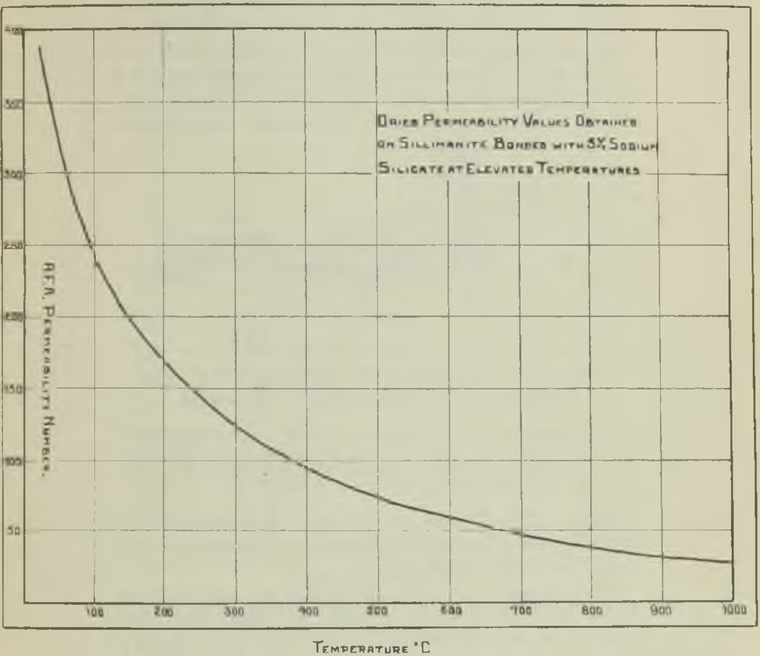



Fig. 6.—Dried Permeability Values obtained on Sillimanite Bonded with 5 per cent. Sodium Silicate at Elevated Temperatures.

or metal gases. In the absence of this ideal the practical founder should keep in mind that the need of employing mould and core materials of high initial permeability becomes more pronounced as:—(1) The temperature of the metal employed increases; (2) the greater the percentage of gas-forming elements present in the sand or metal; (3) the larger the casting; (4) the higher the pouring speed; (5) the smaller the degree of artificial venting or size of risers employed.

### The Effect of Heat on Expansion

The apparatus used for expansion tests is shown in Fig. 7. The lay-out is self-explanatory and is adapted from that used extensively in the refractory trade. It is accepted that this type of equipment is capable of producing very accurate results. The test-piece is $\frac{11}{16}$ in. dia. by 2 in. long, rammed by double compression

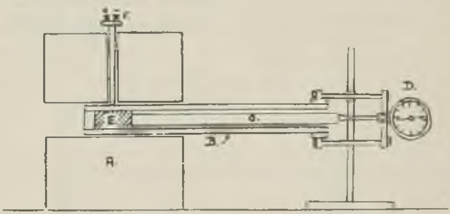



Fig. 7.—Apparatus for determining the Expansion of Refractory Material.

A. Electric furnace. B. Fixed closed-end tube in transparent vitreosil. C. Moving rod in transparent vitreosil. D. Drive micrometer rigidily attached to vitreosil tube. E. Specimen under test. F. Pyrometer.

to the apparent density as shown in Table II, and tested green or, after drying, according to the type of sand employed.

The expansion curves obtained on the various sands are illustrated in Fig. 8. The fact that sands do expand when heated has been known for some considerable time. In 1933 Sixten O. V. Nilsson[3], of the Swedish Manufacturers' Association, drew attention to this fact, and at the last Conference of the American Foundrymen's Association a Paper on the subject was given by H. W. Dietert and F. Valtier.[4] The present investigation indicates that the degree of expansion varies according to the nature of the sand. The addition of materials such as coal dust, saw dust, etc., have a marked effect in reducing the degree of expansion. It is not proposed, however, to go into this side of the question in this present Paper, except to offer it as a possible explanation for one of the reasons why, for example, the ironfoundry green

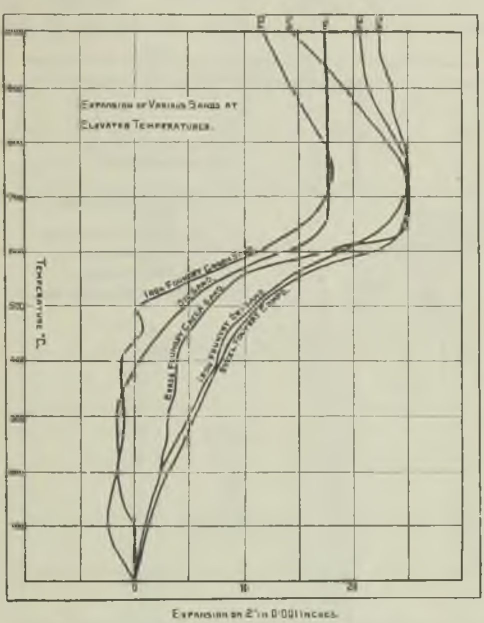



FIG. 8.—EXPANSION OF VARIOUS SANDS AT ELEVATED TEMPERATURES.

sand has less expansion than the ironfoundry dry sand. At the present time the important points to appreciate are:—(1) The greatest degree of expansion in all the sands investigated takes place between 500 and 700 deg. C.; and (2) the total degree of expansion is of such magnitude as to warrant very serious consideration in the production of castings.

The fact that the greatest degree of expansion takes place suddenly, between 500 and 700 deg. C., may possibly lead to the production of defective castings. It should be perfectly obvious that, if during casting one part of the mould is heated to a higher temperature than another, the degree of expansion will vary and buckling of the mould surface may occur. In fact, this does arise very often, due to the design of cast-

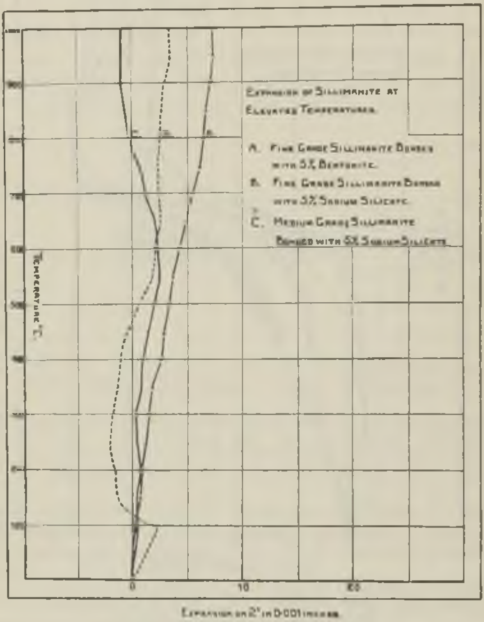



FIG. 9.—EXPANSION OF SILLIMANITE AT ELEVATED TEMPERATURES.

ing or through incorrect "running" methods. In regard to the total degree of expansion, this varies from 0.109 in. up to 0.149 in. per ft., and the data for all the sands tested is shown in Table V.

It is apparent that the degree of expansion is equal to the normal contraction of grey iron and accordingly the question of the expansion of mould and core materials should be treated with considerable respect, particularly if the expansion is associated with high-compression strength, a factor to be considered in a later part of this

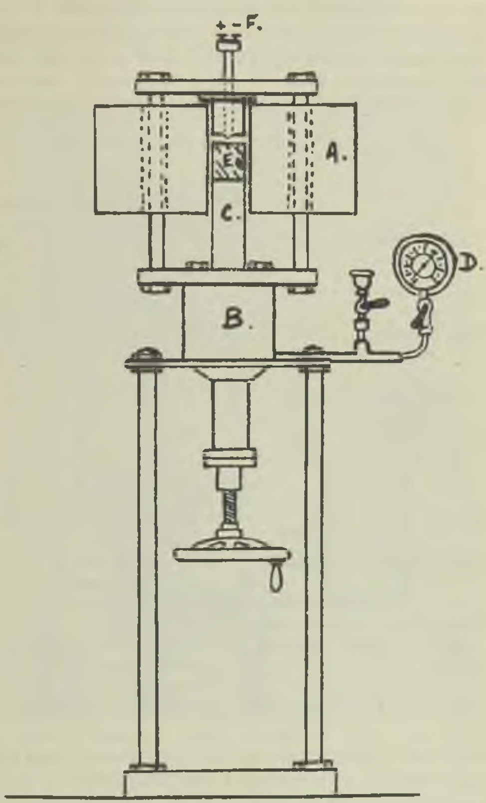



FIG. 10.—APPARATUS FOR DETERMINING COMPRESSIVE STRENGTH AT ELEVATED TEMPERATURES.

A. Electric furnace. B. Oil cylinder for applying load. C. Ni-chrome rams. D. Pressure gauge for indicating load. E. Sand test-piece. F. Pyrometer.

Paper. There is no doubt that a sand having as little expansion on heating as possible would be ideal and of great advantage to the founder, and there is no reason why continued research should not be productive of something tangible in this direction. For example, if any of the expansion test-pieces be reheated and tested a second time, the expansion will be most markedly reduced. Such an example is given for " iron-foundry dry

TABLE V.—*Expansion Data on Various Types of Sand.*

| Designation | App. Density. | Total expansion per ft. on heating to 1,000 deg. C. | |
|---|---|---|---|
| | | Ins. | Per cent. |
| Steel foundry " compo " .. | 1.69<br>1.78 | 0.126<br>0.149 | 1.05<br>1.24 |
| Iron foundry green sand .. | 1.51 | 0.109 | 0.90 |
| Iron foundry dry sand .. | 1.76 | 0.146 | 1.22 |
| (Second reheating to 1,000 deg. C.) .. .. | — | 0.081 | 0.67 |
| Oil sand .. .. .. | 1.46 | 0.111 | 0.92 |
| Brass foundry green sand | 1.75<br>1.55 | 0.149<br>0.142 | 1.24<br>1.18 |
| Sillimanite bonded with sodium silicate (Fig. 9. C.) .. .. .. | 1.60 | 0.014 | 0.12 |

sand " in Table V, when the initial expansion of 0.146 in. per ft. has been reduced down to 0.081 in. Thus it can be concluded that old sand which has already been subjected to high-temperature effects has a lower expansion than new sand. Another refractory material, known as Sillimanite (anhydrous aluminium silicate) gives very little expansion, and this has already been employed for making semi-permanent moulds for repetition castings. Fig. 9 illustrates the expansion of Sillimanite. In this graph it might be pointed out that sample C is that employed, and previously mentioned, in the tests conducted upon the effect of heat on permeability.

### The Effect of Heat on Strength

The previous investigations relative to the effect of heat on permeability and expansion

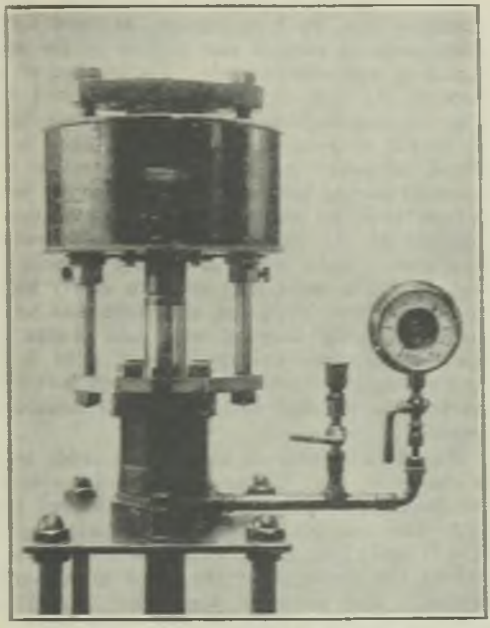


FIG. 11.—VIEW OF THE APPARATUS SHOWN DIAGRAMMATICALLY IN FIG. 10.

were accomplished without undue difficulty, but when the question of strength at elevated temperatures arose the work became really interesting. In the first place no previous work had been done in this direction by any other investigator and the evolution of the apparatus alone required considerable thought, and even modification, as the work progressed to meet minor unthought of points which came to light. Space does not permit description of the trials and tribulations experienced in the evolution of the equipment until satisfactory operation was obtained with the apparatus as shown in Fig. 10.

The test-piece employed is the usual A.F.A. standard 2-in. by 2-in. section, rammed by the drop-ramming method and broken by the application of compressive loads. The method of conducting the test can readily be obtained from Fig. 10, and further description is superfluous. It should be pointed out, however, that it was found necessary to fit an insert made from material having heat-insulating properties to the bottom ram, to prevent overheating of the oil cylinder at the higher range of temperatures employed. This insert is clearly observed in Fig. 11. The sand samples were slowly heated to prevent the formation of cracks and to ensure uniformity between edge and centre and the heating time averaged about 4 to 5 hrs. Any attempt to hasten this operation invariably resulted in cracked test-pieces and inaccurate results.

The effect of heat on the various sands tested is shown in Fig. 12, and the results obtained are rather startling. It will be observed that, with the exception of "ironfoundry green sand" and "oil sand," the effect of heat increases the strength of the sand to a marked degree. For instance, the dried compression strength of the "brassfoundry green sand" is 133 lbs. per sq. in., at room temperature, and this increases to a maximum of 1,260 lbs. per sq. in. at 900 deg. C. Further increase in temperature causes the strength of the sand to rapidly drop to the low figure of 25 lbs. per sq. in. at 1,000 deg. C. During the first period of strength increase, from room temperature up to 900 deg. C., the test-pieces break suddenly with the usual characteristic shear fracture, but during the period of strength decrease, from 900 deg. C. upwards, the effect of heat causes softening of the refractory, with the result that flow takes place and the application of load causes bulging instead of fracture, as shown in

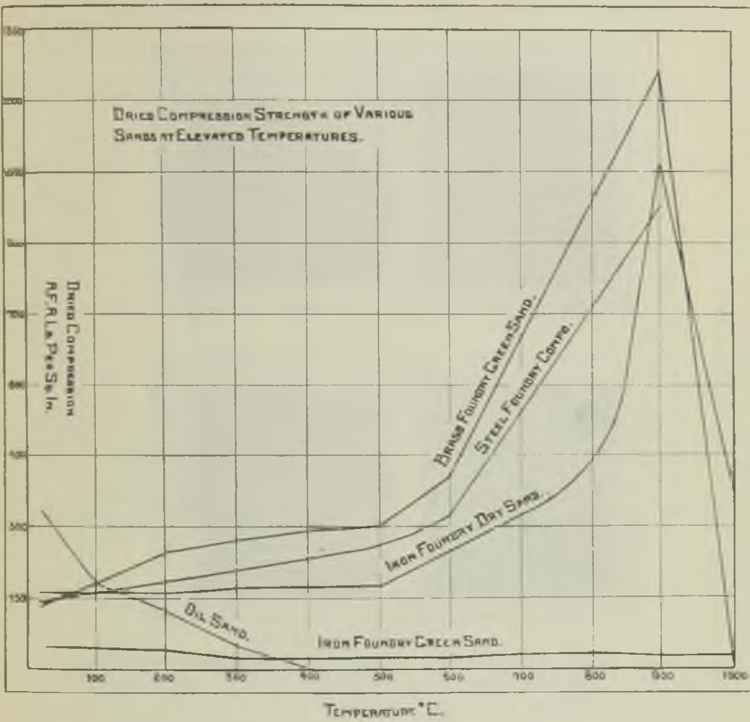
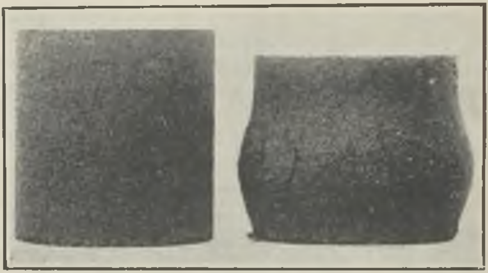
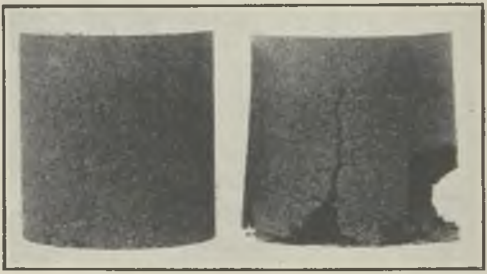



FIG. 12.—DRIED COMPRESSION STRENGTH OF VARIOUS SANDS AT ELEVATED TEMPERATURES.

Figs. 13 and 14. Consequently, in conducting the compression tests when the degree of temperature reached was sufficient to cause flow, it was found necessary to indicate the compression strength by the load necessary to cause compression of the test-piece by $\frac{1}{16}$ in. on its length.

It is also interesting to note from Fig. 12 the remarkable effect of coal dust on the strength of moulding sand at elevated temperatures. Observation of the values obtained on "iron-foundry green sand" in comparison to the "brassfoundry sand" previously discussed,





FIGS. 13 AND 14 SHOWS THAT BULGING RATHER THAN FRACTURE OCCURS AT HIGH TEMPERATURE.

which does not contain coal dust, indicates that the addition of coal dust prevents softening under load at the range of temperature covered by these tests. More important still, the coal-dust addition seems to prevent the large increase in strength which occurs as the temperature of the sand rises, and the value of this fact cannot be over-estimated in its effect on casting production. It might be wise to state at this point that this conclusion is not based on the results of the present tests alone, but has been confirmed by the author more positively in other directions.

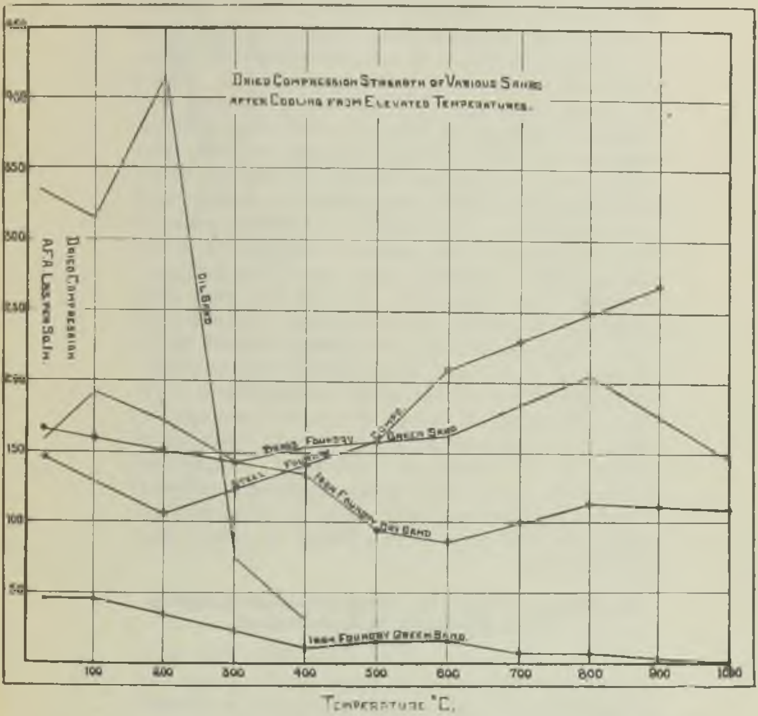



Fig. 15.—Dried Compression Strength of Various Sands after Cooling from Elevated Temperatures.

In regard to the effect of heat on oil sand, the results obtained confirm the general opinion of foundrymen.

## Conclusions

In reaching final conclusions upon the effect of elevated temperatures upon the compression strength of mould and core materials, it is necessary to couple the results with those obtained in connection with expansion. If this be done, it will be found that the sands which expand most are also most subject to increase in strength at elevated temperatures. Such a combination is particularly dangerous, and must be responsible for a large percentage of defective castings in the foundry trade to-day. There is only to be considered hot tears, cracked and distorted castings in the steel industry, cracked castings in the various branches of the iron trade, etc., to see the results of some of these previously unknown properties of mould and core materials. Furthermore, it would seem to the author that the present methods of overcoming these defects, such as "bracketing," "easing" of cores, etc., are at the best only makeshift remedies, and the proper technique of their elimination will ultimately depend upon the use of mould and core materials having suitable properties at elevated temperatures. In the production of large grey-iron castings in loam it is common practice to rely upon loam bricks as a means of relieving contraction stresses on cores. The usual mixtures employed for this purpose cannot possibly be of advantage unless the full text of this Paper be taken into consideration.

### The Effect of Heat on Strength after Cooling from Elevated Temperatures

In the previous section some idea has been obtained of the effect of heat on the properties of mould and core materials such as would appertain during and immediately after the casting operation. There is still another factor which requires consideration before the conclusion of this Paper, and that is the effect of heat on the strength of mould materials after cooling from elevated temperature. Information in this direction determines to a large degree the question of fettling costs.

Accordingly standard A.F.A. compression test-pieces of the various sands were heated up in an electric muffle furnace to the temperatures required and allowed to cool slowly overnight in the furnace. When cold they were broken under compression, and the results obtained are shown in Fig. 15. It will be observed that the increase

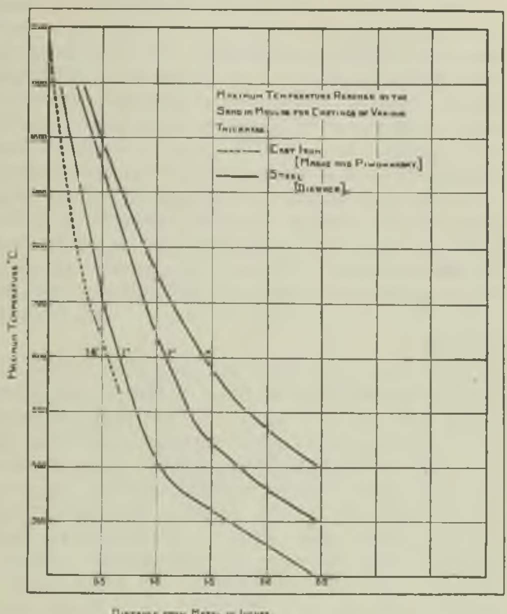


FIG. 16.—MAXIMUM TEMPERATURE REACHED BY THE SAND IN MOULDS FOR CASTINGS OF VARIOUS THICKNESS.

in strength at elevated temperatures of mould and core materials, as illustrated in Fig. 12, is not maintained after these materials have cooled to room temperature under conditions of normal foundry practice. The decrease in strength can be undoubtedly ascribed to the effects of contraction strains in the refractory material itself.

Given a sufficiently slow rate of heating and cooling, extending into several days in either direction, the properties at elevated temperature would undoubtedly be maintained with the resulting production of firebrick articles such as can be observed in brick works. The results obtained in Fig. 15 are interesting, however, as they indicate that the type of mould and core materials employed, together with the temperatures reached, determines the ease or otherwise of the fettling operation. Coal dust additions seem to play a very large part in preventing the sand grains from "fritting" together, and promotes removal of the sand from the casting. It should also be observed that heat affects some sands in a different direction to others. For example, if a mould be considered as made from the steel foundry "Compo," the greater the heat on the mould the greater the difficulty in fettling, whilst the reverse holds good for "iron foundry drysand."

From the data given in this Paper one can obtain a proper appreciation of the properties of mould and core materials at elevated temperatures. The only information now necessary for the transcription of these results into practice is some idea of the existing mould temperatures arising from the casting of various sectioned metals and alloys. No work has been done in this direction by the present author, but Fig. 16 has been drawn up from experiments conducted by Dierker[5] and Maske and Piwowarsky[6], and whilst the information relative to cast iron may not be too complete, the particulars given for steel castings should definitely prove of value.

It is hoped that the results given in this Paper will prove of benefit to the foundry trade as a whole, not only in advancing the technique on a subject which has been far too long overlooked, but also in indicating new lines of research for simplifying and improving the production of castings. In presenting this Paper to the Institute, the author fully appreciates that more could have been said, particularly relative to the effect of the composition of mould and core materials on the physical properties obtained at elevated temperatures, but this omission has been more or less intentional. Continued research in this latter direction has resulted in the production of some extremely interesting data, which will form the basis of another Paper at some later date. For the present it can definitely be assumed that the results embodied in this present Paper are by no means exceptional to the materials tested, but are definitely representative of existing conditions in nearly every foundry to-day. Furthermore, the main intention of this work is to outline some hitherto unknown properties of mould and core materials, properties virtually of fundamental importance, and if this has been accomplished, the main object of the Paper has been served.

In conclusion, the author desires to express his thanks to the directors of Messrs. Glenfield & Kennedy, and Mr. Henry Gardner for permission to publish these results, and also to place on record the valuable assistance given by Mr. R. F. Hudson, who was responsible for conducting many of the tests described. The author is also indebted to Mr. T. R. Walker, chief chemist of the English Steel Corporation, for his courtesy in supplying samples of steel-foundry "Compo."

## Appendix.

In regard to the "dried compression strength" values at elevated temperature, shown in Fig. 12, it should be noted that at 1,000 deg. C. the strength of steel foundry "Compo" was 1,360 lbs. per sq. in. Similarly, in regard to Fig. 15, indicating the strength after cooling from elevated temperature, the value for steel foundry "Compo" was found to be 240 lbs. per sq. in. after cooling from 1,000 deg. C.

These further tests have been completed since the Paper went to press in view of their probable interest to steelfounders.

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## DISCUSSION

Mr. S. H. Russell, Past-President of the Institute, thanked the author and said some of the results had surprised him; others explained things he had known to happen, but had not been able to give a reason for their occurrence. He asked whether Mr. Hudson would explain what was meant by "Scottish Rotten Rock," as he was afraid that the term was unknown in the Midlands district. He noticed that the mixture for green sand in the ironfoundry was principally used sand. To the ordinary foundryman, the numerous curves explained many things noticed in practice, but seldom appreciated. All had noticed how air rushed out of the vents and had heard the peculiar noises caused by restricted vents. It was obvious to all that the volume of cold air in the mould could not be responsible for producing the noises made by the rush of air through the vents. The results shown on the test-cores did not show a point he had noticed in ordinary practice. He referred to the issue from the mould joint of a liquid. One could see a "gummy liquid," and it was fairly certain to assume that would tend to block the pores and cause vent restriction. He had noticed that the strength of sand containing coal dust did not rise when heated. Could Mr. Hudson give any theory why that was so, because in most foundries, particularly when using sand over and over again, coal dust would be persistent through the mixture? He was reminded of a period when he had to overcome "pitting" troubles; he used only a fine grade of coal dust, and it took six months to eliminate the coarse coal dust in the old sand, although using 25 per cent. of new sand in the mixture.

### Scottish Rotten Rock

Mr. Hudson replied that perhaps he should have explained that "Scottish Rotten Rock" was a very strongly-bonded sand, similar to that known in the Midlands as "York Yellow," etc. Similar results could be obtained with Bentonite, but the amount of Bentonite he would have to use in the mix would be about one-sixteenth of 1 per cent., which was impracticable. He had to resort to a material with lower bond than Bentonite, but greater bond than the average moulding sand. The sands as shown were used for the tests, but to supplement the results he had obtained samples from other foundries, and the actual mixture type did not make much difference. If he used 98 per cent. old sand, and another 50 per cent., the results obtained were identical so far as the present investigation was concerned. With regard to the condensation of volatile matter, that could not happen in the laboratory tests, as the sand and tubes were at high temperature. In practice, Mr. Russell's theory would apply, as the mould surface was hot, and farther back the mould was cold. This would cause condensation, and probably reduce the permeability. His theory on the effect of coal dust could probably be explained as follows:—He assumed it was due to carbonaceous matter, so he had tried blacking and crushed coke breeze, and had thought he would get similar results as when using coal dust, but it was not so. Blacking did not prevent the rise in strength. Fifty per cent. breeze and clay gave no reduction in strength. Coal dust gives the reduction in strength, and this is probably due to the volatile matter present.

The metal, on heating the sand to temperature, caused a miniature explosion, due to the condition of the volatile matter in the coal dust, which shattered the bond and so caused the reduction of strength. One should, when adding coal dust, use a fine grade.

### The Question of Silt

Mr. S. H. Russell then asked how Mr. Hudson disposed of the silt in the sand.

Mr. Hudson said his theory of silt, so far as the ironfounder was concerned, was that it just did not form. It was put there by the foundryman. He had run for three years on his present mixture, and sieve tests were taken every week, which indicated that the silt was at least 40 per cent. lower than two years ago, and probably 50 to 60 per cent. lower than three years ago, when ordinary facing sand was used. Excess silt indicated uneconomic use of new sand.

### Coal Dust Replacement

Mr. T. Goodwin said the author's mixture showed 0.3 per cent. coal dust. What was the total percentage of coal dust in the mixture. Also, what was the reason for addition of wood extract to the mixture?

Mr. Hudson said that, as Mr. Russell had indicated, one could not get rid of coal dust, and he had found that 0.3 per cent. was all that was required to replace that burnt out. He maintained a figure of 10 per cent. coal dust by a batch addition of 0.3 per cent. The reason for the use of wood extract was as follows:—To obtain good castings the two important factors were green-bond strength and dry-compression strength. He had found that to get satisfactory castings he must have a green bond of 4 to 6 lbs. per sq. in., and he did not like the dried strength to fall below 50 lbs. per sq. in. The amount of new sand added was only sufficient to bring up the green bond. If he had to rely on new sand additions, the amount to be added to give the specified dried strength would bring the green bond too high. He added wood extract to get the correct dried strength, and in that way he was able to get the properties right.

### Silt Problem

Mr. F. Butters asked the weight of the castings being produced in the green-sand mixture, as he thought the silt question depended largely on the type and weight of castings being produced.

Mr. Hudson said the green-sand mixture was used on castings up to 10 cwts. in weight, but he pointed out that he had also given a dry-sand mixture with 98 per cent. old sand, which was used for castings up to 20 tons weight. He could not find any increase in silt, even with this sand. The dry-sand mixture was lower in silt than a year ago, and he did not have any large percentage of casting defects that could be attributed to the sand.

Mr. H. Bunting said the lecture had given a new line of thought, and asked whether the expansion of the sand gave a permanent growth to the grains, or did it decrease as the sand cooled off? Mr. Hudson had mentioned that an ideal sand would be one that would give a lesser degree of artificial venting. He (Mr. Bunting) was of the opinion there were more waster castings through the lack of understanding of venting than any other cause. Many moulders, in fact he would go so far as to say the majority, did not understand the idea of venting. Could Mr. Hudson give them a sand that would require no artificial venting?

### Seeking a Common Denominator

Mr. Hudson said the main object of his Paper was to give an idea of what was happening. He would say that in reality this was only half a Paper, the remainder to be published at some later date. Perhaps in the second part he would be able to tell Mr. Bunting how to make that foolproof sand, but he did not know at present. One would probably still have to rely on getting the excess air and gas away through some artificial channel. For the present, he had stopped attempting to decrease the permeability any further. In the course of collecting data for the Institute's Sand Sub-committee he had examined sands from all over the country, and was amazed at the variation of the properties of sands. He had seen large castings made in sands that were similar to those used in a light stove-grate foundry. One firm making large castings had a permeability figure of 200, and a firm making similar work had a permeability figure of only 25, and they both made good castings, but handled their sands in a different manner. The low-permeability sand was used with artificial vents and risers. Furthermore, where the sand had a low permeability number the workmen were trained to ram lighter. That was where the skill entered. At one time he thought he could produce a completely foolproof sand, but he had now nearly given up that idea.

### Gas Expansion

Mr. P. A. Russell said it was disturbing to find that Mr. Hudson was saying that the expansion of gas did not conform to the normal physical law, and he thought it would be interesting to see a theoretical curve; he thought it would add to the value of the Paper if that point was elaborated. Mr. Russell admitted that the evidence as to the action of coal dust was conclusive, and also that Mr. Hudson's theories were possible, but more possible in the mould than in the experiments. Did Mr. Hudson intend to indicate these explosions take place at a certain temperature, say, for example, 400 deg. C.? In that case, one would not expect increase in strength up to the point of the explosion. Referring to silt, it was possible to be misled. His firm were using clay-bonded sands, and he understood that it was from clay that silt came, and it was never possible to eliminate silt.

### Silt Reduction

Mr. Hudson said the point of theoretical calculation had already been taken up strongly. Mr. T. R. Walker, of Sheffield, had supplied him with steelfoundry compo for the tests, and he had seen the results and had raised the same point. He (Mr. Hudson) thought it better to do the work in a practical manner instead of by theoretical calculation. In his test, using the Richardson permeability apparatus, the air was passed through, due to displacement of water. He was not clear whether he was getting small particles of moisture going through with the air. If it existed as water vapour, the law should still apply, but not if one had fine particles of water held in suspension. He had thought it advisable to adhere to practical conditions, as far as possible. There was possibility of climatic conditions requiring consideration; for example, fog might drift into the shop. Could fog be classed as a perfect gas? It was suggested that he should heat up the air to 1,000 deg. C. and pass it through the specimen, but it was difficult to pass hot air and control it. Furthermore, as all sands contain carbonaceous matter, he thought he would get CO and $CO_2$ coming out, which would increase the expansion due to heat alone, and this was not adequately taken care of in theoretical calculations.

With regard to artificially-bonded sand and the silt question, he did not think the foundry need utilise artificial sand to prevent the formation of silt. He thought intelligent sand control would go a long way to prevent the formation of silt. The average foundry used a too-heavily-bonded sand. The clay grains, so far as size is concerned, come into the silt classification, and one can only distribute a certain amount of clay around a silica grain. If one had too much clay, it reduced permeability and caused a large percentage of fines. If every foundry put in sand control and made tests, they would be in a position to reduce silt by using a sand with lower green strength. He was convinced the solution of the silt problem was systematic sand control.

Mr. H. Sanders asked what was the amount of new sand used per ton of castings produced.

Mr. Hudson replied that the figure was approximately 0.03 to 0.06 tons of new sand per ton of castings.

Mr. J. F. Driver (Branch-President) asked whether the viscosity of the air at high temperature had anything to do with permeability figures. Also, he thought Mr. Hudson had not answered Mr. Bunting's query as to whether growth of sand grains was permanent, and he also was interested to hear the answer to that question.

Mr. Hudson said he could not say anything about viscosity of air. That was a point he had not considered in the tests. He apologised for omitting Mr. Bunting's question. The expansion on sand grains was not completely permanent, but partly so. Silica goes through changes, and they are dependent on time and temperature. Theoretically, if silica sand was heated up to 1,000 deg. C., there would be a change at about 870 deg. C. His tests had indicated a partial reduction in expansion after cooling, but not complete.

## Vote of Thanks

Mr. A. E. Peace, in voicing the thanks of the meeting, said it was not necessary for him to stress the excellence of the Paper, as that had been done so well by those taking part in the discussion. It might be of interest in connection with the amount of new sand, that he was recently in a foundry where they literally used no new sand, but in particular, green sand, which was made from burnt core sand. Whether that foundry were influenced by the facts of preheating, he did not know. There was one question he would like to raise, and that was whether the degree of ramming for the test-pieces was similar to foundry practice.

The vote of thanks was received with applause.

MR. HUDSON expressed his appreciation, and said he got a good deal of pleasure in coming down to give the Paper. Before replying to Mr. Peace, he would like to make a further remark in regard to Mr. Bunting's question of a foolproof sand. This was the effect of mould and core facings on permeability. Some tests he had conducted for dry sand and oil sand showed the average blackwash completely sealed the pores. A test-piece might give a figure of 200 A.F.A. permeability, but after blackwashing the permeability would drop to a figure of 6. What was the use of a permeable sand if one coated it with a wash that was impervious? In reply to Mr. Peace, all test-pieces were rammed to a density to correspond with their normal practice.

## COMMUNICATIONS

### From Mr. T. R. Walker

### Gay-Lussac's Law

MR. T. R. WALKER wrote :—I have been looking through your Paper and find myself unable to follow your reasoning and remarks regarding the increase in volume of air on heating. For instance, you state that "2,000 cc. of air at normal temperature and pressure" (by which I understand the temperature of 0 deg. C. and 760 mm. pressure) becomes nearly 6,000 cc. at 500 deg. C. and nearly 15,000 cc. at 1,000 deg. C.

Actually, air at constant pressure expands by $\frac{1}{273}$ of its volume at 0 deg. C. for each degree rise in temperature, so that at 1,092 deg. C. its volume will be 10,000 cc. against your 15,000. The expansion of air at constant pressure is at a constant rate, and, therefore, gives a straight-line graph, so that I do not quite see how you obtain the kinks shown in Fig. 4. I presume the explanation is bound up with the fact that you start with 2,000 cc. of air at ordinary temperatures and that as soon as you start passing it through the specimen it expands considerably, so that by the time 2,000 cc. of hot air has passed through the specimen there is still a good deal of the original cold 2,000 cc. left. It seems to me, however, that the only logical way of dealing with this is to heat the original air up to the same temperature as the test-piece and pass 2,000 cc. of this air through the specimen.

The Author then replied:—In regard to my remarks about Gay-Lussac's Law it should be understood that it is not my intention to dispute its validity except so far as the issues in my Paper are concerned. Under carefully controlled laboratory conditions the Law may be correct, but under the practical foundry conditions which my Paper is intended to represent, it cannot be accepted without reservations. I would consider that Gay-Lussac's Law is correct for a perfect gas. Unfortunately, under foundry conditions there are so many variable factors which upset Gay-Lussac's Law. Taking the effect of moisture in the air, you assume that the moisture exists entirely as water vapour. No doubt it does in the normal atmosphere. You do at times, however, get the moisture existing in the finely-divided liquid form. When this condition arises the water will be changed into steam as soon as 100 deg. C. is exceeded, with the consequent formation of a material having 1,600 times greater volume. Using Richardson's permeability apparatus, it is debatable as to whether or not the air being passed through the heated specimen contains water vapour or water particles in suspension. If the air contains any liquid-water particles it is perfectly obvious that this will effect Gay-Lussac's Law, and this was one of the reasons why we preferred to adopt the fine-bored silica-tube method for the determination of expansion rather than calculation.

Similarly, in regard to carbonaceous matter, the test specimen is being heated with a limited supply of oxygen, insufficient to cause a full gaseous reaction. However, when the air is blown through, excess oxygen is supplied which enables the combustible matter to react readily and form gaseous products of large volume. In regard to your query as to the heating time, it might have been mentioned that the total time to reach 1,000 deg. C. was about 5 hrs., giving an average of 30 min. time interval for each 100 deg. C. rise in temperature, 10 min. of this being spent maintaining the temperature at each test-point. As a matter of fact we conducted preliminary tests to ensure that heating was carried through to the centre of the specimen, and the above schedule was found to be satisfactory.

I am not in favour of the use of nitrogen alone, instead of air, for conducting the permeability test at elevated temperatures, as this is not representative of foundry conditions.

It is obvious, however, that from your comments, you have taken a considerable interest in the Paper, and consequently this is gratifying; whilst at the same time you have not produced any evidence to shake the conclusions reached, namely, that the reduction in permeability is principally due to the effect of gaseous expansion.

A second communication from Mr. Walker reads:—With regard to your remarks about Gay-Lussac's Law, I must disagree with you completely regarding the validity of this law at high temperatures. There is no doubt whatever that all the permanent gases obey this law to a far greater degree of accuracy than you could possibly determine in your experiments, to a much higher temperature than 1,000 deg. C. Constant-pressure gas thermometers have been constructed and are employed for the accurate measurement of high temperatures, and in this connection the coefficients of expansion of most of the permanent gases have been determined repeatedly with very close agreement in the results. For example, Jaquerod and Perrot determined the expansion of air from 0 deg. C. to 1,067 deg. C. (the melting point of gold) and found the value of the coefficient to be 0.0036663. This is almost identically the same figure as is obtained for the coefficient of expansion between 0 deg. C. and 100 deg. C., showing that the expansion of air between 0 deg. C. and 1,000 deg. C. is, for all practical purposes, at a uniform rate.

You refer in your letter to the effect of moisture in the air as being sufficient to upset the law. Actually, the coefficient of expansion of water vapour between 0 deg. C. and 247 deg. C. is given in the Smithsonian tables as 0.003799. This figure is somewhat greater than the coefficient of expansion of dry air, but it diminishes as the temperature rises, and above its critical temperature, which is 347 deg. C., it rapidly approaches the coefficient of expansion of the permanent gases.

I notice that you also refer to the presence of combustible matter in the moulding materials vitiating the results of volume calculations, but surely, if combustible or other matter is volatilised during the period of heating, or during the period of standing at a constant temperature (which latter time, incidentally, I feel is much too short to ensure uniformity of temperature throughout the specimen), it will escape, since the specimen is presumably in contact with the external atmosphere, from a pressure point of view, except when the test is actually being carried out?

It is true that any carbonaceous matter present in the material at high temperatures will be oxidised by the passage of heated air through the specimen, but this could be obviated by using nitrogen as the gas to be passed through instead of ordinary air. In any case, at the high temperatures you are using, the carbonaceous material will mostly consist of carbon itself, which, on oxidation, gives carbon dioxide of precisely the same volume as the oxygen which is used up during the process.

Returning to Figs. 3 and 4, assuming, for the sake of argument, that the smooth curve shown in Fig. 3 is correct as a record of the experimental result obtained, it is quite clear that Fig. 4, which is obtained from Fig. 3 merely by calculation, must also be a smooth line instead of a series of straight lines as shown. The fact that it has kinks in it is merely because you have taken only five points and joined them up by straight lines. Actually, there appears to be an arithmetical error in your calculated volume at 200 deg. C., which, by your own method of calculation (reading the value for the permeability from Fig. 3 as accurately as the size will permit), should be 3,220 c.c. instead of the figure shown in Fig. 4 of a little over 4,000 c.c. When this value is inserted and a number of other points are calculated, a smooth curve may be drawn through all the points, giving the result shown on the enclosed diagram. I think, on reckoning your own figures, you will agree with this point.

I quite agree with your remarks that there has so far been far too little work done on the properties of mould and core materials at elevated temperatures, and I am sure that this offers a profitable field for investigation.

To this the AUTHOR replied:—In regard to your letter of November 28, I am interested to note your remarks in regard to the expansion of air. As a matter of fact, we tried to calculate out, as you have done, the degree of expansion at 1,000 deg. C. using the law of Gay-Lussac. Unfortunately, the theoretical results obtained were nowhere near actual practice. After wasting a good deal of time, I came to the very definite conclusion that Gay-Lussac's law cannot be applied under the conditions adopted in my Paper. You will appreciate that even the moisture in the air is sufficient to upset Gay-Lussac's law when temperatures are employed of a degree sufficient to transform moisture into steam. In view of these variables, we decided not to employ the theoretical calculation, but to obtain a definite practical result by passing the air through a hot-silica tube such as outlined in the Paper and as recorded in Fig. 4. We also considered the idea of reheating the air up to the required temperature and passing the hot air through, as you suggest, but found that the control and measurement of this hot air was so difficult as to prevent its adoption. When all is said and done, the results given in the Paper come back to your argument, for, instead of passing 2,000 c.c. of hot air, we employed 2,000 c.c. of cold air, but by the previous determination of its expansion we can readily calculate the effect of 2,000 c.c. of hot air. Furthermore, I would remind you that when you pass hot air through a core containing combustible matter, although you may have measured the air very accurately, this measurement is of no value, due to the fact that the combustible matter in the core gasifies, and this upsets all your calculations.

### From Mr. A. Tipper

Mr. Tipper wrote:—

I expect you will be interested in the curve I enclose showing the theoretical expansion of air, Fig. A, with increase of temperature compared with the curve you obtained from the permeability readings.

With constant pressure this is, to all intents and purposes, a straight line, since dry air obeys Boyle's law very closely.

The correction for pressure is as follows:—

| Manometer pressure. | Correction factor. |
|---|---|
| 10 cms. | 1.00967 |
| 20 cms. | 1.0193 |
| 30 cms. | 1.0290 |
| 40 cms. | 1.0387 |
| 50 cms. | 1.0483 |

It is evident, therefore, that the practical results for true expansion will be slightly below the theoretical curve.

I was interested in the figures you gave for the core sand, and I note that you are using a 10 per cent. addition of Scottish rotten rock.

Tests we have made on this rotten rock have given a clay content of about 10 per cent., and I am wondering how you have obtained 3 per cent. clay in your core sand, as shown in your

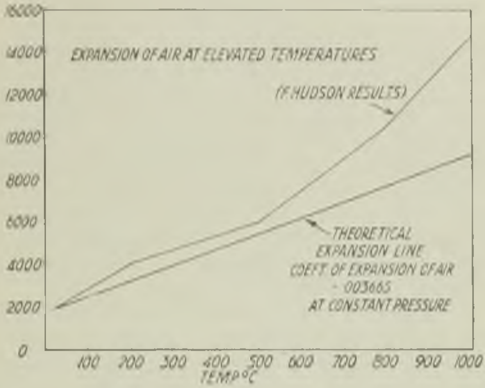


Fig. A.—Theoretical and Determined Expansion of Air at Elevated Temperatures.

table of Sieve Tests, etc. I presume that the clay figures were obtained by the A.F.A. method, and not by elutriation.

I am of the opinion that the compression test for strength of baked cores is not nearly as satisfactory as transverse or tensile tests, though for the purpose of such work as yours the compression test is, of course, the most convenient. The compression strength of our test cores is usually in the region of 700 to 1,000 lbs. per sq. in., so I conclude you are working with a mixture having a relatively high green bond, but very low dry strength.

This will have a bearing on the very rapid drop in strength you obtained, even at as low a temperature as 300 deg. C.

This question of strength of cores at various temperatures is one which well merits further investigation, and I hope to do some work in this direction myself very shortly.

To this Mr. Hudson replied:—I might state that in first commencing our tests on the permeability values at elevated temperatures, we adopted the theoretical value for the expansion of air, but found too large a disagreement with practical results. Consequently the curve you enclose is an old friend. One of my principal reasons for actually determining the effect of air expansion was to see the exact relation with the normal permeability at room temperature, and there are several factors which could not be assessed theoretically. Likewise, your correction factors are familiar, but I decided to bring the results to second decimal place, as published in the Paper, in order to permit easy memorising, *i.e.*, 10 cms. 1.01, 20 cms. 1.02, etc. In other words, add 0.01 for each 10-cm. rise in pressure. The practical results for true expansion will be slightly *above* your theoretical curve and not below it, as stated in your letter.

In regard to your comments on the amount of clay in the oil-sand mixture, it should be noted that there are many types of sand in the rotten-rock group, and they usually contain from 8 to 20 per cent. clay by the A.F.A. method. On top of this the sea sand used is an inland deposit and is contaminated with clay from 0.5 to 1.5 per cent. If you take the top limits I have given, it will be found possible to obtain a clay content up to 3.3 per cent. in the mixture.

Your conclusions relative to my using a core-sand mixture having a high green-bond strength and low dry strength are correct.

The importance of core strength at elevated temperatures cannot be over-estimated, and I am particularly glad to see that you hope to do some work in this direction shortly. The rapid drop in the strength of oil sand between 200 and 300 deg. C. is an asset providing the strength at higher temperatures can be maintained at some limit, say between 50 to 100 lbs. per sq. in., to take care of the longer solidification periods common to castings of heavy section or metals having a high casting temperature such as obtained in the steel foundry.

# East Midlands Branch

## A COMPARISON OF SOME MELTING FURNACES IN A GREY-IRON FOUNDRY

By T. R. Twigger (Associate Member)

### Introductory

This Paper does not profess to be a complete guide to melting furnaces in a grey-iron foundry —its main purpose is to bring out points of comparison which appear to be of some importance. In addition it includes a more detailed reference to some newer types of furnace, with which the author has been intimately connected in two separate foundry departments, one operating continuously on centrifugal castings for piston rings, cylinder liners, brake drums and valve seat inserts, and the other operating on a non-continuous basis for a variety of sand castings.

### Choice of Furnace for Grey-Iron Melting

Apart altogether from economical considerations the choice of a melting unit appears to depend largely upon:—(1) Whether the quality of metal required, or the temperature requirements are such that certain melting furnaces are particularly suitable; (2) whether or not a continuous supply of molten metal is required over several hours or a complete working day, and (3) whether or not a large variety of different mixtures is required in relatively small quantities.

In some instances the above considerations may outweigh the extra operating cost of a particular melting process. It is obvious however that for any particular furnace steps should be taken to see that the operating conditions are on the most economical basis for that type of furnace.

### Sources of Heat

*Coal.*—On account of its abundance and the immensity of the reserves coal still remains the prime source of heat in this country. It has however been little used in its raw state—except to a small extent for air furnace melting, a method but little practised except for roll making in grey-iron foundries. Coal has, however, recently come into use on a considerable scale with the adoption of pulverised fuel furnaces of the Brackelsberg and Sesci types. Coal in the form of coke (cupola and crucible furnaces), gas (crucible furnaces), and electricity (arc and induction furnaces) still represents by far the greater proportion of the heat units generated in melting grey iron.

*Oil.*—Oil, the advantage of which is its controllability, is now a competitor, being used for crucible furnaces, and to an increasing extent at the present time for rotary and other types of melting furnace. There being little or no oil found in this country, and supplies of oil from coal being at present very limited, metallurgists are dependent upon external sources of supply. The position of doubt brought in by the introduction of a tax on fuel oil appears to have been clarified by the fact of the tax not being further increased on oil used for industrial purposes.

An interesting comparison of the cost of heat units in various fuels was given by T. F. Unwin* and is here reproduced.

In conjunction with the description shown on Table I there is of course another factor which enters into final costs and that is the thermal efficiency of the furnace. The author's opinion is that so far as grey-iron melting is concerned the desired efficiency can in general only be obtained with a furnace of either rocking or completely rotating types—with, in the case of combustion furnaces, the maximum recuperation of the waste heat.

### Basis of Melting Costs

In comparing the costs of melting by various furnaces, some clearly-defined method of deter-

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* Foundry Trade Journal, November 17, 1932.

TABLE I.

| Fuel. | Calorific value. | Cost per therm (100,000 B.T.U.) | B.T.U. for 1d. | Calculated at |
|---|---|---|---|---|
| Electricity .. .. | 3,413 B.T.U. per unit .. .. | 14.65d. | 6,826 | ½d. per unit. |
| Town gas .. .. | 500 B.T.U. per cub. ft. .. .. | 4.8d. | 20,833 | 2s. per 1,000 cub. ft. |
| Fuel oil .. .. | 19,000 B.T.U. per lb. .. .. | 1.83d. | 54,500 | 65s. per ton. |
| Producer gas .. | 150 B.T.U. per cub. ft. .. .. | 2d. | 50,000 | 3d. per 1,000 cub. ft. |
| Coke oven gas .. | 500 ,, ,, ,, .. .. | 1.8d. | 55,500 | 9s. ,, ,, |
| Coke .. .. | 11,000 B.T.U. per lb. .. .. | 1.46d. | 68,400 | 30s. per ton. |
| Coal .. .. .. | 13,500 ,, ,, .. .. | 0.79d. | 126,000 | 20s. ,, |

mining the melting cost per lb. of metal delivered is obviously necessary. Attention has recently been given to this matter by the Institute's Costings Sub-Committee.*

In the author's opinion, it is necessary in a foundry using several types of melting furnace that a separate melting cost should be determined for each particular furnace. In the works with which the author is connected a comparison of melting costs from different furnaces has been made during the past two years on the basis of the following items:—(*a*) Power; (*b*) fuel; (*c*) labour; (*d*) refractories; (*e*) depreciation; (*f*) repairs and maintenance; and (*g*) metal lost in melting. It will be noticed that these items follow closely the basis recommended by the Institute's Costing Sub-Committee. With regard to labour costs, it is fairly clear that the appropriate overhead charge should be added, although in cases where the overheads normally contain some of all the items given above, the overhead charges in arriving at the melting cost will be correspondingly reduced. It is considered better to determine the cost of molten metal delivered by the melting unit making no allowance for the yield of good castings, due allowance for this being made in the final cost figure, which will, of course, include moulding, coremaking, finishing, etc., in addition to melting.

It is obvious that melting costs depend very largely on the prevalent conditions—type of work, etc.—in various foundries; therefore, it is seldom satisfactory to compare the figures obtained in one foundry with those from another. It is, however, possible for any particular foundry using various types of melting furnace to obtain a fairly accurate comparison between the various units on the basis of the methods suggested above.

A comparison of some melting costs for various furnaces was given in a Paper† by J. E.

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* Foundry Trade Journal, November 8, 1934.
† J. E. Hurst. "The Cupola Furnace." Foundry Trade Journal, November 19, 1931.

Hurst a few years ago. These figures were obtained in a Continental works, and do not, of course, include the cost of the material.

*Total Melting Costs for 1 Ton of Material.*

| | £ per ton |
|---|---|
| Crucible furnace .. .. .. | 3.564 |
| Cupola furnace .. .. .. | 0.74 |
| Oil furnace .. .. .. .. | 1.86 |
| Brackelsberg furnace .. .. .. | 0.78 |
| Electric furnace .. .. .. | 2.6 |

## Cupolas

No attempt is here made to describe the working of this furnace, which has so long been recognised as the standard melting unit for grey cast iron. In spite of its relatively low thermal efficiency, it is usually considered the cheapest melting unit in general use. There is little doubt that in many instances the cheapness of melting and the general convenience of operation have been the cause of lack of attention being paid to the obtaining of maximum efficiency. Under conditions of strict control the cupola can be made to give over a period of many hours a supply of hot, clean metal of good consistency as regards composition, although frequently some slight changes may be necessary in the charges at various times in the day to offset variation in composition (especially in total carbon) which may occur according to the height of the bed in the cupola. This may especially happen at the commencement of a long blow, using a high coke bed in which case a quantity of steel is frequently added to the early charges.

Considerable attention has recently been focused on the subject of carbon pick-up. Results of actual tests were published in the report* of the Cast Iron Sub-Committee of the Institute presented to the annual conference in 1934. Personal experience has been that the quality of the coke has a considerable bearing

* Proceedings, Institute of British Foundrymen, Vol. xxvii, p. 76.

on the percentage of total carbon in the iron. Softer coke of the South Wales type gives an iron of maximum temperature, but there is a tendency to obtain distinctly high total carbon. Coke of the Durham type, on the other hand, which is usually harder and somewhat higher in sulphur, tends to give lower total carbon. In the author's experience, two types of coke are used; the proportions of these are usually kept the same, but they are sometimes varied as special conditions arise. In connection with the development of cupola practice, devices for ensuring a constant weight of air supplied to the cupola are becoming more common, especially in America.

The balanced-blast type of cupola as developed by the British Cast Iron Research Association appears to be gaining favour, 95 cupolas now having been converted or built for this type of working. Claims are made for greater economy of operation, and this, in spite of the higher bed which is necessary. It is claimed that 40 per cent. of the bed coke is recovered in good condition. Experience on the operation of balanced-blast cupolas will be found in a Paper by H. Shepherd.*

The author has no personal experience on balanced-blast cupolas, as his firm's cupolas are of the type which is more difficult to convert, and, owing to the restricted space between the foundry wall and the cupolas, the latter would have to be moved to another position.

The great disadvantage to which any cupola appears to be subject is the great difficulty of accurately separating charges of different composition. Some interesting experiments in this direction were recorded by P. A. Russell† in a Paper presented to the London and East Midland Branches last year.

The writer's experience in trying to separate metal charges in the cupola has been definitely

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* Proceedings, Institute of British Foundrymen, Vol. xxvi, p. 348.

† Proceedings, Institute of British Foundrymen, Vol. xxviii p. 482.

unsatisfactory, particularly when the charges have been fairly high in alloy additions; for example, charges of iron containing 1 to 1½ per cent. nickel and 0.3 to 0.5 per cent. chromium have shown less than half this amount when tapped from the cupola at the precise time which the alloy iron should have appeared. In the case of charges containing a large percentage of steel, there is often a considerable variation in the composition of successive tappings from a cupola, particularly if the latter is small.

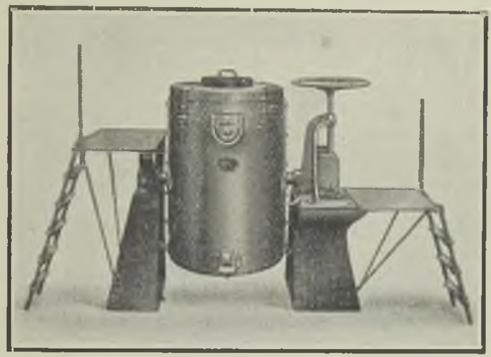


FIG. 1.—MORGAN OIL-FIRED CRUCIBLE FURNACE (CENTRAL-AXIS TYPE).

When melting charges of austenitic iron it has frequently occurred that not only has the supposed austenitic iron as tapped from the cupola had to be scrapped, but a considerable amount of the following material as well, owing to the high alloy additions which are found in the succeeding charge. Should it be necessary to melt a charge of austenitic iron during a day's run it is found better completely to "blow down" the cupola and add a fresh bed of coke before melting the charge of austenitic iron, but other methods of melting austenitic iron are now more common. In the case of the centrifugal foundry a charge of special mixture is sometimes run at the commencement of a blow, this special charge being separated from the standard mixture which follows by an extra charge of coke. With considerable care a high degree of accuracy is maintained, but generally the metal tapped immediately following the special charge is used for heating the centrifugal moulds.

### Rotary Pulverised Coal-Fired Furnaces

The author has no personal experience of the Brackelsberg or Sesci types of furnace, although both have been considered in relation to the foundry with which he is connected. The amount of pulverising and storage plant required, with its consequently large demand on floor space, also the high initial cost, appear to render its use of doubtful economy in the case of small installations. In the case of foundries melting large quantities of special grey iron or refined pig-iron, these furnaces appear to be capable of utilising cheap raw material to produce high-quality material at an economic cost. It is understood that in these types of furnaces the melting losses are always relatively low. Considerable trouble was anticipated in connection with the refractory linings, but information to hand is that a furnace of the Sesci type using a rammed lining of French material (mixture containing 6 per cent. moisture as rammed) gives, with a certain amount of patching during its working life, a total of from 200 to 240 heats on a 10-ton furnace and from 100 to 140 on a 2-ton furnace. This is for iron relatively low in carbon, which renders the operating conditions more severe. Also, the metal is frequently held for some time on account of adjustments of composition. It is considered that for normal types of grey cast iron the lining life should be in the region of 300 heats for the 10-ton furnace and 200 heats for the 2-ton furnace.

### Crucible Furnaces

In spite of the relatively high cost of melting in these units, due to the indirect transmission of heat and also to the fact that it is difficult to melt and superheat iron in less than about 3 or $3\frac{1}{2}$ hrs., these furnaces are used to the author's knowledge in some instances where the

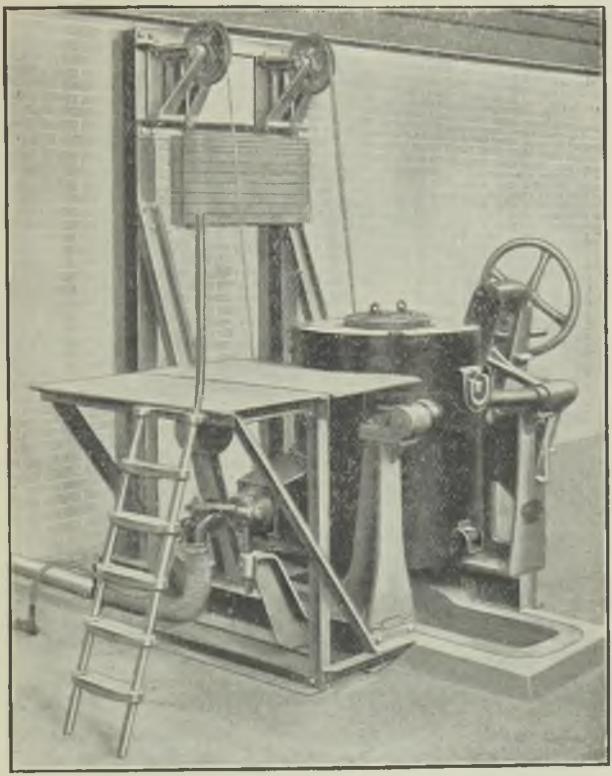


FIG. 2.—MORGAN OIL-FIRED CRUCIBLE FURNACE (LIP-AXIS TYPE).

iron is of a very special nature. They have the advantage of exact control of metal composition due to the absence of oxidation.

The oil-fired crucible furnace appears to score over the coke-fired unit for grey-iron melting on account of the greater certainty with which the desired high temperature can be obtained and the greater convenience in operation. These furnaces (typical modern examples of which are illustrated in Figs. 1 and 2) may be either of the lip-pouring or central-axis type. The lip-pouring type is naturally more expensive—but is of advantage in some instances, although in a grey-iron foundry provision can usually be made for withdrawing the metal on different levels, as, of course, happens with the central-axis type furnace.

In the British Piston Ring Company's foundry, oil-fired crucible furnaces are not used for melting except in very rare cases, but they have proved extremely useful in holding metal for use as required over a period of several hours. They frequently enable a special charge of metal to be melted in the cupola at the commencement of a blow and stored, thus furnishing a supply of molten metal which may be sufficient to operate one or more centrifugal casting machines, which run continuously for several hours on end. A method frequently practised is to melt a special charge, transfer it to the crucible furnace, and then use a percentage of the crucible-stored mixture with a percentage of standard cupola metal.

Under such conditions crucible life is normally approximately 120 hrs. for standard Salamander crucibles, but shorter life is, however, likely to be experienced if metal high in nickel or chromium is stored in the crucible.

### Rotary Oil-Fired Furnaces

A furnace of the Stein type, having a nominal capacity of 1 ton, is installed for use in the sand-casting foundry, which is not operated on continuous lines (Figs. 3 and 4). Obviously, one rotary furnace could not operate in a continuous casting foundry, unless used for duplexing on the principle of constant addition and withdrawal of molten metal. This furnace was installed largely on account of the difficulty of separating mixtures of different composition in the cupola. As will be seen from the illustrations, the furnace consists of a cylindrical shell

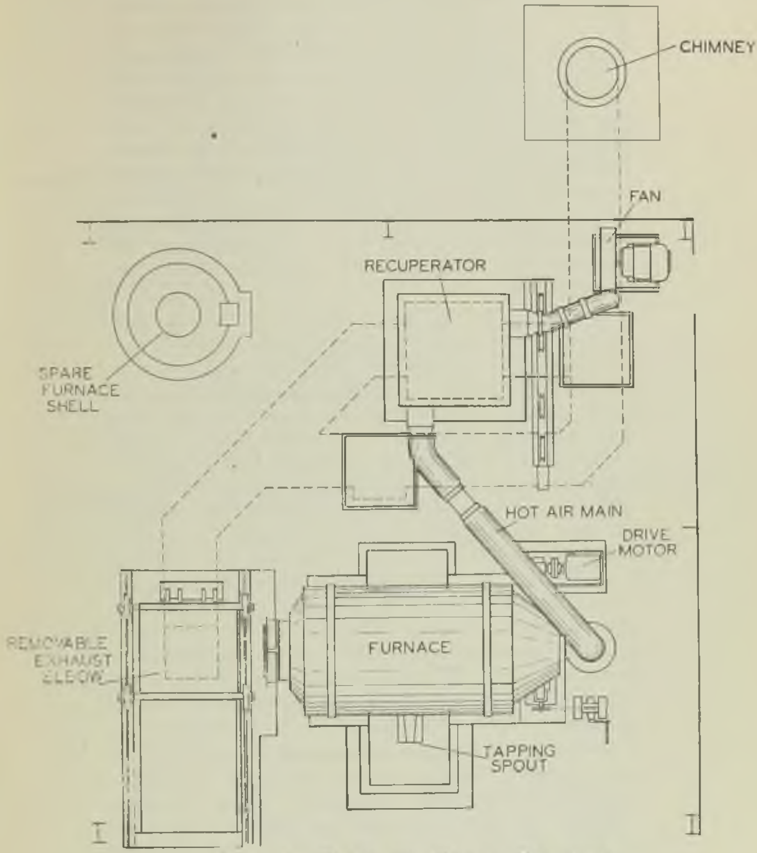



Fig. 3.—Plan of Stein Oil-fired Rotary-Furnace Installation.

having a special oil burner at one end with an exit at the other end for the products of combustion, which are conducted by a hood and elbow to underground flues, from which they pass into the recuperator. The latter consists of a brickwork chamber containing a series of "U"-shaped tubes through which cold air from the fan is blown, to be heated by passage through the tubes and then conveyed through the insulated pipe to the burner. When first starting the furnace, all the products of combustion go through the recuperator, but, should the temperature in the flue at the bottom of the recuperator rise above 900 deg. C., it is necessary to open the bypass flue so that some of the heat goes to the stack. It may also be necessary to close the flues leading from the recuperator.

In the case of the plant with which the author is connected, difficulty was at first experienced due to the fact that the temperature at the base of the recuperator quickly rose to 1,000 deg. C., necessitating restriction in the flow of heat through the recuperator, under which conditions the air preheat was considerably lower than it should have been. This is attributed to the fact that, as water was found at flue foundation level, waterproof concrete was used for the flues, and this has an insulating effect. The difficulty has now been eliminated by the use of an injector system, which uses a small jet of air from the fan to introduce a considerable volume of atmospheric air into the flue. By this means the recuperator temperature is restricted somewhat, but an air preheat of up to 300 deg. C. is obtained.

Owing to a certain amount of difficulty with the furnace charging door, which is normally opened for charging and kept closed during melting, the door was removed, and the furnace is now charged direct through a hole, 11-in. dia., in the charging end.

### Furnace Linings

The lining life presented one of the largest unknown factors in the choice of this furnace. It can be stated, however, that the present lining life is satisfactory, using British refractories. The lining, which is originally 10 in. thick, is worn down to about $2\frac{1}{2}$ in. thick before renewing. At the present time the practice is to chip back the remaining lining material and renew the lining by pneumatic hammer ramming with new refractory (the moisture content of which is carefully controlled at 6 per cent.). To renew a worn lining takes about $3\frac{1}{2}$

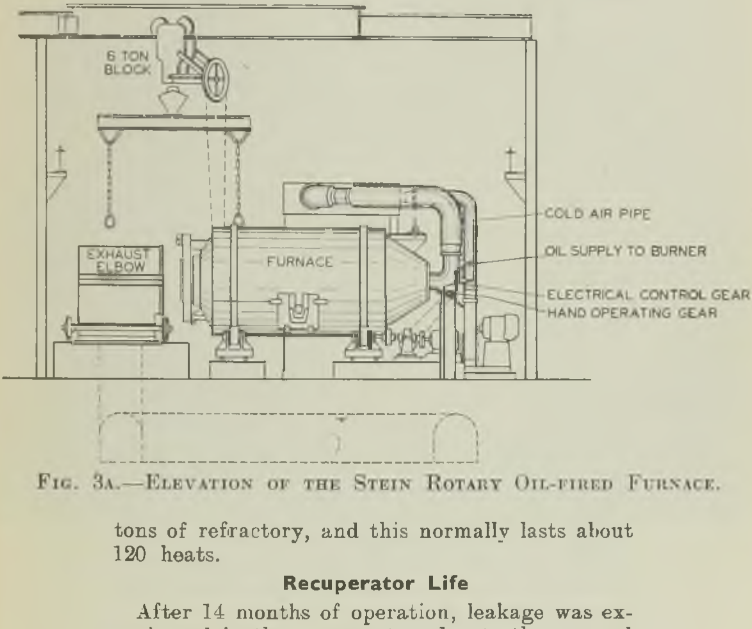



FIG. 3A.—ELEVATION OF THE STEIN ROTARY OIL-FIRED FURNACE.

tons of refractory, and this normally lasts about 120 heats.

### Recuperator Life

After 14 months of operation, leakage was experienced in the recuperator, due to the screwed joints at the bottom of the tubes having failed; the remainder of the tubes are, however, in satisfactory condition.

### Fuel Consumption

The fuel used is heavy fuel oil, averaging 0.92 specific gravity. It is pumped from the main storage tank into a service tank, which maintains a constant pressure to the burners. Electric heaters are provided in the service tank and also in the supply line to the burner. The fuel consumption over three heats per day averages about 18 to 20 per cent. by weight of the total weight of metal charged. This is for metal required to have a high degree of superheat as tapped from the furnace.

### Melting Losses

These are usually in relation to the length of time the charge is in the furnace; consequently the first heat, which normally takes $2\frac{1}{4}$ hrs., shows melting losses of approximately 0.5 per cent. carbon and 0.4 per cent. silicon; for subsequent heats the losses are reduced to 0.3 per cent. carbon and 0.3 per cent. silicon. This is for charges containing a considerable amount of small chippings (obtained from the fettling department of the centrifugal foundry). The losses are always considerably higher when using fine scrap. Finely-crushed gas coke is used to offset some of the reduction in carbon, but this should not be added to the extent of more than 2 cwts. per ton, this amount being sufficient to offset a loss of about 0.3 per cent. in the carbon content. Crushed petroleum coke has been used, but this does not appear to have any advantage over gas coke in minimising carbon losses. With the use of borings, the losses are very much higher, and charges of all borings do not appear justified, even when using a considerable amount of crushed coke. Incidentally, the charge has 60 lbs. of limestone added per ton to take care of oxidation products.

### Economic Considerations

To give the maximum efficiency with regard to fuel consumption, the furnace should be kept in regular use, melting not less than three heats per days (preferably four), in which case the first heat is charged overnight; this considerably minimises the preheat period. It is obviously inadvisable and uneconomical to hold the heat of metal in the furnace for any length of time while tapping. Careful records of cost obtained over a considerable period indicate that, provided the number of heats is not less than three per day, the melting costs are approximately similar to those of cupola-melted

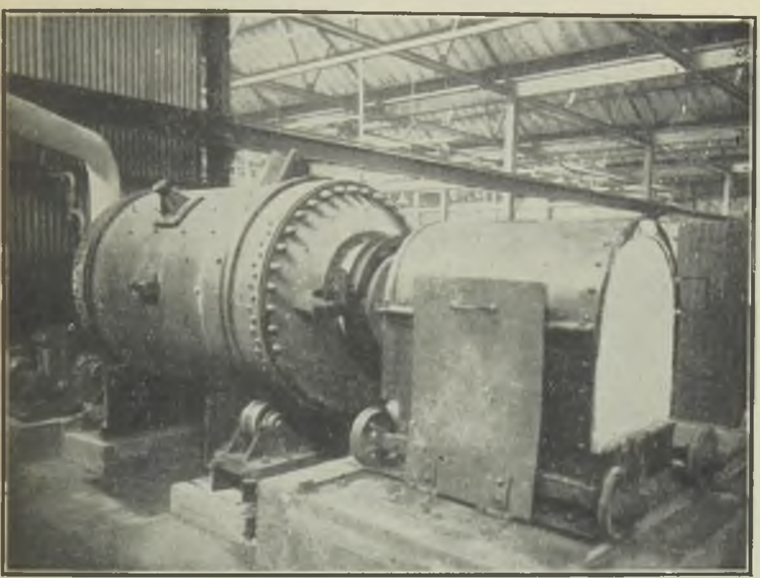


FIG. 4.—STEIN ROTARY OIL-FIRED FURNACE, 1-TON CAPACITY (RECUPERATOR NOT SHOWN).

metal of the same quality, but this is only true when the charge for the Stein furnace contains low saleable value scrap and low-price pig-iron, as compared with the use of higher-priced pig-iron or refined iron in the cupola.

**Electric Furnaces**

The direct-arc furnaces, as commonly used for the melting of steel, appear to be very little used in this country for cast iron. In America the " Lectromelt " direct-arc furnace is used on a considerable scale, together with the Detroit rocking indirect-arc furnace. The writer's experience extends solely to two furnaces of the latter type (50- and 350-lb. cold-melting capacity). The latter will be seen in Fig. 5. It is the L.F.A.-type furnace of 350 lbs. cold charge or 500 lbs. molten capacity. The furnace consists of a cylindrical shell lined with suitable refractory, the electrodes entering through suitable refractory sleeves on the axis of the furnace. On the small 50-lb. cold capacity furnace an ingenious rocking mechanism is employed, by means of which the angle of rock, which, of course, is very small, soon after charging cold metal, automatically increases to the maximum rock by the time the charge is melted, the principle being that much heat is transferred direct from the lining to the metal charge. In the case of the larger types of furnace, automatic rocking has not yet been developed, the angle of rock being gradually increased by variable stops controlling the angle of rock. Automatic electrode control has not been applied to the smaller types of furnace, as the advantage does not appear to outweigh the extra cost. Such mechanism could no doubt profitably be applied to the larger sizes of furnace. There appears to have been reluctance on the part of some electricity-supply authorities to permit single-phase operation, which is required with the horizontal arc furnace, from the multi-phase supply. It is understood that these objections are now being withdrawn. This has a considerable bearing on the development of this type of furnace, as a very costly transformer equipment is needed should single-phase current be desired from a multi-phase supply. Where there are a number of furnaces, individual units can be wired across separate phases. In the case of the furnaces with which the author is familiar, no objection has been raised to single-phase operation, and current is supplied at normal bulk-supply tariff, this rate applying provided the furnaces are not used between 4.15 and 5.45 p.m. during November, December, January and February. It is understood that other power corporations in the country have granted special concessions, which indicates a commendable desire to extend the use of electric power for industrial purposes.

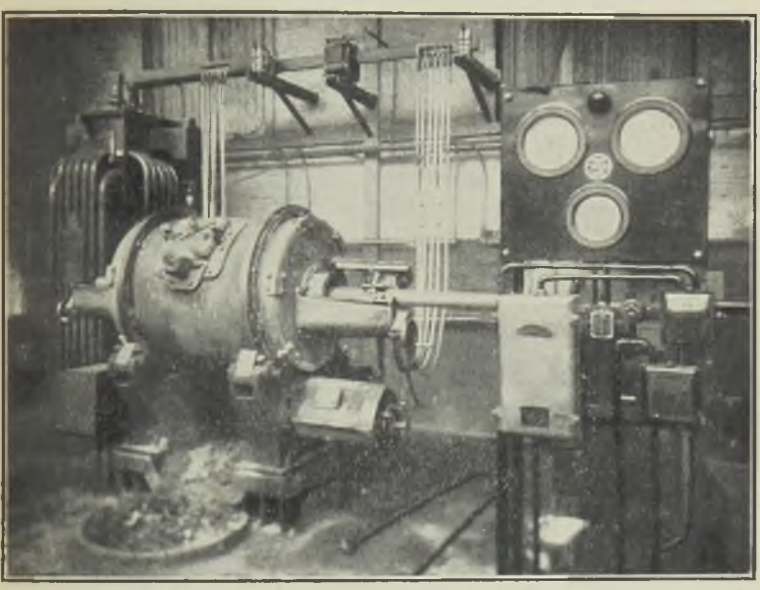


FIG. 5.—BIRLEC DETROIT ROCKING INDIRECT-ARC FURNACE (L.F.A. TYPE).

**Current Consumption**

In melting charges of grey cast iron in the L.F.A. type of furnace, the current consumption averages 650 kw.-hrs. per ton. This is for good melting conditions, where charges follow one another in quick succession, and this consumption is considered satisfactory for a small furnace. When duplexing charges, the current consumption naturally varies with the amount of solid material added and the degree of superheat desired.

### Melting Losses

One of the principal advantages of the rocking-arc furnaces is the close control which can be maintained over metal composition. The losses of carbon and silicon are extremely low, being virtually negligible except when the metal is held any length of time in the furnace. An example of the losses of carbon, silicon and manganese after 4 hrs. in the furnace is given in Table II.

TABLE II.—*Electric Furnace Losses.*
Cast U.59.

| | Fracture. | T.C., per cent. | Si, per cent. | Rockwell hardness value. |
|---|---|---|---|---|
| As charged into furnace .. .. | Grey | 3.38 | 2.03 | C.19 |
| After 1 hr. in furnace .. .. | ,, | 3.36 | 1.95 | — |
| After 2 hrs. in furnace .. .. | ,, | 3.28 | 1.89 | C.20 |
| After 3 hrs. in furnace .. .. | ,, | 3.34 | 1.81 | — |
| After 4 hrs. in furnace .. .. | Mottled | 3.20 | 1.72 | C.25 |

Where it is desired to increase the carbon content over that of the original mixture, crushed petroleum coke is added, and with hypoeutectic irons this is usually effective to the extent of 75 per cent. of the carbon contained in the coke.

### Lining Life

Linings of fused alumina, sillimanite, and rammed magnesite have been used for ordinary types of grey iron, and a lining of special magnesite bricks has been contemplated. The alumina or sillimanite appear to give satisfactory results on normal grades of iron—the life depending upon whether or not the lining is patched during its working life. It is understood that in America on furnaces which are patched each week-end linings have been in use two to three years. The sillimanite, and to a lesser extent the alumina, appear to be somewhat readily attacked by irons high in nickel and chromium. The best result so far attained is 150 heats for an alumina lining in the L.F.A. furnace. It is hoped by patching to obtain 200 heats before the lining is completely unserviceable. It is not general to use any flux in melting grey cast iron, although in the case of very dirty or rusty scrap some crushed glass may be used.

TABLE III.—*Re-melting Borings in the Electric Furnace.*

| | Total carbon, per cent. | Silicon, per cent. | Manganese, per cent. |
|---|---|---|---|
| Borings as charged | 3.35 | 2.25 | 0.88 |
| Melt as tapped .. | 3.14 | 2.14 | 0.84 |

## Economic Considerations

As with the oil-fired rotary furnace, it is not economical to utilise the furnace for holding metal for any length of time, largely on account of the current consumed, and partly because of the destructive action on the refractory material. Where it is desired to hold metal for any length of time, it is probably better practice to empty the contents of the electric furnace into a crucible furnace. It is obvious that a number of methods of using the furnaces are open to choice, amongst these being:—(1) Direct cold-melting; (2) direct cold-melting, mixing the electric-furnace metal with standard cupola iron; (3) duplexing cupola-melted metal with varying amounts of alloys and solid scrap, and (4) duplexing on the basis of constant additions of solid or molten metal and withdrawing the equivalent amount of molten metal.

As this type of furnace has a high capital cost it is obviously desirable to minimise idle time. In arriving at melting costs, the water used for cooling the electrode holders and the cost of electrodes must be taken into account, in addition to the general items mentioned earlier. As with the oil-fired rotary furnace it is obvious that the electric furnace can only compete with cupola melting when low-value scrap is used. It is understood that in America charges of 100 per cent. borings are sometimes used, although personal experience has been that a high percentage of borings has not been an unqualified success for important work.

## Conclusion

In the author's opinion the next decade is likely to witness the still further adoption of rotary furnaces for grey-iron melting and also a considerable extension of electric-furnace melting for high-grade castings. Electric-furnace melting would be greatly stimulated by a reduction in electricity charges. It will be realised that details of operation of various furnaces have not been exhaustively dealt with in this Paper, as the desire was rather to consider the principles underlying the choice of particular furnaces.

The author wishes to acknowledge his thanks to the Morgan Crucible Company, Messrs. Stein & Atkinson, Limited, and Birmingham Electric Furnaces, Limited, for illustrations supplied, to Messrs. Armstrong Whitworth, Limited, for information regarding lining life in Sesci furnaces, and to the directors of his own firm (the British Piston Ring Company, Limited) for permission to give this Paper.

# Sheffield Branch

## THE MANUFACTURE AND UTILISATION OF ELECTRIC STEEL IN THE FOUNDRY

By T. R. Walker, B.A. (Member), and C. J. Dadswell, Ph.D., B.Sc. (Associate Member)

### Historical

Although the production of large quantities of steel by electric melting is of comparatively recent growth, Siemens, as far back as 1878, took out a patent for an electric-arc furnace which, in its essentials, is very similar to the furnaces operated at the present time. The fact that this Siemens furnace was not used commercially was due, primarily, to the prohibitive cost of generating electricity at that time and for many years afterwards. It was not until the early years of the twentieth century that electricity became cheap enough to be used on a large scale industrially. About that time many types of electric melting furnaces were designed, utilising different principles, and the first electric steel manufactured in this country was made at the Vickers Sheffield Works in 1907. The furnace employed was a Kjellin furnace, which operated by utilising the heating effect of low-frequency currents applied to the charge. This furnace had a brief and undistinguished career, as it was uneconomical in operation and had the great disadvantage that part of the charge had to be left in the furnace to conduct the electricity for the following charge, so that it was impracticable to make successive charges of substantially different chemical analysis.

In 1910 the first Héroult furnace in this country was put down at Edgar Allen's works in Sheffield, and this was followed a year later by one at the Vickers Works. These furnaces were of the three-electrode type, using electric arcs, and arc furnaces of this and similar designs have been very popular both in this country and elsewhere ever since.

In the early days of electric melting it was commonly thought that good electric steel could be made from any type of raw material, whether this was good or bad. The same opinion was held shortly after the introduction of the basic open-hearth process, but in each case it has been found subsequently by experience that the manufacture of good steel by the basic process demands good raw material and care at each stage during its manufacture.

### Steel for Castings

From a foundry point of view, steel which is to be regarded as good should lie quietly in the moulds without any evolution of gas, it should be fluid over a wide range of temperature, and it should not attack the mould materials. To some extent these requirements are incompatible. If the mould material is not to be attacked, the steel should be poured at as low a temperature as possible. This practice is likely to introduce difficulties in the way of short runs, cold shuts, cold laps and other defects, and also to lead to the occurrence of skull in a ladle after casting. Castings made from electric steel are, in general, small compared with those made from open-hearth steel, and this often involves a considerable number of openings and closings of the ladle nozzle. It is quite common, for example, for the nozzle of a 3-ton ladle to be opened and closed between 50 and 100 times during the pouring of a heat, and the steel must be hot enough and sufficiently fluid to allow this to be carried out. Where large numbers of small castings are made in this way, it is clear that if the steel is of the correct temperature at first, it will be cold by the time the last castings are poured, and if it is correct at the end of the pouring it will be too hot for the first castings run. This may lead to enlarged shrinkage cavities where the steel is too hot and cold laps or short runs where the steel is too cold, so that a compromise must be adopted to suit the various circumstances as well as possible.

The fluidity, "castability" or running life of electric steel is not entirely governed by the temperature. In some cases the steel may be extremely hot, but at the same time sluggish and difficult to run. It is then said to be "dazed," over-killed or too dead. This condition of the steel is extremely difficult to correct in any reasonable time when once it has been allowed to develop its occurrence, and must, therefore, be prevented by attention to detail throughout the operation of making the steel.

### Basic Electric Steel

Steel manufactured in electric furnaces may be made in furnaces with either an acid or a basic lining, the difference being that in the case of acid-lined furnaces no reduction of sulphur and phosphorus is possible, whilst with basic-lined furnaces a considerable reduction in these elements, particularly in the case of phosphorus, may be carried out. Electric furnaces with acid linings are coming into prominence in the United States, but acid electric melting has not hitherto been carried out to any great extent in this country. From a steelmaking point of view, therefore, it appears best to confine the Paper to basic electric steel. On this subject alone books have been written, very many different methods being available for the production of such steel, and in the time available it is proposed to refer to only one particular method of making basic electric steel, a method which has been found to give very good results. It is particularly suited to the production of carbon steel for castings, containing, say, 0.15 to 0.4 per cent. of carbon, which embraces the composition of the majority of castings made in English foundries, and it gives very good results when used for the manufacture of green-sand castings, which are ordinarily more difficult to make sound than castings made in dried moulds.

A brief outline of the steps taken in the manufacture of a heat of steel of the kind referred to is as follows. The charge is first melted, precautions being taken to prevent the oxidation of the iron which would yield oxides very difficult to remove subsequently. Next, any dissolved gases other than carbon monoxide, such as nitrogen and hydrogen, are removed by means of a current of carbon monoxide. The carbon monoxide remaining in the bath is then removed, the steel deoxidised and raised to the tapping temperature. Final additions are made and the steel tested on the furnace stage before being tapped and sent into the foundry.

### Contrasts with Open Hearth

In open-hearth practice the charge usually consists of a mixture of pig-iron and scrap, but in electric-furnace practice the charge frequently consists entirely of scrap, made up partly of runners, risers and waster castings, and generally containing a substantial proportion of steel turnings, frequently more or less oxidised. The melting of this charge is accompanied by the oxidation of the elements in it, this process being facilitated if the initial small bath of molten material is allowed to rise to a very high temperature. The bulk of the charge consists of iron, and during melting the other elements present, notably carbon and manganese, are oxidised before the iron, but if the content of these elements is allowed to fall to a very low figure the iron of the bath begins to oxidise, producing oxides of iron which are extremely difficult to remove, and give rise to very undesirable effects in the steel. Where turnings are allowed to accumulate in considerable quantities they should be stored under cover so as to reduce the surface oxidation, since any oxides in the charge will readily react with both carbon and manganese on heating.

Since the charge consists entirely of steel, it will naturally melt with a much lower carbon content than is usual in the open-hearth furnace, where a good deal of the charge consists of pig-iron. In order to provide enough carbon and manganese to protect the iron from oxidation, and also to provide a sufficiently high-carbon content for a boil, which will be referred to later, it is advisable to include in the charge powdered anthracite, ground electrode or ground coke, these consisting essentially of carbon, and also to include some manganese-steel scrap, or some ferro-manganese if manganese steel is not available. Most of the steel used in a foundry contains 0.2 to 0.3 per cent. carbon and for the manufacture of this sufficient materials containing carbon and manganese should be added to the charge to give a melting carbon of 0.4 to 0.5 per cent., with a manganese content of round about 0.2 per cent. Melting down should be carried out moderately hard, but not so quickly as to develop small lakes of highly-heated metal below the electrodes.

When the charge is melted a sample is taken for analysis and will give the carbon and manganese at this stage. The first slag is now made in the usual manner and dissolved gases, such as nitrogen and hydrogen, are expelled from the bath by a current of carbon monoxide. This carbon monoxide is produced by additions of ore, the oxygen in which reacts with the carbon of the bath, giving bubbles of carbon monoxide which are evolved as a gas.

### A New Viewpoint

It is necessary to eliminate dissolved gases as far as possible so as to avoid an evolution of gases when the steel is poured into the moulds. If the steel during casting contained a good deal of dissolved gases it would be unsuitable, particularly for green-sand work, since steam is evolved from the surface of green-sand moulds and a current of steam passing through the liquid steel would disturb the equilibrium of the dissolved gases, causing them to be evolved. In addition, any sharp excrescences in the mould would favour the evolution of dissolved gases in exactly the same way as a piece of material with sharp points will prevent the bumping or intermittent boiling of water in a flask.

The boil produced in the steel should be as vigorous as possible and the ore added should, therefore, be in lumps of, say, first size and not in powder form. A short brisk boil is far more valuable in driving out dissolved gases than a long slow boil, even although the reduction in carbon content, and consequently the amount of carbon monoxide evolved, is the same in each case. The amount of ore to be added per ton of charge naturally depends on the melting carbon and should be sufficient to reduce the carbon to such a figure below the final carbon content desired as will allow the difference to be made up by the addition of recarburising and deoxidising alloys. In any case, the carbon content of the bath must be reduced to such a figure as will enable dephosphorisation to take place, since a substantial content of carbon protects phosphorus from oxidation. If the scrap used for the charge consist entirely of waste material from the same foundry dephosphorisation is not important since the scrap will all be of the low-phosphorus type. Usually, however, the charge includes turnings derived from material other than that melted in the electric furnace, and in such cases dephosphorisation is advisable.

## Slagging Off

When the charge is entirely melted the bath is raised to a moderately high temperature. It must be made hot enough to ensure a complete separation of metal and slag, and also to allow the power to be cut off in a few minutes during the slagging operation without the bath beginning to freeze. For slagging off, the furnace is tilted slightly and the slag removed through the back door. It is important that this slag should be completely removed, since any small islands of slag remaining would allow rephosphorisation to take place, and would also take up a good deal of time in getting the second slag into condition.

At this stage the bath is saturated with carbon monoxide and contains other oxides, so that a sample of the metal will rise in the spoon and be full of holes. It is, therefore, necessary for reduction processes to be carried out. If a sample taken for analysis now shows that the carbon content is too low, some carbon is added to the bath in the form of powdered anthracite, powdered electrode or some other form of carbon with low ash content. At this point it is quite easy to deoxidise the bath, or in other words reduce any dissolved oxides present, by a sudden heavy dose of ferro-silicon. This eliminates other oxides but leaves as its product of the deoxidising process silica, the oxide of silicon, forming insoluble non-metallic inclusions in the steel which are very difficult to remove, and interfere seriously with the fluidity of the steel as cast. It is much better to carry out the deoxidation as far as possible with manganese, since this gives as a product of the process manganese oxide which can easily be decomposed and reformed, and is also easily moved from the bath into the slag and *vice versa*. The process is as follows: The manganese reduces oxides in the steel such as carbon monoxide and ferrous oxide, being itself converted to manganese oxide which then moves upwards into the slag. In the slag the manganese oxide is reduced by silicon to metallic manganese which returns to the metal bath. Here it reduces more oxides and is converted to manganese oxide which moves into the slag and is reduced to metallic manganese and so on. The production is thus carried out substantially by manganese in the metal and by silicon in the slag.

### Deoxidation and Desulphurisation

After slagging off, therefore, about two-thirds of the ferro-manganese required in the ordinary way for finishing, is added to the bath in lump form, the exact amount depending on the manganese content of the bath at this stage. Slag-making materials in the form of lime and fluorspar are added, together with some anthracite coal dust, this latter serving partly to hold the carbon content of the bath and partly to assist as an additional element in the reducing process. The slag quickly turns brown or black owing to the presence of manganese, and further additions of lime and fluorspar are made at intervals, as required, to keep the slag in condition. Small amounts of powdered coal are also added at intervals for the same purposes as before. Gradually, the slag begins to turn lighter in colour and steel-spoon samples show that the bath is becoming less wild. At the beginning of the deoxidising stage the steel is much below the temperature required for tapping. The steel should be heated only gradually during this stage. It should not be quickly raised to a very high temperature and kept there, since if the steel is very hot throughout the reducing stage, it is extremely difficult to maintain a proper control over the slag and metal conditions.

During the reducing process, as the temperature is rising gradually, it is often found that when a certain temperature is reached successive samples of the metal do not become less wild, in other words, the process of reduction is suspended. This is because the deoxidising power of manganese diminishes as the temperature rises until it is unable to reduce carbon monoxide. In this case it is impracticable to carry out complete deoxidation by manganese alone, and a stronger reducing agent must be used at the higher temperatures. This agent is silicon, and it is, therefore, necessary to add small amounts of powdered ferro-silicon to complete the deoxidation of the bath. This powdered ferro-silicon should be added at intervals and no more than is necessary for complete deoxidation should be used on account of its bad effect on the running life of the steel. At this stage it will be found that the slag lightens in colour very rapidly and finally turns white. Shortly after this it falls to a powder on being exposed to the air for a short time and the powder smells of acetylene. This falling white slag represents the final stage in the process of reduction, and it is important that the metal should not be maintained under this slag for longer than is necessary.

### Composition Adjustment

An amount of lump ferro-silicon, representing that necessary to give the silicon content required in the finished steel, is now added, and ferro-manganese, also sufficient to give the carbon and manganese contents required, is put into the bath, this amount being judged from the analysis of a spoon sample taken a few minutes before the addition. Throughout this latter period the temperature of the steel has been gradually rising and at this stage it should be just right for tapping. Its temperature is judged by taking a spoon sample and noting the time which elapses before the surface of the sample solidifies. The steel will be in good condition and the sample will solidify quietly without any evolution of gas. It is advisable now to verify the fact that the steel contains only a small amount of dissolved gases, especially if the metal is to be used for green-sand castings. It is, therefore, tested by pouring a sample into a small green-sand mould on the stage. The steel should lie quietly in this and solidify without any evolution of gas.

### Stewing

It sometimes happens, unfortunately, that there is some delay at this stage owing to the ladle not being ready, or cranes being busy, or to the fact that the foundry workers have not completed the closing of the moulds. It is important to realise that when steel is brought into condition and to a tapping temperature it is ready to come out of the furnace, in exactly the same way as a cake which is properly cooked. Any long period during which the steel is held at the tapping temperature under a falling white slag gives bad effects. If it is known in time that there is going to be a considerable waiting period, it is much better to delay bringing the steel into tapping condition, and not to obtain a white slag by the addition of ferro-silicon.

When the steel is sent to the foundry floor, it is good practice to cast two small rectangular castings, say, 2 in. sq. by 7 or 8 in. long, one in green sand and the other in a chill mould. These may be subsequently sectioned and afford valuable evidence regarding the soundness of the solidified steel. This is sometimes very useful when complaints are received that some castings

B A

FIG. 1.—TEST INGOTS FOR ASCERTAINING SOUNDNESS.

in a particular heat show gas cavities. These, of course, may be due to the condition of the steel, but they are frequently caused by errors in the manufacture of the moulds.

### A Control Method

Fig. 1 shows the sections of two of these small test samples cast from two separate heats of the same composition—in this case carbon steel, containing 0.35 per cent. of carbon. The sample "A" shows that the steel solidified soundly apart from the natural contraction cavity at the top of the sample. Sample "B," however, shows a number of gas holes, located chiefly under the surface of the sample. From these results it might be expected that castings from the heat represented by "A" would be satisfactory, whilst those from the same cast as "B" would be likely to show gas cavities.

Fig. 2 shows part of the rim of a cast wheel, the edge of the rim having been machined by the removal of a thin skin. A good many holes are visible which may, without further evidence, be due either to faulty steel or bad foundry practice. In this particular case the casting was run from the centre. In the same cast one or two other exactly similar castings were run from the rim by means of a tangential runner. In this latter case the number of pinholes was very much less than in the casting shown, so that the existence of these holes, in this case at any rate, is largely attributable to the method of casting adopted in the foundry.

## Typical Charge Sheet

The following is a typical history of a 3-ton electric steel cast for mild carbon-steel castings made by the process outlined above.

| | C. Per cent. | Si. Per cent. | Mn. Per cent. | S. Per cent. | P. Per cent. |
|---|---|---|---|---|---|
| *Specified analysis* .. | 0.20–0.23 | 0.4 max. | 0.8–1.1 | 0.04 max. | 0.04 max. |
| *Actual analysis* .. | 0.215 | 0.226 | 0.94 | 0.024 | 0.021 |

| | Lbs. |
|---|---|
| *Charge*—Carbon steel turnings .. .. .. | 5,264 |
| Foundry carbon steel scrap .. .. | 2,464 |
| Foundry manganese steel scrap .. | 336 |
| Total metal charged .. .. | 8,064 |

24 lbs. crushed coal }
70 lbs. lime .. } also charged.

Time.
2.35 Power on. Current approximately 6,000 amps. at 90 volts.
4.45 Clear melted. Sample analysed gave carbon 0.30 per cent. Voltage reduced to 60.
5.07 35 lbs. ore added in small quantities at a time.
5.17 Sample analysed gave carbon 0.12 per cent.
5.23 336 lbs. Manganese steel scrap added.
5.35–5.39 First slag removed
5.40 14 lbs. lump ferro-manganese added, followed by 110 lbs. lime, 20 lbs. fluorspar and 3 lbs. coal dust for slag making.
5.45 Slag brown/black. Metal spoon sample wild.
5.50 3 lbs. coal dust added.
5.55 4 lbs. fluorspar added.
5.58 Spoon sample analysed—gave carbon 0.18; Mn 0.60 per cent.—metal still wild.
6.01 6 lbs. coal dust and 8 lbs. powdered ferro-silicon added.
6.02 Slag lightening in colour—metal sample less wild.
6.05 30 lbs. lime; 8 lbs. powdered ferro-silicon and 6 lbs. coal dust added.
6.06 Slag dirty grey.
6.13 6 lbs. powdered ferro-silicon and 4 lbs. coal dust added.
6.20 Slag white. Metal spoon sample slightly wild—metal cool.
6.20 4 lbs. lime; 4 lbs. coal dust; 4 lbs. powdered ferro-silicon added.
6.21 28 lbs. lump ferro-silicon added for finishing.
6.27 27 lbs. lump ferro-manganese added for finishing. Slag white and falling.
6.35 Metal sample quiet and almost hot enough.
6.38 Furnace ready for tapping.
6.39 Furnace tapped.

### High Temperature and Poor Life

Earlier in the Paper reference was made to the fact that it is quite possible for steel melted in an electric furnace to be extremely hot and at the same time to be sluggish in running, the steel in this condition being said to be dazed or over-killed. Such steel is also referred to sometimes as being over-reduced. These latter two terms have the same significance, both referring to the removal of oxides and oxygen from the steel. The solubility of liquid steel for gases and oxides increases with rise of temperature, and if at a high temperature the steel is saturated with gases, these gases will come out as solution and be evolved on cooling, and also

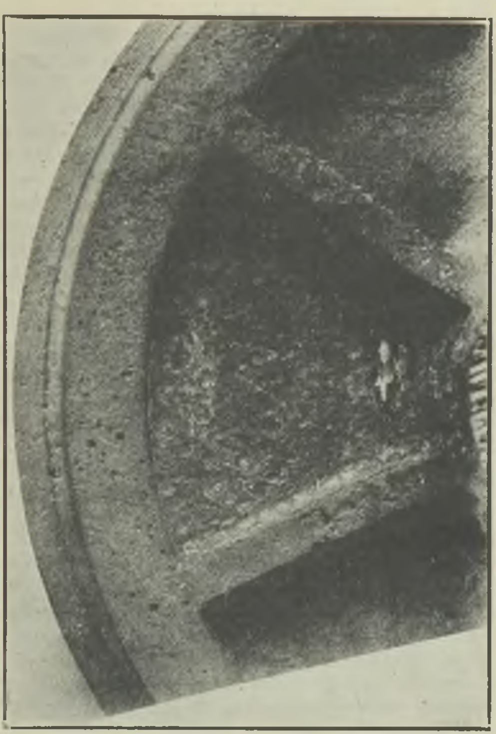


FIG. 2.—CAST WHEEL EXHIBITING BLOW-HOLES DUE TO METHOD OF RUNNING.

subsequently during freezing. The solubility of oxygen and of iron oxide in steel is only small. but if the steel is nearly saturated with oxide, this will react with the carbon present in the steel as the temperature falls, producing carbon monoxide as a gas. It might be considered, therefore, that the ideal condition of liquid steel would be one in which there were no oxides of metal present and no carbon monoxide dissolved. This is, however, by no means the case.

If steel be held under a reducing slag for a considerable length of time, oxides of various kinds are progressively reduced, and the total oxygen content of the steel falls to a low figure. This is the condition in which the steel, although extremely hot, may at the same time be viscous and difficult to pour into moulds so as to fill them completely. It seems, therefore, that it is necessary to have a small amount of oxides present in the steel, but these should be limited in amount and be present in such forms as do not interfere with the fluidity of the steel. Actually, a small content of oxygen and oxides increases the running life of liquid steel considerably, and this is, therefore, the condition to be sought in the production of steel for castings. This condition in which a small amount of oxygen is left in the steel, the amount being neither small enough to cause the steel to be sluggish nor large enough to permit of gas evolution during casting, is not always easy to arrive at with certainty. As a general rule, it is better to aim at having the steel somewhat too little reduced than over-reduced, so that there will be some slight tendency to the formation of gas cavities. This tendency is easily removed by the addition to the metal in the ladle of metallic aluminium; such an addition should be made with care, and it should never be necessary to add more than 6 ozs. of aluminium to the ton of steel. This addition will have a small effect in reducing the castability or running life of the steel, but this is much preferable to having a condition in which the steel is over-reduced.

### The Resultant Steel

From a foundry point of view, although the basic electric furnace can produce excellent steel, it can also yield steel with very poor properties. With ordinary furnace practice, however, there should be no difficulty in obtaining the mechanical tests called for in the usual specifications for steel castings. As has already been remarked, one of the most important requirements from electric steel for foundries is that it should have a long running life, since it is usually poured through the bottom of a ladle, the nozzle of which must be opened and closed a great many times during the filling of the moulds. As this property of running life or "castability" is so important in foundry steels it is quite time that steps were taken by the technical bodies concerned to standardise the use of some one word to describe it, since its value, whilst important, depends on many different factors, such as viscosity, temperature and chemical composition.

## Life Tests

Comparing basic electric steel with that made by other methods, in castability basic electric steel is probably not so good as Tropenas steel and acid electric steel; these latter two are very similar in this respect, though acid electric steel has the slight advantage that its temperature can be more easily controlled than that of Tropenas steel. Acid open-hearth steel is scarcely so suitable for foundry purposes as basic electric steel, again owing to the fact that the temperature of the basic electric steel can be more readily controlled, and in particular because, when required, the electric steel can be made very hot without losing its good qualities. Nowadays, acid open-hearth furnaces are not often used as small units for making steel castings. For example, a common size for basic electric furnaces is 3 tons capacity, whilst open-hearth furnaces seldom have a capacity less than 10 to 15 tons. In the case of the open-hearth charge there is, therefore, at the beginning of the pouring a very much greater head of steel in the ladle, and this naturally has important effects when the first moulds are being filled.

Reference must be made here to the manufacture of basic open-hearth steel for foundries. This has not hitherto been employed to any extent in this country, but is regularly used in America for making green-sand castings, some of which are about 5 cwts. in weight with a minimum thickness of half an inch, but it is in any case difficult to compare British and American foundry practice, since the requirements both of the foundry and of the inspectors are so different in the two cases.

## Green-Sand Castings

The manufacture of light steel castings in green sand is a somewhat specialised branch of foundry practice which is of increasing importance in this country, and there are various points which merit consideration when it is desired to make steel castings which from their nature appear to be on the border-line as regards possibility of manufacture in green sand. Some of these points are as follow:—(1) Adequacy in size and correctness of distribution of the runners, and (2) the provision of a sufficient number of whistlers and heads to enable the air in the mould and any evolved gases to escape.

These points may appear elementary, but they frequently receive insufficient attention when a new type of casting is to be made in a steel foundry specialising in green-sand work. There is often, for example, a tendency to multiply the number of feeder heads quite unnecessarily in making some types of complicated light castings now manufactured in large quantities in green sand. Beyond serving the purpose of adding to the fluid pressure of the steel in the mould during pouring and for a few seconds afterwards, and also as a means of collecting mould dirt and slag, these heads have very little effect subsequently in feeding the liquid steel whilst it is contracting, the reason being that many of the more complicated castings have thick sections joined to thin sections through which ordinary feeding is impossible. Apart from the weight of material involved in the use of an excessive number of feeder heads, there is a substantial increase in cost involved in removing them and in dressing the casting.

The soundness of these thick sections can be ensured with greater certainty by the use of internal and external chills. In this connection the following modification of moulding practice is frequently of appreciable value. When quantities of green-sand moulds are being made on a

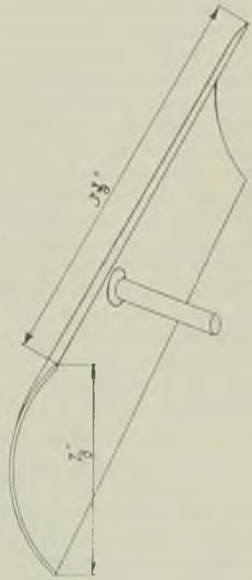


FIG. 3.—FORM OF STEEL SHEET CHILL FOR FILLETED POSITIONS.

jolting machine, and it is desired to introduce an extra chill into the mould, to place the chill on the pattern and to jolt it up with the sand usually gives unsatisfactory results, since the chill may be placed wrongly, and even if put in the correct position will probably be jolted out of place. In this case it is much better to put a print on the pattern and to introduce the chill into the mould during closing in exactly the same way as one introduces cores.

### Sheet-Steel Chills

Another method of chilling which is particularly useful for light sections where it is desired to carry out extra chilling in such places as fillets, is to have sheet steel, about $\frac{1}{8}$ in. thick, bent to the form of the mould and attached to the sand during closing by means of a sprig or spike welded to the sheet. A simple form of this type of chill is illustrated in Fig. 3. These chills can be manufactured very cheaply by pressing, and the cost of the press tools is small if a large quantity of similar chills are to be made for mass-production work. Such chills can be applied very easily to a green-sand mould during closing and have the additional advantage that they do not drop from the castings, removing in this way one source of danger to the conveyors where mechanical knock-out systems are in use. Again, the chills are so cheap that there is no need to collect them for repeated use as in the case of cast-iron chills, and if they are in an inaccessible position, for example in cores, they may be left in the casting without any ill-effects. Chills of this type are used in several foundries in America, but have so far not been utilised to any extent in British foundries.

### Medium Carbon Steel

Reverting to the use of basic electric steel in foundries, the most troublesome steel, as far as the occurrence of gas holes is concerned, is a carbon steel containing about 0.35 to 0.4 per cent. carbon. With this composition it is at times extremely difficult to avoid the formation of gas holes, especially in green-sand moulds, these very often taking the form of small pinholes. It is sometimes found with this type of steel that castings made in dry sand are free from this trouble, whilst those in the same cast made in green-sand moulds contain a good many pinholes, so that for some reason, which has not yet been satisfactorily explained, steel of this carbon is very prone to evolve gases. Trouble with carbon steel of this composition is not, however, confined to that made by the basic electric process, as when made by other methods it has sometimes proved unreliable in its properties.

The formation of pinholes, referred to above, is by no means to be ascribed to the use of green-sand moulds containing an excessive quantity of water, as it occurs even when the green sand contains less than 3 per cent. of water. One suggestion for the explanation of the formation of gas holes, especially in green-sand moulds, has been put forward by Mr. Lemoine, who maintains that if the turnings used in the furnace charge are wet, the moisture present on being heated to the temperature of the electric furnace, dissociates into oxygen and hydrogen, the hydrogen dissolving in the liquid steel. He suggests that if this hydrogen is not completely removed whilst the steel is in the furnace, the intense local heating of the surface of the green-sand mould produces dissociation of the steam evolved from the mould, thus giving a further amount of hydrogen which the steel is unable to dissolve, the additional amount being evolved as a gas. If, however, the charge is given an adequate boil as recommended earlier in this Paper any hydrogen dissolved in the bath will be removed, rendering pin-hole formation less likely.

### An American Theory

A theory very different from the above has recently been advanced in America to explain the formation of subcutaneous blowholes, claiming that they are due to non-metallic inclusions. It is suggested that when liquid steel fills a green-sand mould gases are generated which try to escape through both the mould material and the liquid steel. At first it is easier for them to escape through the mould material, since the steel skin formed quickly on the surface of the mould is supported by the ferrostatic pressure of the liquid steel inside. As the mould becomes heated the gas pressure increases. The envelope of steel solidifies at a much higher temperature than the inclusions, and it is suggested that at some time during this period a small amount of mould gas is able to enter the casting by way of the still liquid inclusions.

## Cracks in Castings

Turning now to the occurrence of cracks in foundry steel, basic electric steel, at least in the case of the lower carbon steels, such as magnet steel and castings containing 0.2 to 0.3 per cent. carbon, gives much less trouble in this respect than steel of the same composition made either by the Tropenas or by the acid open-hearth process. The steel foundry with which the writers are connected is served by both basic electric and acid open-hearth steel, and the superiority of the electric steel in this respect has been very definitely observed. In order to suggest an explanation of the reason why electric steel is superior in this way it will be useful to recapitulate briefly the practices commonly adopted for controlling the occurrence of contraction cracks. These are as follow:—

(1) The composition and preparation of the steel in the furnace; (2) the selection of a suitable pouring temperature and a satisfactory pouring rate; (3) the careful preparation of moulds and cores to avoid undue stresses in the castings; (4) the use of chills and brackets; (5) the correct placing of runners; (6) the easing of the moulds and cores immediately after casting; (7) casting into moulds which have previously been warmed, and (8) careful consideration of the design of castings.

On many occasions when castings from the same pattern have been made in basic electric and in acid open-hearth steel, the only differences which could have influenced a tendency to crack have been covered by the first two factors enumerated above, all the others being eliminated since they are common to both processes. As a rule the temperature of the electric steel is somewhat higher than that of the open-hearth steel, so that to this extent the electric steel would be at a disadvantage compared with the open-hearth steel. The difference in chemical composition between the two charges is largely a matter of sulphur and phosphorus content, this being lower in the case of the electric steel, but as in general the sulphur and phosphorus in the open-hearth steel would not exceed in each case 0.04 per cent., it does not appear that a difference in chemical composition can account for the difference in behaviour of the two steels.

The electric steel is poured through the bottom of a 3-ton ladle, whilst the open hearth is cast in a similar way from a 15-ton ladle, and it might be thought that this difference was significant. Actually, however, experiments have been carried out in which the ladle stream from the 15-ton ladle has been interrupted, for example, by means of a tundish, without any improvement being secured in the results from a cracking point of view. It seems probable, therefore, that the preparation of the electric steel in the way described above, gives it in some way a distinct advantage over the acid open-hearth steel as far as cracking is concerned.

## Cost Reduction

It will be interesting at this point to consider the possibilities of reducing the cost of liquid electric steel supplied to the foundry. Where the scrap used for making up the charge is entirely derived from a foundry in which basic electric steel is exclusively used, the sulphur and phosphorus contents of the scrap are much below the specified maximum, and it seems in these cases a wasteful procedure to occupy time in dephosphorising. It would certainly be possible to tap the steel when the first slag had been removed, and the bath merely brought into condition for adding the finishings. In some cases the steel thus produced would be quite satisfactory for its intended purpose, but it must be emphasised that to save time it would be necessary to abandon the vigorous boil recommended earlier in the Paper, so that the steel produced would not be particularly suitable for the manufacture of light green-sand castings.

With the basic electric process, the modern furnaces have an appreciably higher melting rate than the older ones, but there is a limit beyond which the melting rate should not be pushed, and other considerations limit the voltages and electrode sizes which it is possible to use, so that when every consideration is favourable, there is a minimum cost of melting by the basic electric process which cannot safely be further reduced. These facts, together with the difficulties experienced in obtaining good magnesite during the late war, led many steel-foundries in America to investigate the possibilities of developing the acid electric process. A year or two ago there were over 250 acid electric furnaces in operation in the United States, and at present on the Continent they are becoming increasingly popular. The acid electric furnace is very suitable for the rapid production of small castings, especially in green sand, since, when properly prepared, the steel made in it has a considerable running life. On the Continent small furnaces of 1 or 2 tons capacity are employed for this type of work very successfully. Usually such furnaces are not made with a greater capacity than about 6 tons.

### Acid Electric Steel

The properties of acid electric steel have been investigated by Sisco, who claims that it is best for light castings, weighing 200 lbs. or less, especially where high production and economy of operation are of prior importance. He claims that it gives steel with a power consumption of about 10 per cent. less than that necessary in basic practice, whilst the cost of refractories is appreciably lower for the acid steel. It is, however, desirable to limit the application of electric steel to cases where refining is not necessary, where sulphur and phosphorus need not be particularly low, where there is a plentiful supply of good scrap, where the specified analysis permits of considerable variation, and where there is little call for alloyed steels. In addition, acid steel is applicable where the property of high surface tensions possessed by the acid slag is of importance, for example, in cases where it is desired to pour over the lip either of a ladle or of a shank.

In furnaces of the Héroult type all the electrodes are fixed above the surface of the bath, arcs being struck between each electrode and the bath. In electric furnaces of the Electro-metals type, on the other hand, one of the electrodes is situated in the bottom of the furnace, below the bath. Basic refractories of the magnesite type become sufficiently good conductors of electricity at high temperatures to allow the electric current to be conveyed from electrodes above the bath to an electrode underneath the bottom of the furnace, but acid refractories, such as silica, remain at high temperatures, insufficiently good conductors to allow the current to be conducted in this way. Consequently, although the change-over from basic to acid working is possible, in the case of Heroult and similar type furnaces, by changing the nature of the furnace lining, it is impracticable in the case of furnaces having a bottom electrode to adopt an acid lining, and this is probably one of the reasons why acid electric steel has made much less progress in this country than in the United States and on the Continent.

## DISCUSSION

### Green or Dried Sand for Steel Castings

Mr. S. Leetch said he had listened with great interest to the Paper by Mr. Walker and Mr. Dadswell. He thought that they had made out a very good case for electric steel and seemed to have anticipated a few of the drawbacks that one might mention, and had dealt with them faithfully. His own view about electric steel was that if one could shank it and carry it about the shop as they could Tropenas steel, it would be very convenient. Mr. Dadswell and Mr. Walker had referred a great deal to green sand, and its relative merits should be very carefully considered. Where one had light things, such as bolsters, to deal with, those with whom he was associated used green sand. Where a great deal of machining was to be done on a small casting, it was considered much better to build up the job in oil-sand moulds. One could then be sure of a good sand mould. The question of the steel being satisfactory could, in ninety-nine cases out of a hundred, be left to the steelmaker. One found one or two exceptions occasionally where there were pinholes and blowholes in castings. One might insist that it was the steelmaker's fault, but, generally speaking, a rising heat was a very rare occurrence in any foundry. When faults such as pinholes occurred, he thought they would be due either to the mould not being thoroughly dry, or the oven not being correct. This was something that one must look after oneself. He recognised that a great deal of work could be done on the subject of green sand, but to his mind the question was whether it was going to give the customer the same satisfaction as a casting made in dry-sand moulds. He (Mr. Leetch) was greatly interested in the use of the $\frac{1}{8}$-in.-thick chills to which Mr. Dadswell had referred. His own idea of chilling had been the conducting of the heat from the heavier portion of the steel, and thereby the equalising of the cooling and the rate of contraction. He was not quite sure whether the very light chill which Mr. Dadswell advocated would produce a nice clean face in the radius, but that, if one were to saw through a certain point, a distinct cavity might be found.

### Life of Electric Steel

Mr. Walker said that he, personally, had not had much experience of Tropenas steel for foundries, and was surprised that Mr. Leetch should be so anxious regarding the use of electric steel for small castings. The firm with which he (Mr. Walker) was associated found no difficulty in making, say, 150 manganese steel links, weighing about 4½ lbs. each, from a single charge, made in a 3-ton electric furnace.

With regard to green-sand and dry-sand practice, the advantage of green-sand moulding was that it was cheaper to produce green-sand castings than dry-sand castings. There was a saving of cost because moulds had not to be dried, but, apart from this, a good deal of time was saved in actual operations in the foundry. Moulds could be made and the castings poured a short time afterwards, so that the boxes could be knocked out and refilled again much more quickly than was possible if the moulds had to be dried.

### Advantages of Shanking

MR. DADSWELL agreed with Mr. Walker that they were very successful in making small castings from an electric furnace, but said that there were decided advantages in shanking. For example, shanking was useful for snap-flask work. With a mould made from a bumper squeezer machine in a snap flask without jackets they could not cast anything of, say, 3 lbs. to 4 lbs. with a bottom-pouring ladle, as the metal would burst out at the joints. At his works they were filling shanks from a bottom-poured ladle. They confined themselves to shanking about 25 moulds with each cast of 3 tons brought on the floor for other work. The jar squeezer machine was a useful adjunct to the foundry for making small castings, which one accepted on sufferance sometimes in order to get bigger orders and which were very costly if built up in cores. He agreed that it was inadvisable to cast too many castings off the same runner because it was difficult to get them all sound by that method.

### Green-Sand Work Shows Economies

As far as using green or dry sand was concerned, there was a very large saving in using green sand. In regard to external chills, these were useful from two points of view—they prevented cracking and helped soundness. In regard to Mr. Leetch's reference to American green sand, he agreed that their castings were rough, judged from English standards. In fact, English inspectors would not accept them. At the same time, they were often good enough for the job for which they were required. As long as the casting was sound, what did it matter if it were a bit rough when placed, say, underneath a wagon? He believed that one of the reasons for the American castings being rougher was that the Americans cheapened production considerably by reclaiming sand. In many of the mass-production foundries on railway work in America hardly any new sand was used, perhaps 10 per cent. of new sand being used only. In England they used a better-quality sand than the Americans, and consequently made better-finished jobs, but at a greater and unnecessary cost.

### Steam and Soundness

Mr. E. J. Crawley asked for some explanation relating to the encouragement which steam from green-sand moulds gave to the evolution of carbon monoxide in castings.

Mr. Walker said that green-sand moulds contained water which, on being heated to 100 deg. C., vaporised to form steam. That steam, if sufficiently heated, would dissociate into oxygen and hydrogen, but the percentage of dissociation at the temperatures reached in the moulds would be negligible. If, however, the steam came into contact with liquid steel containing a substantial amount of dissolved gases, a considerable portion of the gases would be evolved. What happened could be compared with the passing of a stream of air into a solution of carbon dioxide in water. Carbon dioxide was very much more soluble in water than air, and the result of passing in the air would be that nearly all the carbon dioxide would come out of solution, leaving behind a saturated solution of air containing much less dissolved gas. If afterwards a stream of carbon monoxide, which was practically insoluble in water, was passed into the air solution, the air in turn would be driven out and at the end there would be very little gas left in solution in the water on account of the very low solubility of the carbon monoxide. In the same way, steam passing through liquid steel which was saturated with gases would have a mechanical effect resulting in the evolution of some of the gases as such.

### Metal Handling

Mr. J. Roxburgh said Mr. Walker had shown them the head of a casting that had a skin of high carbon, and stated that it was due to the absorption of the facing which had been used on the green-sand mould. He wondered whether it was possible in the steel foundries to cast into green-sand moulds without using blacking. Then Mr. Walker had referred to the fact that they were casting a great number of castings from a 3-ton ladle. He wondered if it would not be possible to divide the metal in the first place into three separate ton ladles, and thus get rid of it in a much quicker time. He would also like to know what Mr. Dadswell would say was the largest section of casting that he had made in green sand.

### Why One Ladle is Used

Mr. Walker said that no blacking had been put on the green-sand moulds at all. He had shown slides illustrating the effect of surface-blacking on a mould merely as an item of interest. Regarding the suggestion that a 3-ton charge could be poured into a ladle at intervals and used in separate portions, he explained that when the furnace was tapped, the steel was run into the ladle until all the steel came out and was covered by a layer of slag. This slag served a very useful purpose in keeping the steel hot. If a portion of the charge was run out instead, it would have no protective covering of slag and would cool down very rapidly when it was taken into the foundry.

### The Largest Green-Sand Casting

Mr. Dadswell, dealing with Mr. Roxburgh's question relating to the largest section of casting made in green sand, said they had made one of 15 cwts. in weight, and about 1 in. thick. Large flat surfaces in green sand were not so easy to obtain satisfactorily.

Mr. Leetch said that at his works they made 2-ft. 9-in. wagon centres in green sand.

The authors of the Paper were accorded a vote of thanks, on the proposition of Mr. Leetch, seconded by Mr. Roxburgh.

# Sheffield Branch

## SAND- AND SHOT-BLASTING

By J. H. D. Bradshaw (Associate Member)

Sand- or shot-blasting is the term usually employed to describe a process for cleaning castings, stampings and other objects. It consists essentially of the introduction of sharp-edged quartz sand or steel grit into a stream of compressed air. This stream of abrasive and air enters a nozzle, in which its energy is converted into speed, serving to throw the particles of abrasive against the surfaces to be cleaned. Owing to their sharp edges and hardness, the abrasive produces a somewhat rough or etched effect by removing small pieces of material, during which action the abrasive itself undergoes destruction.

The origin of sand-blasting is not known with any degree of accuracy. It is, however, claimed that an observant traveller saw the commercial possibilities in the action of sand blown across the face of the Sphinx. With the historical aspect of the subject, the present Paper will not deal; sufficient for the purpose to say that, whatever the origin, it has developed into a great labour-saving industry, which provides a finish entirely unobtainable by any other method, and in addition, for some processes, is absolutely essential.

### Common Applications

Some of the more common applications of the process are the cleaning of all metallic objects. Castings may be treated to remove sand, etc., while scale, grease and other foreign matter may be removed from stampings or forgings in order to produce surfaces suitable for painting, enamelling (vitreous or synthetic), plating, galvanising, rustproofing, sherardising, or metal spraying. It is also used for the cleaning of ships' hulls, the matt-surfacing of metals, roughing the handles of instruments and tools, etching of glass and marble, and for producing a rustic effect on the surface of building bricks, also on wood in order to develop the grain and give an appearance of antiquity.

As outlined above, the discharge of abrasive is usually through a nozzle, but the manner of application to the object to be treated is of many forms, in order to meet varying conditions and requirements. In some remote operations steam is used instead of compressed air, while recently-introduced machines dispense with both.

### Systems Generally Used

Dependent upon the way in which the abrasive is mixed with the compressed air, three different systems can be recognised:—(1) The suction system, in which the abrasive is aspired; (2) the gravity system, wherein the abrasive falls into the nozzle by gravity; and (3) the pressure system, in which abrasive and compressed air are mixed in a chamber and the mixture subsequently carried to the nozzle.

### The Suction System

In this system the discharge unit consists of a discharge nozzle projecting from one end of a mixing chamber, into the other end of which is fitted an air nipple. A suction pipe leads from the atmosphere past the sand-control valve to the side of the mixing chamber. The sand-control valve communicates with the sand bin. Pressure air is fed by a separate pipe direct to the air nipple, discharged into the mixing chamber, there depressing the pressure below atmospheric, with the result that air from the open end flows along the suction pipe, picks up the abrasive material, and carries it to the mixing chamber. There, pressure air, suction air, and abrasive are mixed, and finally expelled through the discharge nozzle. The abrasive used during projection falls on a sieve, which retains any large impurities, and from this sieve it returns to the sand bin. From the sand bin the abrasive is again drawn into the nozzle. The circuit of the abrasive is therefore a closed one, and the system is automatically continuous in operation, but, owing to the abrasive being introduced into the air stream at or near the point of discharge, the delivered pressure is actually below gauge indication, with consequent decreased velocity.

In order to minimise the production of large clouds of dust, which usually accompanies sand-blasting (using sand as abrasive), two iron sheets covered with rubber plates are sometimes placed inside the machine in an inclined position. The spent abrasive strikes these plates and falls to the bottom of the machine, where it is then out of reach of the air current. It is also important that a good exhaust is continually maintained within the apparatus in order to prevent escape of dust. The disadvantage of the suction system is that it requires considerably more power than any other blast system.

An apparatus employing the suction system is the so-called "Midget Barrel," which is particularly suitable for cleaning small articles (*e.g.*, screws). This barrel works in an inclined position, and at the bottom is provided with a perforated cone, which facilitates rotation of the work being treated. The drum itself revolves round a hollow shaft, which conducts dust and abrasive into a receiver. The dust is drawn away and the abrasive returned for further use. The advantage of this machine lies in the small space required and the facilities it offers by continually turning the work being treated.

### The Gravity System

This is somewhat similar to the suction system, the chief difference lying in the fact that the abrasive is fed to the mixing chamber under the influence of gravity, additional to any suction effect. As in the suction system, the abrasive is mixed with the air immediately prior to entering the nozzle, but in this system produces more efficient operation accompanied by less wear.

The gravity system is generally employed in revolving drums and rotary tables. Drums are more economical in use and give a greater output than rotary tables. This is largely due to the fact that the articles being treated are in layers, and the ability of the abrasive to penetrate into the spaces, thereby resulting in better utilisation of the jet.

The main objective in rotating the drum is slowly to turn the objects being cleaned in order that the stream of abrasive may reach everywhere. For this reason, drums are generally designed to turn rather slowly (about 1 r.p.m.). The abrasive is sieved before entering the nozzle, and is employed until completely destroyed. It is then removed as dust and simply requires replacing with new material. This is generally added by means of a shovel at intervals. The operator has simply to fill and discharge the machine.

Another apparatus employing the gravity system is the rotary table. The table of the machine is covered with a movable iron grid, the surface of which is sprayed by one or more nozzles. In operation, the articles to be cleaned are packed closely together on the table, and after exposure to the jet are turned round in order to be cleaned on the other side. These machines generally present the inconvenience of not being entirely dust-proof, in addition to which they are not particularly efficient owing to the fact that it is practically impossible to pack the table in such a manner that open spaces are completely avoided.

Furthermore, the action of the nozzles cannot be used to their full extent on these machines, owing to the fact that the same spots are continuously being hit. In view of the above remarks, it is clear that only flat objects can be economically cleaned on rotary tables. A cube, for instance, may have to be turned six times in order to be cleaned all over. An improvement is obtained by arranging the nozzles so that they describe a circular movement in a slightly inclined plane.

An elevator is usually employed on machines working this system, to carry the abrasive to the sieves, from which it again falls to the nozzles.

### The Pressure System

The best outputs are undoubtedly obtained with the pressure system, but, unfortunately, it has the great disadvantage of subjecting various parts of the apparatus, *e.g.*, abrasive carrying pipes, to excessive wear. In this system the abrasive is contained in a closed pressure chamber to which is fed pressure air, and from which a mixture of air and abrasive passes through a control valve into a pipe line in which pressure air is flowing, the whole being discharged through a nozzle at the end of the pipe.

The higher efficiency of this system is due to the fact that the abrasive itself is under pressure, whilst the great advantage of the method is that the blast pressure is not reduced by the introduction of secondary air at atmospheric pressure, which is the case of both the gravity and suction systems.

The simplest sand-blast unit for this system consists of a pressure chamber, below which is the control valve, and above which is an abrasive hopper, a hand-operated valve being placed between the abrasive hopper and the pressure chamber. When the pressure chamber has been emptied of abrasive, air must be shut off to allow the chamber to be refilled from the hopper. Therefore, continuous operating time is limited by the size of the pressure chamber. For some purposes this fact, together with the fact that time is needed to refill the pressure chamber, is not a serious disadvantage—*e.g.*, when applied to a tumbling barrel—when a batch of castings can be cleaned before the pressure chamber empties. This may, therefore, be called a non-continuous plant.

To overcome the inconvenience arising through service interruptions in the single-chamber apparatus, machines with several chambers are now being made. With these, blasting can take place from one chamber while another one is filling from the hopper.

### Sand-Blasting without Compressed Air

The air consumption in the compressed-air type of machines is seldom realised, neither is the power absorbed in compressing it. Table I will illustrate both points.

These figures show that the power consumption for compressing air for sand-blasting is an expensive item, which expense is seriously increased by the fact that the nozzles are subject to excessive wear, and when they become worn

TABLE I.—*Air Consumption in Sand Blasting.*

| Working pressure, lbs. per sq. in. | | Dia. of nozzle. | | |
|---|---|---|---|---|
| | | $\frac{5}{16}$ in. | $\frac{3}{8}$ in. | $\frac{7}{16}$ in. |
| 30 | Cub. ft. per min. .. | 62 | 90 | 122 |
| | H.p. absorbed .. | 7 | 11 | 14 |
| 45 | Cub. ft. per min. .. | 84 | 122 | 165 |
| | H.p. absorbed .. | 12 | 17 | 24 |
| 70 | Cub. ft. per min. .. | 118 | 170 | 230 |
| | H.p. absorbed .. | 21 | 30 | 40 |

by the cutting action of the abrasive, the consumption of air is still further increased. A new principle in the design of sand-blasting machines has been introduced, for which is claimed a very substantial reduction in power consumption. This new principle embodies the use of centrifugal force, in which the abrasive is fed by gravity on to revolving blades and thrown direct upon the work to be treated, without any intervening pipe involving loss of efficiency. The stream of abrasive can be delivered in any required direction.

The advantages of the new machines may be summarised briefly in the following comparative order of importance:—

(1) The quality of work is equal to the work turned out by the ordinary compressed-air apparatus.

(2) Lower power costs. It is claimed that an apparatus working two nozzles at an equivalent of 60 lbs. pressure requires only 6 b.h.p. instead of 40 b.h.p.

(3) The apparatus is practically noiseless in operation, and can be installed in a machine shop without any inconvenience.

(4) They do not require any air compressor, with its electric motor and control gear, air receiver, etc.

(5) Easy loading and unloading.

(6) Positive cleaning of abrasive—all dust and fines removed by air wash.

(7) Accessibility. All drives and bearings thoroughly protected from dust and abrasive, but easily inspected.

There are also other interesting points of comparison. For example, in the compressed-air type of plant it is well known that moisture should be eliminated as far as possible on account of its tendency to rust the abrasive medium, with clogging at the valves and nozzles.

The centrifugal-force type of machines are suitable for use with either quartz sand or chilled-steel abrasives, according to the class of work to be treated, and the same considerations apply to the selection of the abrasive as in the compressed-air type machine. Chilled-steel abrasive is strongly recommended, however, on account of the greater output and the smaller quantity of dust made. The spent abrasive falls into a lower chamber, whence it is raised by an elevator, passed through a sifter, and into the hopper, from which it again falls on to the centrifugal throwing device. The circulation of the abrasive is completely automatic in action and leaves the operator entirely free for other work. Originally, this type of machine was only available in the barrel form, but now rotary tables employing the centrifugal principle are available.

## Output of Sand-Blast Machines

The output depends on the following basic factors:—(*a*) air consumption, (*b*) air pressure, (*c*) length of nozzle, (*d*) distance between nozzle and article to be cleaned, (*e*) the angle at which the jet hits the object, (*f*) the kind and nature of abrasive, its quality, and (*g*) the system employed.

(*a*) *Air Consumption.*—The air consumption and pressure of the apparatus depends upon the interior diameter of the nozzle and the system. The relationship between air consumption and pressure and diameter of nozzle is shown on the diagram, Fig. 1. As the diameter of the nozzle is not constant, however, but enlarges with use, one of two things may happen—(1) the volume

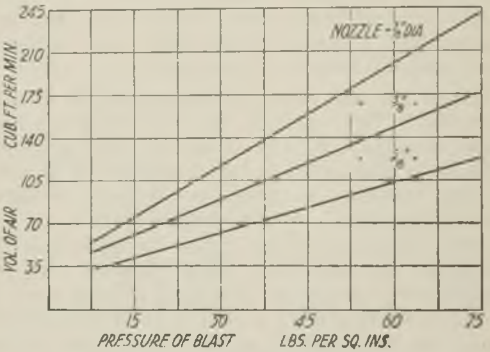



**Fig. 1.—Showing Relationship between Air Consumption and Pressure.**

of air flow increases or (2) the pressure drops. If the latter occurs, cleaning will probably be slower; but if the compressors are capable of maintaining a constant pressure, cleaning should be quicker.

(*b*) *Air Pressure.*—In order to obtain maximum efficiency in cleaning, it is essential constantly to maintain the desired air pressure, which must be adapted to the ability of the material being treated to withstand the impact of the abrasive. Efficiency in sand-blasting depends on several factors, but, others being equal, it may be stated the higher the pressure, the more rapid the cleaning, and, broadly speaking, twice as much work may be accomplished at, say, 60 lbs. pressure as at 30 lbs.

(c) *Length of Nozzle.*—The efficiency of a nozzle of $\frac{1}{2}$ in. dia., measured by loss of weight of articles treated, is only slightly improved by an increase of length, as is shown in Fig. 2.

(d) *Distance between Nozzle and Article to be Cleaned.*—The distance between nozzle and surfaces is of considerable importance. This is clearly shown in the diagram, Fig. 3. As a general rule, the greater the distance, the greater the area covered, but less weight is removed. It is usual to take a big distance when simply cleaning parts from grease, etc., and to work at a short distance for removing scale, etc. The position of the nozzle relative to the

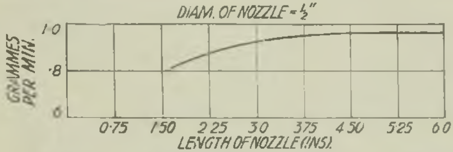



FIG. 2.—SHOWING INFLUENCE OF LENGTH OF NOZZLE ON EFFICIENCY.

work for greatest efficiency depends, therefore, on the nature of the work. If an article is cleaned only with difficulty, the nozzle should be close to the work. If, on the other hand, it is cleaned with ease, the nozzle can be farther away and the abrasive allowed to spread.

(e) *Angle of Projection.* — The best angle of projection, using quartz sand, is 15 deg. This gave the largest area sprayed and the greatest quantity of material removed, as is shown in Fig. 4. Using No. 24 angular-steel abrasives on C.R.C.A. plate, Neville* found that 30 deg. was the best, and on cast iron 50 deg. With No. 24 round shot, the same investigator found that an angle of 60 deg. produced the most satisfactory results. In practice, therefore, it is recommended that the nozzle be held obliquely to the work—say, 45 deg.—not perpendicular to it.

* "Proceedings, Institute of British Foundrymen," Vol. XIX. page 555/575.

(*f*) *Size of Abrasives.* — Regarding the influence of the size of abrasive on the output of sand-blast machines, it may be stated as a general principle that the grain may be increased in size with the hardness of the material treated and the thickness of the layer that has to be removed. For the cleaning of iron and steel castings, the best sizes are from Nos. 8 to 20, whereas thin sheet articles for enamelling are best treated with the finer grades, say, Nos. 20 to 60. The quality and class of abrasive, together with the air pressure to be used,

TABLE II.—*Suggested Abrasives and Air Pressure for Various Cleaning Jobs.*

| Type of material. | Type of abrasive | Air pressure, lb. per sq. in. |
|---|---|---|
| Non-ferrous castings and objects of soft materials | Fine angular, say No. 60 .. | 18 to 20 |
| Iron castings .. | No. 24 or 30 angular.. | 25 to 35 |
| Malleable castings (annealed) .. | No. 24 angular | 40 to 45 |
| Steel castings .. | No. 10 or 12 angular | 60 to 80 |
| Steel stampings, forgings, plates, sections .. | No. 16, 18 or 24 round | 45 to 60 |

depend entirely upon the surface of the material to be cleaned, but, as a somewhat general guide, the data in Table II are put forward.

### Hardness of Abrasive

Of the properties desired in a satisfactory abrasive, the one of hardness is undoubtedly the most important, but it is with regret one records that hitherto no published information is available regarding this property. There are now available several types of suitable apparatus (*e.g.*, Vickers hardness tester, and the Firth Hardometer) for determining the hardness value, and the suggestion is hereby expressed that some standard method of ascertaining this value will in future be adapted.

During the manufacture of chilled-steel abrasives at the works with which the author is connected, control is strictly exercised over the hardness. Hardness determinations of individual particles of abrasive are made with the Firth Hardometer, using the diamond indenting tool. (Fig. 5.) The results of such tests indicate the Brinell diamond hardness to be from 750 to 875.

## Effect of Moisture

Compressed air contains moisture, which should be removed before delivery to the sand-blast, to prevent dampening the abrasive, with con-

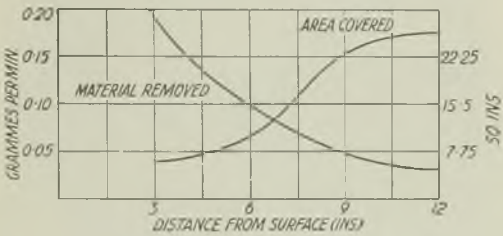



Fig. 3.—Showing Effect of Varying Distance from Surface Treated.

sequent clogging and other troubles. This clogging is minimised by the installation of gas rings beneath the pressure chamber, whilst frequent cleaning out of the plant is practised in some works in order to overcome the trouble. It is, of course, a well-known fact that the finer grades of abrasives possess greater clogging tendencies than the coarser grades. This moisture problem has always been one of the difficulties encountered when changing from quartz to steel abrasives, which unfortunately becomes increasingly difficult with increased pressure.

## Finish Obtained on Iron Castings

The finish obtained on samples of cast iron cleaned under standard conditions, but using different abrasives, has been studied by Neville,* who obtained the results shown in Table III.

### Wear of Nozzles

This has already been briefly considered, when discussing tho output of sand-blast machines, but it is of such vital importance that further reference is considered necessary. Nozzles are subject to wear at both the inlet and outlet, each of which has its own peculiar influence.

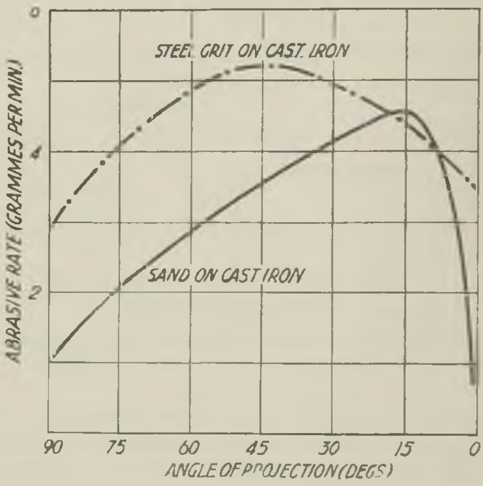



Fig. 4.—Showing Effect of Varying Angle of Projection.

Maximum efficiency is only maintained so long as the abrasive stream is concentrated, but efficiency is decreased whenever the abrasive stream is spread over too great an area. Nozzles worn beyond the limit of good practice are an added expense, as they increase the total sand-blasting costs by many times the price of new nozzles.

A nozzle should be changed immediately the

* *Loc. cit.*

outlet has worn to such an extent that the time of blasting is out of all proportion to the flow of compressed air and abrasive. Wear at the outlet is caused by the side thrust of the abrasive against the walls of the nozzle. This action takes place gradually from the inlet, and results in the production of a somewhat bell-mouthed opening, which causes the abrasive

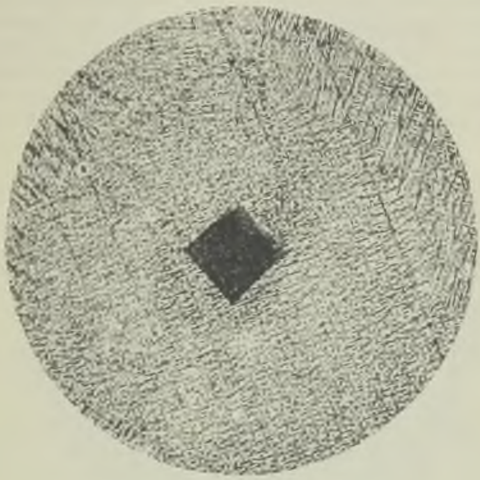


FIG. 5.—IMPRESSION ON CHILLED-STEEL ABRASIVE BY FIRTH HARDOMETER.

stream to spread, with its serious loss in production.

### Norbide Nozzles

Nozzles are usually made of a hard white cast iron, but gas tubing is sometimes used. They are not, therefore, very expensive, but it should be emphasised, however, that they are probably one of the largest factors in controlling operating costs. There are now on the market nozzles which have a guaranteed working life of 1,500 hrs., during which time the outlet will not enlarge to more than 50 per cent. of its original diameter. They are somewhat revolutionary in shape, and the holder is incorporated with, and is part of, the sand-blast hose. The actual nozzle is turned out of mild steel and lined with an exceptionally hard material, known as "Norbide" (boron carbide, $B_4C$).

"Norbide" nozzles are made in all the common styles and sizes used in foundries. Their life varies considerably with different installations, depending on many factors, *e.g.*, nozzle size, abrasive material used, and air pressure. The standard guarantee at pressures not exceeding 90 lbs. per sq. in., is that wear at the outlet end will not exceed 50 per cent. of the

TABLE III.—*Finish Related to Abrasive* (*Neville*).

| No. | Abrasive. | Finish. |
|---|---|---|
| 1 | Fine steel grit .. | Bright silver grey |
| 2 | Coarse steel grit .. | ,, ,, but etched surface. |
| 3 | Fine steel shot .. | Dull, smooth surface. |
| 4 | Coarse steel shot .. | Dull etched surface. |
| 5 | Quartz sand .. .. | Etched, not so bright as with fine steel grit. |

original orifice diameter for a period of 200 hrs. with aluminium-oxide abrasive, 750 hrs. with silica sand, and 1,500 hrs. with chilled-steel abrasives. Owing to the fact that the opening in a "Norbide" nozzle remains practically constant in size for a long time, air consumption is considerably decreased. Some users report that they are able to lower the setting of their compressor by 10 lbs., and in addition there is a saving in the volume of air consumed. Owing to the opening in a "Norbide" nozzle retaining its true cylindrical shape and size, the abrasive stream remains concentrated, and therefore the abrasive velocity does not drop.

### Metallic or Non-Metallic Abrasives

The possibilities of using chilled-steel abrasives have during recent years been very much discussed. Broadly, the question may be considered from two angles, and, for lack of a better description, they will be called (*a*) the hygienic and (*b*) the economical aspect.

(*a*) *Hygienic.*—It has already been suggested that sand or some form of siliceous material was the original medium used for sand-blasting; hence the name. In use, this sand disintegrates into a very fine dust, which, inhaled into the human system, produces that dreadful disease,

FIG. 6.—MICROSTRUCTURE OF CHILLED-STEEL ABRASIVE.

silicosis, for which there is no cure. This is, indeed, a disease to be feared, and every considerate factory executive having the welfare of his workers at heart will welcome the Home Office suggestion to suppress wherever possible the use of any materials that contribute to its cause.

If one reviews very briefly some of the published statistics regarding deaths from this cause, it will be seen that the Home Office regulations are, in the interests of humanity, quite justified.

In a Paper presented to The Institute of Vitreous Enamellers last year, on the subject of "Silicosis," Dr. Middleton (H.M. Medical Inspector of Factories) made the following statement:—"It was not possible to estimate accurately the effect of the disease, but reliable sources indicate that over 300 deaths occur every year in England and Wales from this cause. The disease progressed slowly, and some degree of disablement appeared long before it proved fatal. Over £100,000 was paid in compensation in a single year in this country." Dr. Middleton further states: "There was no remedy for the disease once the lungs have become affected. The only alternative was prevention, which could be effected by:—(1) Avoidance of injurious materials; (2) suppression of dust at its source; (3) removal of dust as near as possible to the point of origin; and (4) protection of the workman."

Of the four suggestions made by Dr. Middleton, the one to be most successful is undoubtedly the first, viz., the avoidance of all injurious materials. In this respect, the sand-blasting industry is very fortunately placed in so far as an efficient and economical substitute for the dangerous sand is to be obtained, and it is with pleasure one records that the majority of works to-day use chilled-steel abrasives.

In a Paper recently read before the British Works Management Association on "Health in Workshops," the Medical Officer of Health for Coventry (Dr. Massey) quoted the following figures for the City of Coventry for the year 1934:—Death-rate from pulmonary tuberculosis among the general population was 0.77 per 1,000, and death-rate from pulmonary tuberculosis among sand-blasters was 23.2 per 1,000.

(*b*) *Economics.*—From an economical point of view, the use of chilled-steel abrasives is distinctly advantageous. Although more expensive in first cost, they have from 10 to 20 times the life of sand, while their use avoids the immense dust formation, and other risks are considerably reduced. For some purposes they have a life as high as 60 times that of sand. On the other hand, when cleaning castings for enamelling purposes, it is usually estimated that 1 ton of a suitable chilled-steel abrasive will do the work of 16 tons of quartz. Large storage bins are therefore unnecessary, while large tonnage can be stored in a small space by stacking the bags or containers, one on top of the other.

FIG. 7.—SURFACE OBTAINED BY BLASTING WITH SAND.

The weight of chilled-steel abrasives is approximately 2½ times that of an equal volume of quartz; therefore, a pressure double that used for sand must be employed in order to obtain equal production. With sand the pressure used is generally from 10 to 30 lbs., whereas chilled-steel abrasives are usually worked with 25 to 60 lbs. per sq. in., while pressures as high as 90 lbs. are not uncommon. If one considers the action of sand-blasting, one readily realises that at each impact a certain amount of abrasive is pulverised and taken away as dust by the exhaust fan. Sand, owing to its crystalline structure, very rapidly disintegrates, and as a consequence a great amount of dust is generated.

According to tests made a few years ago by Neville, Leighton Buzzard sand loses 10 per cent. of its weight per impact at a pressure of 15 lbs., whereas No. 24 chilled-steel angular abrasive at the same pressure only loses one-tenth of 1 per cent. of its weight per impact. Therefore, despite its comparatively high initial cost, it is more economical than sand.

Metallic abrasives differ from all other natural abrasives (*e.g.*, emery, sand or quartz) in that each grain is a solid homogeneous mass, devoid of cleavage lines. Owing to this property, metallic abrasives do not break up readily on impact, they simply wear away. On the other hand, mineral abrasives have cleavage. They are built up of a large number of minute crystals held together by a common bond. On impact, such crystals disintegrate very rapidly. This disintegration proceeds until all cleavage lines disappear and the abrasive is reduced to a useless condition. In the meantime, production is hampered and costs are increased by the production of large clouds of dust.

The replacement of sand by chilled-steel abrasives for general purposes, *e.g.*, removal of foundry sand, scale, etc., has now become almost universal, but considerable opposition to its use still remains in a few isolated plants engaged on cleaning castings prior to vitreous enamelling. The principal objections raised are: (1) steel shot produces a "peened" surface, to which the enamel will not adhere perfectly, and (2) the tendency of certain acid-resisting enamels to blister when fused on castings cleaned with chilled-steel abrasives.

### "Peening"

The production of a peened surface is entirely avoided by the use of an angular abrasive of fairly large size, which produces the etched surface so necessary for successful enamelling. This is clearly seen by an examination of Figs. 7 and 8. Fig. 7 is a macrograph of a sample of an ordinary cast-iron plate prepared for enamelling by means of a sand abrasive, whilst Fig. 8 is of an identical sample prepared by using a chilled-steel angular abrasive. The surface obtained by the latter is probably too rough for enamelling by the wet process, but the

Fig. 8.—Surface obtained by Blasting with Chilled-Steel Abrasives.

result obtained is a maximum one, and by varying either the pressure of the compressed air or the size of the abrasive, it is possible to produce a large range of surfaces.

### Blistering

The tendency to blister exhibited by some enamels is due to what is sometimes termed "metallic smudge" and its presence is due to inefficient cleaning of the abrasive in the plant. This foreign matter has in the past been erroneously called "graphite carbon." In order to remove the foreign matter, and thereby prevent blistering, the use of an abrasive cleaner and separator is strongly recommended.

## Conclusions

It may be said that (1) sand-blasting will remove scale, rust etc., and will give to an article a surface particularly suitable for painting, lacquering, enamelling, etc. It is universally agreed that enamel will adhere with considerably greater tenacity to a sand-blasted, than to a non-sand-blasted surface, and in addition, a more uniform covering is obtained. Less paint is required to give a satisfactory film. which if applied immediately after sand-blasting, will have a much longer life, owing to prevention of oxidation. (2) Fused sand and embedded particles are removed from the surface, thereby preventing damage to tools in the machine shop. (3) Dust from cores, etc., is readily removed without spreading over the foundry, and (4) it is much less costly and far more convenient than the old-fashioned pickling process.

It has also been shown that chilled-steel abrasives can successfully replace sand or quartz in order to achieve any of the above named results. To anyone considering a change from non-metallic to metallic abrasives, however, it should be pointed out that a sand-blast operator who is only familiar with the use of flint grit cannot be expected to produce first-class results immediately a change-over is made. He has to become accustomed to the new material, which may require slight alteration of the conditions under which the plant was formerly operated.

Finally, the author tenders his thanks to the Directors of Bradley & Foster, Limited, for permission to give the Paper.

## DISCUSSION

The CHAIRMAN (Mr. Arthur Whiteley) said he had listened to the lecture with considerable interest. It seemed to him that the lecturer had sounded the death knell of sand as a blasting medium, but sand merchants would not object if steel shot was helping to increase the efficiency of foundries and lengthen the life of foundrymen. The refractories industry was well aware of the dread results of silicosis. In the production of ganister and silica bricks, he thought that particular disease was probably more rampant than in any other branch of industry.

It had been of considerable interest to him to listen to Mr. Bradshaw and to hear his arguments in favour of the use of steel shot. He was especially interested in the references to angular steel shot. Personally, he had always been under the impression that steel shot was spherical, and the angular grain of natural sand had been one of the arguments in favour of sand. He was a little disappointed at not having heard how steel shot was made, as he had hoped to have seen some illustrations of the process of manufacture. Perhaps that was a subject that he ought not to mention, but it occurred to him that it might have interested the members of the Sheffield Branch.

### Iron Oxide and Silicosis

Mr. R. C. Tucker said silicosis was certainly caused by sand, but it could also be caused by iron oxide. It was very prevalent among the hematite miners in Cumberland, and he often felt that if rusty material was sand-blasted there was a danger, even though they were using clean steel shot, of fine iron-oxide dust being present, and he wondered whether that was perhaps an argument in favour of the older method of pickling castings or rusty materials to remove the scale.

With regard to the loss of weight of abrasive, Mr. Bradshaw had stated that Leighton Buzzard sand lost 10 per cent. of its weight at 15 to 20 lbs. pressure, whereas steel shot lost a very much smaller proportion of its weight at the same pressure. Mr. Bradshaw also stated, however, that steel shot was always used at greater pressure, so perhaps it would be a fairer comparison to give the loss of weight at the working pressure. He (Mr. Tucker) wondered if Mr. Bradshaw had any information on that point. He should think that the majority of those present, as iron-founders, were interested in sand blasting simply as a means of cleaning castings, and he always felt that they could only clean simple shapes economically by sand blasting. He remembered a case where he had some filter plates which had little sand cores in the corners, which were the cause of much trouble. He could not imagine a sand-blast nozzle getting into those little cores, and he thought that pickling would be the solution of that problem, rather than sand blasting. He would like Mr. Bradshaw's comments on the question of what castings could be cleaned economically by the use of sand blasting. They all knew that plate work, or simple work, could be cleaned very efficiently and very cheaply by this method, but would the lecturer tell them how a fairly complicated cylinder head, say, could be cleaned by sand blasting.

Mr. Bradshaw, referring to Mr. Tucker's remarks on hematite mining, said it was the "free" silica, really, that was the cause of silicosis. In the glass industry, for instance, there was a big risk of contracting silicosis, but he believed that was due to the materials. Once the silica had got into combination with other elements, it formed compounds which were not so dangerous.

Mr. Tucker agreed, and said quite a lot of work had been done on the question of stone dusting in mines, and that silicates were found to be quite harmless. But it was a fact that other materials besides true silica could give silicosis.

Mr. Bradshaw said he agreed—for instance, asbestos could cause this disease, but with regard to ferric oxide he should be sceptical, since iron salts were soluble in the human system.

Mr. Tucker: But when they are deposited in the lungs, they do actually grow.

Mr. J. E. Hurst asked Mr. Tucker whether there was any difference in the behaviour of the respective oxides of iron.

Mr. Tucker: That has not been proved yet.

Mr. Hurst: There is no evidence with regard to magnetic oxide?

Mr. Tucker: No.

Mr. Hurst: But there is with regard to $Fe_2O_3$?

Mr. Tucker replied that the hematite miners which he had mentioned were only one case.

Mr. Hurst thought that was important, because the majority of the oxide on castings that one had to contend with was the magnetic oxide.

Mr. Tucker: Yes, unless the castings were rusty.

Mr. Hurst said that a good deal of publicity had been given to this question of silicosis, and it was of some importance not to create any scare about it.

Mr. Tucker: There is no evidence yet of a particular form of iron oxide being more dangerous than the others, but the question is still in its infancy. That it is some form of iron oxide, however, is fairly certain.

## Life of Sand and Shot

Mr. Bradshaw, replying to Mr. Tucker's question with regard to loss of weight, said he took it that the gentleman was referring to the information which he (the lecturer) published, and which was based on Neville's work of some five or six years ago. Neville conducted experiments at a pressure of about 15 lbs., with the results that were given in the Paper. He (the speaker) had not any actual data on that. The only information he could give was that chilled steel abrasive would last approximately 15 times as long as sand under the same conditions. Of course, Mr. Tucker would realise that the higher pressure was necessary to carry the heavier material. With regard to the economical removal of cores, what was the size of the cores?

Mr. Tucker: Only about $\frac{3}{8}$ in.

Mr. Bradshaw, agreeing, said if it were $\frac{3}{8}$ in., it would probably be quicker to get it out with a file, or something of that sort. Cylinder blocks were being cleaned successfully by the sand blasting process.

Mr. T. R. Walker said that they had heard a lot that evening about silicosis. He thought that in this respect Mr. Bradshaw had perhaps rather overstated the case for steel shot, and he did not think that Mr. Bradshaw would claim that a foundry using steel shot instead of sand for blasting would be exempt from the provisions of the Silicosis Act. After all, most castings were made in sand moulds and any process likely to produce dust, whether from the surface of the casting or from the blasting material with a silica content of 80 per cent. or over, came under the provisions of the Act. He was quite sure that all the best foundries recognised the danger of silicosis and in those foundries, owing to the precautions taken by the management, there were very few cases of silicosis whether the foundries were using sand or shot blasting.

He was interested in Mr. Bradshaw's remarks about the lowered efficiency of nozzles as they enlarged with wear, but he took it that Mr. Bradshaw's remarks applied principally to cases where the air compressor was of insufficient capacity to maintain the pressure at its proper value when the nozzle became enlarged. If it maintained the pressure it seemed to him that any increase in the size of the nozzle, according to what Mr. Bradshaw had said, meant an increased rapidity in the shot blasting until, of course, the end of the nozzles became of a definite barrel shape, when the efficiency would fall off owing to the large increase in area covered by the shot from the nozzles. He was also interested in Mr. Bradshaw's remarks about the guarantee given with nozzles lined with Norbide. In view of the differences in the guaranteed hours given for alumina, silica sand

and chilled steel shot as abrasives, it seemed to him that aluminium oxide abrasives were apparently the ones which removed material most quickly. Could the author give any information regarding the efficiency of aluminium oxide abrasives when used for cleaning castings?

Mr. Bradshaw, replying to Mr. Walker's question as to exemption from the Silicosis Regulations when cleaning castings, said the use of a chilled steel abrasive was advocated and recommended by all His Majesty's Factory Inspectors. It was claimed that the sand that was fused on the surface of a casting was really a silicate, and as such, when working, was less dangerous than the actual free silica. With regard to nozzles, it was really a question of whether one could maintain the pressure, and if one's apparatus was sufficient to maintain a constant pressure irrespective of the diameter of the nozzle, then, of course, one could efficiently sand blast. But very often the compressor was not capable of that, and, as the nozzle wore, so the pressure decreased. With some of the older plants, at any rate, that happened. With regard to the query as to aluminium oxide, he regretted that he had no available information on that point.

Mr. Tucker said aluminium oxide was too hard, and even scratched cast iron very badly.

Mr. Hurst said he should imagine that much depended on the actual cleaning operation that one was engaged upon. It was not necessarily the hardest material that was the best from a cleaning point of view. The actual energy content of the individual blows struck by the particles of material was equally important in some cases. If they had to raise the velocity of aluminium oxide particles to give a momentum equivalent to iron particles, it was quite possible that the cost of doing that might be out of proportion.

Mr. Walker: Surely the specific gravity of aluminium oxide is not very different from that of silica.

Mr. Hurst: But it is very different from that of the metallic chilled steel abrasives.

Mr. Walker: But we have in the Paper the ratios of the pressures required for use with silica sand and with chilled shot, so that it ought to be easy to obtain the pressure necessary for use with aluminium oxide abrasives.

Mr. Hurst: Yes.

Mr. Tucker presumed that aluminium oxide would not cause silicosis.

Mr. Walker: Certainly, but it might cause a similar disease, called by another name.

Mr. Tucker: I rather think it is the other way round, that a lot of diseases are incorrectly called silicosis.

Mr. Walker: Oh, certainly.

Mr. Tucker: Do you claim for the steel shot process that the cleaning costs per ton of castings are less than with sand?

Mr. Bradshaw said he claimed that the cleaning cost per ton, cleaned with chilled steel abrasive, was less than with the sand, but he was basing that on the fact that a quicker output was obtained from the machines. The abrasive is quicker, and there was a longer life from the abrasive, and, from a given plant, a bigger output was obtained.

Mr. Tucker: But supposing a sand plant was sufficient to deal with the output of your foundry, would it pay you to go over to steel shot?

Mr. Bradshaw: Yes, from the point of view of longer life of the abrasive medium.

Mr. Tucker: Does that balance the initial cost?

Mr. Bradshaw: Yes, certainly; in fact, there is a big margin.

## Airless Machines

Mr. C. H. Sanders asked which was the better machine for cleaning castings, the centrifugal or the air machine?

Mr. Bradshaw said it was really a question of economics, and the amount of work they had to do. If they had a large amount of work of a fairly small type coming through, then a centrifugal machine was better from that point of view, but if the work was of the larger type, of course, they had to go back to the pneumatic or blasting machine.

Mr. Walker asked what happened to the angular shot when it wore. Did it wear round or angular?

Mr. Bradshaw said that if it was a good sample, it should not wear round. It would break away and disintegrate, and keep in use, maintaining its angular character until it was so small that it passed away through the exhaust fan.

Mr. Walker: In that case, then, it resembles the sand.

Mr. Bradshaw: Yes.

Mr. Walker: But it takes longer to do it?

Mr. Bradshaw: Oh, yes.

Mr. Walker said he did not suggest that the shot would round over but thought that the projecting edges would get worn down a bit. Even a diamond point would wear down with constant use but it would not round over.

Mr. Tucker said wind borne sand was round. Desert sands, and sea sands, were round, merely by attrition. It was a question of velocity of impact. He thought the impact value of a hard steel was very low. If they had an angular particle hitting a hard casting surface with a certain momentum, they might exceed, with the very fine, very small area of attack, the impact value of that steel, and they might break pieces off. It was very difficult sometimes to imagine the force that came into play over such a small area. A few weeks ago he heard a Paper which described a very small spindle. This only weighed about five grammes, and it was on such a fine steel point that the pressure was 100 lbs. per sq. in. on the point, and they got a peculiar form of corrosion there, due to the excessive pressure.

Mr. Walker, reverting to the question of breakage, asked if Mr. Bradshaw did not claim in his Paper as one of the advantages of chilled shot the fact that it had no cleavage planes, and therefore would not break?

Mr. Bradshaw said he thought Mr. Walker would agree that, although there were no cleavage planes, it was a brittle material, and as such it should break rather than round over. If the material was of a soft character, then of course there would be a tendency for it, during wear, to take on a round shape.

Mr. Sanders asked what kind of nozzle was used for the centrifugal machine, as against the ordinary machine. Was it a wide or a round nozzle?

Mr. Bradshaw said there was actually no nozzle in the sense in which they understood it on the ordinary sand blast plant. The material dropped down from a hopper on to a revolving disc, which forced it by directing it into the machine through a kind of rectangular opening.

## Vote of Thanks

Mr. Hurst said there were two types of centrifugal machine at the moment—one which was very much like the Sandslinger with the single blade, and the other which had an impeller like the centrifugal pump.

Going on to propose a vote of thanks to the lecturer, Mr. Hurst said the members would have gathered that Mr. Bradshaw was a colleague of his. He could assure them that Mr. Bradshaw had devoted a good deal of time to the study of questions regarding sand blasting, and the efficient use of materials for the process. He supposed it was true to say that sand blasting, as a method of cleaning castings, was a very old method, but it was only of comparatively recent years that it had been thoroughly studied. It was probably true to say that a good deal of this attention had arisen owing to questions concerning the disease of silicosis. Whilst it might be admitted that there was a good deal yet to be learned about silicosis, Government officials did apparently take a serious view of the disease, and in so far as sand blasting was concerned, they had begun to give it their attention and to consider the question of the materials for actual use in the sand blasting machine. Whatever was said about those materials, there was one thing that could be said about chilled steel abrasives, which was that they were intrinsically free from silica, and from that point of view they might have some effect in minimising the tendency to silicosis. One object in giving a lecture was to endeavour to impart as much information to the members as the lecturer could, and the other was to derive as much information as he could from them; and he felt certain that Mr. Bradshaw, like himself, would have been very glad to have heard what some of their steel foundry friends had had to say about the use of sand blasting, particularly about using shot as a method of cleaning steel castings. However, he was certain that Mr. Bradshaw would be satisfied with the rather bright discussion, and that it would repay him for his time and trouble in preparing the Paper.

Mr. A. Carr, in seconding, said they had a good deal to thank the lecturer for. Mr. Whiteley had suggested that Mr. Bradshaw might tell them how steel shot was made. He was afraid that he (the speaker) could not throw any light upon it. The lecture had been very interesting. He agreed with Mr. Hurst that it was rather disappointing that more members from the steel-foundries in Sheffield had not been present, because he thought their attendance would have added to the general interest and would also have been more gratifying to the lecturer.

The CHAIRMAN, in supporting, said perhaps they would hear something about how steel abrasives were made some other time.

The resolution was carried.

MR. BRADSHAW, in reply, said it was always a pleasure to come to Sheffield to give a Paper. That was the third time he had been there and he always seemed to get a warm reception and a lively discussion, which repaid a man for preparing a Paper, because it showed that some of the remarks had been useful. With regard to Mr. Tucker's remark on sea sand, he would point out that the rounded particles were caused primarily by a rolling action. It was not impact, but was simply a case of revolving one over the other, whereas with a sand blast they had a decided impact and blow, and that, of couse, produced the differences in the product.

# Lancashire Branch*

## ALLOY CAST IRONS

By P. A. Russell, B.Sc. (Member)

An enormous amount of attention has been given to the subject of alloy cast irons in recent years, and a large number of Papers have been presented, both on the subject in general and on various particular aspects of it. A study of the bibliography appended, which is far from exhaustive, will show that two Papers on this subject were given at the Newcastle Conference of the Institute of British Foundrymen in 1932, followed by three more in 1933. Two further Papers are included in the 1933-34 "Proceedings of the Institute," and numerous other Papers have been given to the Branches or contributed to the Technical Press, together with the excellent series of publications by the Bureau of Information on Nickel.

It is thus not possible to give much new material, but it is thought that some of the information given on Ni-tensyl is novel and interesting. A difficulty is in the definition of the term alloy cast iron. Cast iron is in itself an alloy in the strict sense of the term, so that the term is redundant and liable to misapprehension.

It has recently been suggested by MM. Thomas and Ballay[11] that the term "special cast iron" should be applied to cast irons containing one or more of the following elements in excess of:—Nickel 0.3, chromium 0.3, copper 0.3, titanium 0.15, vanadium 0.10, molybdenum 0.10, silicon 5.0 and manganese 1.5 per cent., and that the term "high-grade cast iron" should be applied to irons produced by special processes which do not contain the above alloys. The author does not agree with these terms, but

* Joint Meeting with Manchester Association of Engineers and Manchester Metallurgical Society.

they are given to indicate the trend of opinion in some quarters.

It is felt that the term " alloy cast iron," if not too pedantically interpreted, is sufficient for the present purpose, and it is intended to use it in its widest sense and to include reference to all cast irons that have physical properties out of the ordinary. It must be agreed that there is a limit, and broadly the figures given by Thomas and Ballay can be accepted. For instance, the addition of 0.1 per cent. of nickel does not entitle the product to be called nickel cast iron, as such a small amount has no effect on the character of the iron. On the other hand, the addition of 0.1 per cent. of sulphur would have a considerable effect on most grades of cast iron, and if such additions were usefully made, the result could be called " alloy cast iron."

## Principles of Alloying

The underlying principles of all alloy additions to cast iron consist of their effect on the iron in two distinct, but frequently interrelated, directions. These are their effect on :—(1) The size and distribution of the graphite flakes and (2) the matrix of the iron, as to whether it is ferritic, pearlitic, sorbitic, martensitic or austenitic.

It is generally understood that the best iron for most purposes is that which contains fairly fine-flake graphite in a matrix of pearlite. This condition can be obtained without the use of alloys by carbon and silicon control, usually from the use of steel scrap, refined or cold-blast pig-iron in the cupola charge. The limitation of this method is that the iron is very susceptible to change of section, so that only one composition gives the maximum results in one sectional thickness; if this thickness is exceeded there is a falling-off of properties, and, more serious still, in thinner sections free cementite will appear with resulting hardness and machining difficulties, and also brittleness. It is, therefore, proposed to examine the principal alloying elements from the point of view of their effects on the graphite and matrix.

*Nickel* is a graphitiser, about one-third as powerful as silicon, but with the advantage that the graphite produced by nickel is finer than

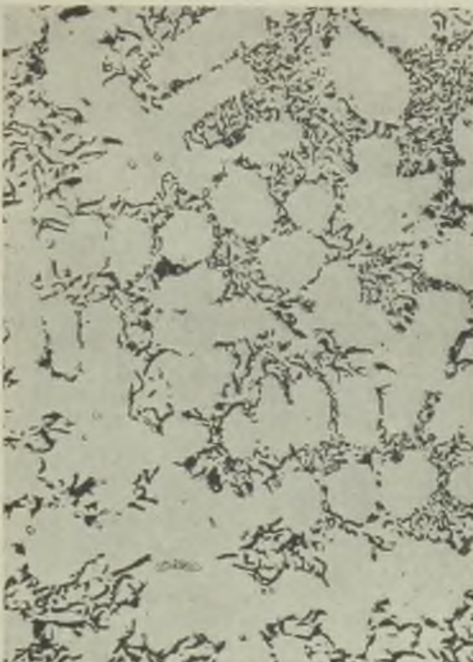


FIG. 1.—"SILAL," SHOWING CARBON IN THE SUPERCOOLED FORM. × 200.

that produced by an equivalent amount of silicon. Nickel also acts on the matrix to produce pearlite in preference to ferrite or cementite. Thus, an iron in which a proportion of the silicon has been replaced by three times its amount of nickel will have finer graphite and be much more uniform in varying sections with a greatly reduced tendency to chill. The strength and hardness of the pearlite will also be improved.

Above about 2½ per cent. nickel has a further action on the matrix, tending to make the iron progressively sorbitic, martensitic and austenitic, the latter condition being fully reached with about 17 per cent. of nickel. This very valuable property is used extensively, as will be shown later.

*Chromium* suppresses the formation of graphite, working in the opposite direction to silicon, an addition of 1 per cent. of chromium being equivalent to the subtraction of 1 per cent. of silicon. Used alone it has very much the same effect as would be obtained by using an equivalently low silicon iron, except that the carbides, both within the pearlite and as free cementite, are harder and more stable, not readily decomposing under heat. If machineable castings are required, silicon has to be added, and the net result does not give a very great gain. If the castings do not require to be machined, then chromium is of more value.

Chromium is used extensively in combination with nickel, to counteract the graphitising effect of the latter, the benefits of both elements being obtained without their disadvantages.

*Silicon* above about 5 per cent. is regarded as an alloying element. It is, of course, a strong graphitiser, so that these irons are usually ferritic unless the carbon is very low. In addition, iron silicide is formed, and this is responsible for the properties associated with the 14 to 16 per cent. silicon acid-resisting iron.

*Manganese* above about 2 per cent. is alloying. It has a tendency to form carbides, but is principally used to replace some of the nickel necessary to form austenite in certain forms of austenitic cast iron.

*Copper* is, to a small extent, a graphitiser and its use is attracting much attention at the moment. It has proved of definite value in certain cases, but the mechanism of its action is not yet fully understood. Its use is limited to a certain extent by the limit of its solubility in iron. This solubility is helped by the presence of nickel, and it is used to replace a portion of the nickel in certain cases, particularly in austenitic cast iron of the Ni-Resist type.

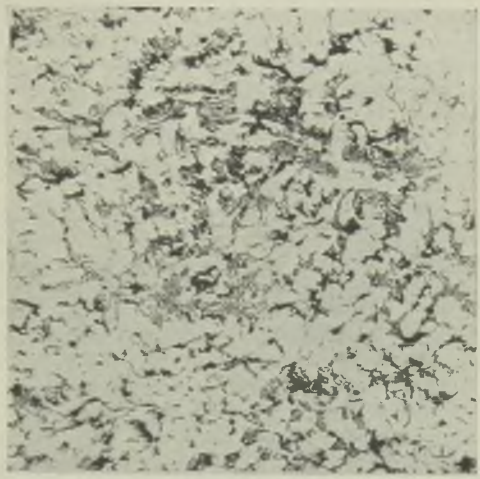


Fig. 2.—Austenitic Cast Iron, Ni-Resist type. × 200.

*Molybdenum* is somewhat similar to nickel in its power to assist uniformity and increase hardness, strength and toughness. The proportions usually used are about one-third those of nickel. The use of molybdenum is not very fully exploited in this country, but its use will undoubtedly be extended.

The action of the various elements has been dealt with rather scantily, but it is hoped that these remarks will be sufficient for the purpose of understanding the later account of the various alloy cast irons. For extended reference to these and other elements reference should be made to the bibliography.

It is now proposed to deal with alloy cast irons from the point of view of the selection of suitable types for specific purposes.

### Heat-Resisting Cast Irons

The mechanism of the deterioration of cast iron under heat is now fairly well understood, and is due to the following factors:—(1) The spread of internal oxidation via the graphite flakes; (2) the breakdown of pearlite, with consequent setting up of internal strains which weaken the iron, cause cracks, and thereby assist the spread of oxidation; and (3) the general weakness of iron due to high temperature *per se.*

The success or otherwise of any particular form of heat-resisting cast iron is therefore dependent not only on the working temperature, but on the fluctuations of that temperature and also the conditions of the surrounding atmosphere. For instance, an iron that will successfully withstand continuous service at 700 deg. C. for six months, may fail in a much less time if it is heated daily from cold to 700 deg. C.

The reduction of oxidation via the graphite flakes is effected by reducing the size and quantity of the graphite, large flakes being obviously bad, whilst the difficulty due to pearlite breakdown may be overcome in one of two ways:—(*a*) The suppression of pearlite into ferrite, or, better still, into austenite; or (*b*) by making the pearlite as stable as possible. The third factor, that of the weakness of iron at high temperature, is inherent, but there is evidence to show that irons that are austenitic as cast are stronger than irons that are ferritic or pearlitic as cast, although these latter are, of course, austenitic when heated above the upper critical point. Heat-resisting cast irons are therefore widely divergent and can be classified as follows, approximately in order of increasing heat-resisting value.

(1) *Chromium or Nickel-Chromium Pearlitic Grey Cast Irons* (Cr 0.3 to 1.5 per cent., Ni 0.5 to 2.0 per cent.).—The addition of chromium gives stability to the pearlite and a fairly fine graphitic structure is obtained. The chromium-silicon balance must be maintained to ensure freedom from chill. Nickel is an advantage in that the tendency to chill in thin places is reduced and graphite is refined.

(2) *Chromium White Cast Irons* (Cr 0.5 to 1.5 per cent.).—Graphite is eliminated and the carbides formed are reasonably stable. These irons are unmachinable and rather brittle, so that their use is limited.

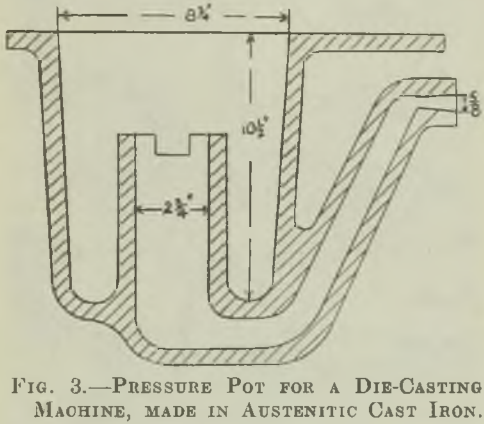


Fig. 3.—Pressure Pot for a Die-Casting Machine, made in Austenitic Cast Iron.

(3) *Silal* (silicon 5 to 6 per cent.).—When satisfactorily produced with low carbon (about 2.2 per cent.) the carbon is in the "super-cooled" form, as shown in Fig. 1, reducing oxygen penetration to a minimum. The iron is also completely ferritic so that there is no pearlite breakdown. The silicon also protects the iron, to some extent, from oxidation, so that scaling is reduced.

(4) *Austenitic Cast Iron* of the Ni-Resist type (Ni 14 to 16, Cu 6 to 7, and Cr 2 to 5 per

cent.).—This iron is austenitic in the cold, so that there is no internal transformation on heating. Graphite is also reduced in quantity and size, and the iron is reasonably resistant to oxidation. The structure of this is shown in Fig. 2, the structure consisting of graphite and chromium

FIG. 4.—"NICROSILAL"—AN AUSTENITIC CAST IRON. × 200.

carbide in a matrix of austenite. Fig. 3 shows a drawing of a pot for a pressure die-casting machine which is one of the numerous applications of this type of iron.

(5) *Nicrosilal Austenite Cast Iron* (Ni 18 to 20 per cent., Si 4.5 to 5.5 per cent., Cr 2 to 4 per

cent.).—This iron combines the advantages of the Ni-Resist type of austenitic cast iron with the "supercooled" structure of graphite and the protection against oxidation afforded by silicon. The structure is shown in Fig. 4, and shows supercooled graphite with chromium carbides in a matrix of austenite. Fig. 5 shows a Nicrosilal furnace component. This is 5 ft. 3 in. long and weighs $1\frac{1}{4}$ cwts.

All reference to service temperatures has been purposely avoided, owing to the variety of factors involved. It should be said, however, that the use of the first two types should be limited to service below about 550 deg. C., for once the pearlite commences to break down the iron rapidly deteriorates. Moreover, no heat-resisting cast iron operating above about 750 deg. C. can

FIG. 5.—FURNACE COMPONENT MADE IN NICROSILAL.

be regarded as absolutely permanent, though the life may be measured in years. As the temperature rises the life factor is shortened, and whilst all classes of iron are capable of withstanding occasional rises up to within a few degrees of their melting points, such rises considerably shorten the life. An illustration of the effect of service temperature is given in Figs. 6 and 7. Fig. 6 shows a Silal firebar that is still in good condition after 15 months' service in a heat-treatment furnace, as against a maximum life of six months for an unalloyed pearlitic iron. Fig. 7 shows Silal and Ni-Resist firebars after five one-month cycles in a high-temperature kiln. The Ni-Resist bar is still quite good, but the Silal bar has obviously been working above its maximum service temperature. In choosing a heat-resisting iron, attention should be paid not only to the first cost against life obtained, but also to the cost of fixing the replacement, and it is always advisable to have an iron that is, if possible, well above its job.

There are two further factors that must be taken into consideration for certain types of heat-resisting applications. These are expansion and thermal shock. When a casting is subjected to local heating in one part whilst other parts or faces are comparatively cool, expansion and conductivity are of prime importance. As austenitic irons have a higher expansion than pearlitic irons (18 against $12 \times 10^{-6}$), and as conduc-

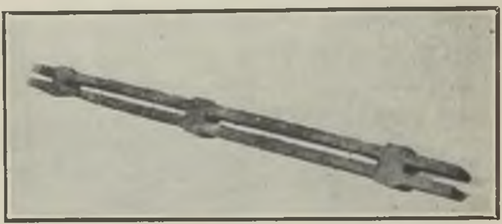


FIG. 6.—FIREBAR MADE IN SILAL OF 15 MONTHS' SERVICE.

tivity decreases with increasing silicon, it is sometimes found that the low-silicon irons of the first type give better results than any other, in applications where the working temperature is not too high to cause pearlite breakdown.

With regard to thermal shock, the presence of a certain amount of fairly coarse graphite seems to be desirable, and this point must be borne in mind when selecting heat-resisting cast irons.

### Corrosion-Resisting Cast Irons

The problem of corrosion is still less straightforward than that of heat-resistance owing to the wide variation of corrosive media and the difficulty of reproducing service conditions in laboratory tests.

There have been many attempts to improve the corrosion resistance of pearlitic cast iron both with and without alloying. Any such improvements are of a minor character, and the differences between the various types of iron are very small. There are divergent views as to the influence of graphite, some authorities maintaining that coarse graphite is best and others fine graphite. The author's own observations are that corrosion depends upon the area of the matrix exposed to attack, not only on the surface, but as far as the medium can penetrate along the graphite flakes, so that it would

Fig. 7.—Showing the Superiority of Ni-Resist over Silal for High-Temperature Kiln Work.

appear that short flakes of graphite in as small a quantity as possible are desirable. The graphite is in itself very corrosion resistant, but graphite flakes in cast iron are very porous, and all the area observed as black lines in a microstructure is not occupied by graphite, a very considerable proportion being unoccupied space or "voids." So, all major improvements in corrosion resistance lie in making the matrix more resistant. It is, of course, imperative that all castings should be uniform and free from patches of porosity, and it is in this respect that nickel and chromium are of value as additions to pearlitic cast iron. Copper additions have been used to assist in corrosion resistance, but the results obtained from various sources are conflicting.

When irons are made austenitic by nickel and other additions, then the matrix becomes definitely resistant to many forms of corrosive attack, particularly that of weak acids. Fig. 8 shows four specimens subjected to intermittent immersion in sea water for 27 days, and the superiority of Ni-Resist is clearly demonstrated. The other four specimens are after one day in 10 per cent. sulphuric acid, Ni-Resist being still more pronouncedly beneficial, the machining marks on the specimen being practically untouched. Ni-Resist is the usual type of austenitic cast iron used for corrosion resistance, but Nicrosilal is superior in a few cases. Neither of these are absolutely rustproof, and will show slight surface rusting on exposure to damp atmosphere. They are, of course, far superior to either cast iron or steel in this respect.

High-silicon cast iron (about 14 per cent. Si) is another iron having very good corrosion-resisting properties. The author has, however, no personal knowledge of its production, and can do no more than refer to it. This iron, it is thought, is almost unmachinable and rather brittle, so that its application is limited. It is necessary to emphasise that each corrosion problem is distinct and it is impossible to draw up any hard-and-fast rules.

### Wear-Resisting Cast Irons

Here again is a property that is hard to define and almost impossible to measure in laboratory tests. Very broadly, the harder the iron the more resistant it is to wear, but a large variety of other factors enter into the problem. It is in this field that alloy cast irons are of prime importance. Nickel, chromium and molybdenum definitely improve the wear resistance of the pearlitic matrix of cast iron. A set of press-tool castings in a 1.5 per cent. Ni, 0.5 per cent. Cr cast iron had, on the last personal inspection, handled 6,000 18-gauge stainless-steel sheets with very little signs of wear.

In selecting an alloy cast iron to resist wear, one must bear in mind that one of the reasons

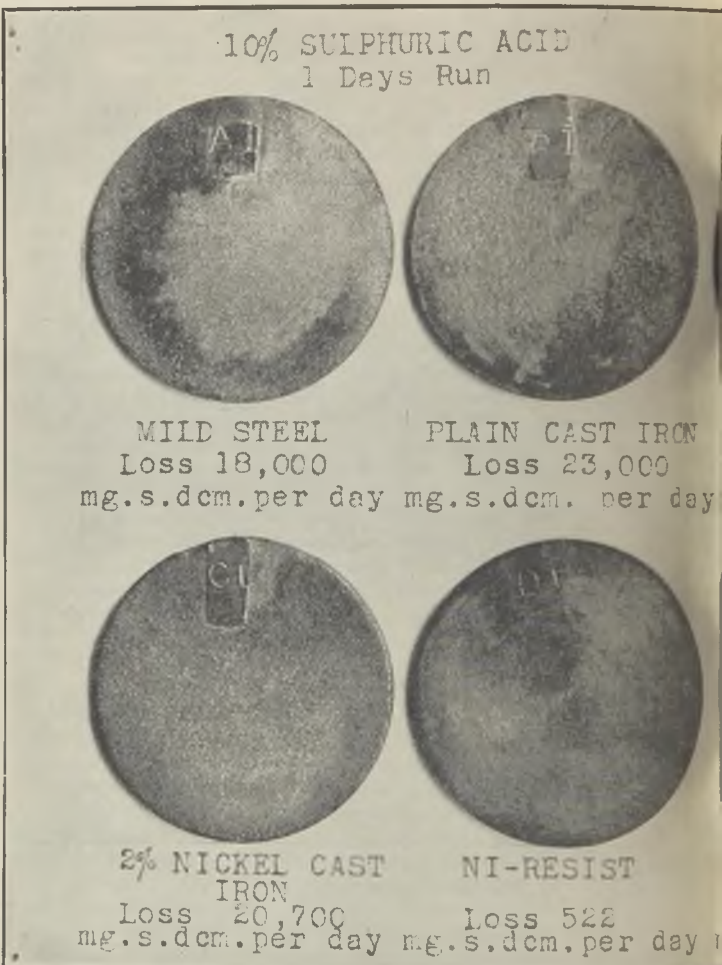
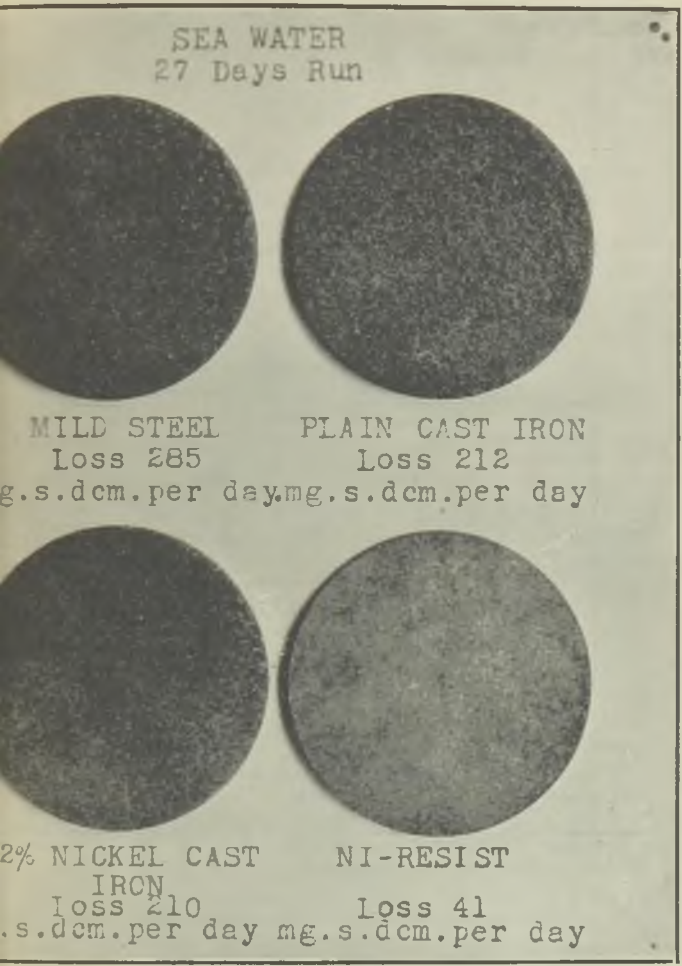



FIG. 8.—CORROSION-RESISTING PROPERTIES OF AI




AND ORDINARY CAST IRON AND MILD STEEL.

why cast iron is a good material for such applications is that the graphite flakes serve a double purpose of providing a graphitic lubricant and reservoirs for other lubricants. Thus, whilst reasonably fine graphite is desirable for strength, which in many cases is allied to wear, the graphite must not be excessively fine.

In cases of unmachined castings subjected to severe abrasive wear, a fairly high-carbon white cast iron containing chromium to harden the carbides is of great value.

Further improvement in resistance to wear is effected by changing the pearlitic matrix to martensite or one of the intermediate materials. This can be accomplished in ordinary irons by drastic quenching from above the critical point. This is, however, too drastic in the majority of cases, and nickel and molybdenum are used to enable this effect to be obtained without such drastic treatment. A 3 per cent. nickel cast iron will be almost wholly martensitic if quenched in oil from 850 deg. C., and will be partially so if cooled in an air stream. Heat-treated irons require to be tempered to restore their strength, though some hardness is lost thereby. The heat-treatment of this class of iron is very similar to that applied to steel.

If the nickel content be increased up to 4½ per cent. then the iron will be martensitic as cast, and such iron can only be made machinable by an anneal followed by a very slow cooling. Re-hardening is effected by heating and then exposing to the air. If such nickel additions are made to white cast iron, together with chromium to counteract the graphitising effect of carbon, then cast irons of maximum hardness are obtained. A Paper on this subject has been presented to the Lancashire Branch of the Institute.[7]

As increasing amounts of nickel are added the martensitic stage passes into austenite. Austenite is machinable and of rather low Brinell hardness. Thus, if the additions are kept on the low limit for austenite, the iron can be hardened by slow cooling or softened by quick cooling, the reverse action to normal. In this class of iron martensite is also formed by working, so that with wear of the type caused by the impingement of particles such as sand, good resistance is obtained, the surface becoming work-hardened.

In addition, a special type of alloy cast iron containing, amongst other things, aluminium, has been developed for hardening by the nitrogen process,[10] which not only gives a very high hardness, but also does not require such a high temperature for heat-treatment, so that there is less liability to distortion.

## High-Strength Cast Irons

It is recognised that reasonably finely-divided graphite combined with an all-pearlitic matrix gives, in normal cast iron, the highest strength. This may be as high as 18 tons per sq. in., but as explained at the beginning of this Paper, such iron is very sensitive to sectional changes, and the result is obtained far more easily and safely by the use of nickel and chromium additions (usually 1.5 per cent. Ni, 0.5 per cent. Cr). Such iron is definitely better than a corresponding unalloyed iron, particularly in the maintenance of strength in thick sections. Also, rather higher carbons can be used and foundry problems thereby reduced.

To obtain strengths above 20 tons per sq. in. in cast iron, it is necessary to resort to some form of process, such as superheating or inoculation. Whilst superheating cannot be said to come under the category of alloy cast iron, the author is deliberately including inoculation, for he claims that the addition of an element to cast iron, other than those obtained by normal pig and scrap mixtures, is alloying in the broadest sense of the term.

The Meehanite method of inoculation with calcium silicide is the most widely known, but the author has no experience of this method and can only indicate its broadest outlines. It is produced from a cupola running on a charge very high in steel, and the inoculant is added in a carefully-controlled amount as the metal runs from the cupola. Not all grades of Meehanite are of 20 tons per sq. in and over; in fact, only the two highest of the five grades are of this strength. For special purposes, it is thought that Meehanite contains alloys on the principles outlined above.

An alternative to Meehanite is Ni-tensyl, which is a cast iron produced by inoculation with

Brinell hardness readings:

| | | | |
|---|---|---|---|
| | | | 207 |
| | | 207 | 201 |
| | 217 | 207 | |
| | | | 201 |
| 235 | | 207 | |
| | 223 | | 201 |
| | | 212 | 201 |
| | | | 207 |

Fig. 9.—Showing Hardness Uniformity in Ni-Tensyl Iron.

ferro-silicon and nickel. Having had some personal experience in the production of this, it is possible to give some account of its properties. With a composition of T.C. 2.8 to 2.9 per cent., Si 1.5 to 2.0 per cent., and Ni 1.0 per cent. a minimum tensile strength of 22 tons per sq. in. is obtained. Higher strengths can be reached with lower carbon, but the foundry problems become considerably more acute.

An important feature of Ni-Tensyl is its uniformity in varying section. Fig. 9 shows a series of sections cut from the centre of bars

12 in. long of various section, from $\frac{7}{8}$ in. dia. to 5 in. dia. It will be noticed that, whilst the Brinell hardness drops with increasing section, the hardness within each particular section is remarkably regular.

This uniformity is more clearly demonstrated in the next two illustrations. Fig. 10 shows a cylinder casting sectioned. The high polish will be noted, as will also the fact that it has been sectioned by a milling cutter, and is freely machinable even on the extremities of the fins. Fig. 11 shows a coupling boss that has been poured from the same batch of metal and which exhibits a very fine structure in all parts, particularly in the bore. This casting is 12 in. over and weighs 70 lbs. Similar but much larger castings, and weighing 7 cwts., have been produced in the same material with equal results. Such results are not possible in cast iron with any ordinary method, and it is thought that the nickel in Ni-Tensyl is of added value as compared with Meehanite from the point of view of uniformity. This uniformity is further demonstrated in the transverse strength of the three standard bars shown in Table I, no adjustment of mixture being made for section. This feature of uniformity is of equal if not more value than the feature of high strength. The strength can be improved by heat-treatment up to well over 30 tons per sq. in.

TABLE I.—*Transverse Tests on Ni-Tensyl.*

Average of nine sets, each set poured from same ladle of metal.

| | Transverse rupture stress. Tons per sq. in. |
|---|---|
| S bar, $\frac{7}{8}$ in. dia. .. | 37.7 |
| M ,, 1.2 in. dia. .. | 38.1 |
| L ,, 2.2 in dia. .. | 37.6 |

Ni-Tensyl is a good material for resistance to wear, both dry and lubricated, a rapid test being obtained by using Ni-Tensyl blades in the sand mill in the author's foundry. It is also used for cams, both in the as-cast and heat-treated conditions.

Doubt has been expressed in certain quarters as to the ability of this type of cast iron to withstand shock, but so far no difficulty has been encountered in this direction, and its superiority in repeated impact tests is clearly illustrated by Table II.

Fig. 10.—Section of a Cylinder Casting Cut Through with a Milling Cutter.

### Special-Purpose Cast Irons

Austenitic cast irons are of value to the electrical industry on account of their non-magnetic properties, and also for their high resistivity combined with a low-temperature coefficient. Nomag, an austenitic cast iron containing about 5 per cent. manganese, 10 to 5 per cent. nickel, and 0 to 5 per cent. copper, is usually employed, as it contains less nickel than the other forms of austenitic iron. It is not so strong as Ni-Resist, nor does it possess such good heat- and corrosion-resisting properties.

For chilled rolls, alloys, particularly molybdenum, nickel, chromium and titanium, are of value in controlling chill depth and hardness, martensitic structures being obtained in certain cases.

The cast iron, if it can be called cast iron, that is used for crankshafts has the following

TABLE II.—*Repeated Impact Tests.*

| Material. | Actual transverse strength. (T.R.S. tons per sq. in.). | Approx. tensile strength. Tons per sq. in. | Re-peated impact blows to fracture. |
|---|---|---|---|
| Ordinary cast iron .. | 23.0 | 11.0 | 32 |
| Machinery cast iron .. | 28.3 | 15.0 | 162 |
| Ni-resist cast iron : | | | |
| As cast .. .. | 27.2 | 13.0 | 1,020 |
| Heat-treated .. .. | 28.3 | 14.0 | 1,772 |
| Ni-Tensyl : | | | |
| As cast .. .. | 36.8 | 23.0 | 1,838 |
| Heat-treated to 302 Brinell .. .. | — | 33.0 | 2,817 |

All bars machined from broken halves of $\frac{7}{8}$-in. dia. transverse test-bars.

Repeated Impact test figures are average of 2 tests.

Weight of blow, 0.481 ft.-lb. on notched bar 13-mm dia. at root of notch supported on centres 145 mm. apart.

Repeated impact tests carried out by the British Cast Iron Research Association.

analysis:—T.C., 1.35 to 1.60 per cent.; Si, 0.85 to 1.1 per cent.; Mn, 0.6 to 0.8 per cent.; P, 0.1 per cent. max.; S, 0.06 per cent. max.; Cu, 1.5 to 2.0 per cent.; Cr, 0.4 to 0.5 per cent.,[12] which is heat-treated. Another analysis that may be quoted is:—T.C., 3.3 to 3.4 per cent.; Si, 1.7 per cent.; P, 0.2 per cent. max.; Mn, 0.6 to 0.8 per cent.; Ni, 2.0 per cent.; Cr, 0.75 per cent.,[13] produced from a cupola mixture with

18 per cent. steel. This is, of course, much more like cast iron as generally understood, but the author cannot give any details of the results obtained.

Many of the cast irons to which reference has been made are made under patent licence, notably Silal, Nicrosilal, Ni-Hard, Meehanite and Ni-Tensyl.

The author has already dealt elsewhere[14] with the foundry properties of alloy cast irons, and does not propose to enlarge upon this subject here, but just to indicate the salient features.

Austenitic cast irons and low-carbon alloy irons

Fig. 11.—Coupling Boss Cast in Ni-Tensyl.

require a great deal of attention to be paid to the feeding of the castings. It is useless attempting to produce alloy cast irons without strict foundry control and careful regulation of the melting process. Cold alloys up to 4 per cent. of the bulk of the metal may be successfully incorporated in hot metal, but amounts above that should either be added to the furnace charge or melted separately in a crucible and then added to the molten cast iron.

In conclusion, the author wishes to thank his co-directors of S. Russell & Sons, Limited, for permission to publish results given in this Paper, and Mr. D. W. Berridge for assistance with the slides. He must also acknowledge the assistance of the Mond Nickel Company and the British United Shoe Machinery Company in the tests on

Ni-Tensyl when heat-treated and the British Cast Iron Research Association for carrying out the repeated impact tests and for the loan of a few of the slides.

## DISCUSSION

Mr. L. E. Benson (President of the Manchester Metallurgical Society) said that in changing over from plain carbon steels to alloy steels it had been found that although certain benefits could be obtained yet troubles arose which were quite new to the industry. One of these troubles was that of hair-cracks, which had proved to be a most serious problem in regard to steel forgings, and had been the cause of serious accidents.

Hair-cracks were almost unknown with carbon steels. Another difficulty was that of temper brittleness which, again, was not a feature of ordinary carbon steels, but was sometimes a very serious feature of alloy steels.

### Heat Resistance and Pearlitic Structure

He had not understood one point referred to by the lecturer. Apparently, a small amount of nickel was sometimes used to render cast iron entirely pearlitic, thus making it more heat-resisting. He could not understand why because the iron was pearlitic it should be heat-resisting. If the graphite flakes were made curly, instead of being straight, or shorter than they would be without nickel he could understand the statement. The advantage of nickel in this connection was also difficult to understand since nickel and cobalt accelerated graphitisation at moderate temperatures.

### Hydrogen in Cast Iron

If he were an ironfounder, interested in the development of cast iron, there were one or two developments taking place at the present time of very great importance to metallurgical science which he would follow very closely. One of them concerned the effect of gases in metals. A considerable amount of information had been published regarding the effects of oxygen, hydrogen, nitrogen, carbon-monoxide, and other gases on cast metals, both ferrous and non-ferrous. Some of the latest and most important information, coming from Germany, showed that dissolved hydrogen in steel, at any rate, was exceedingly important, and might even be the solution of the hair-crack problem. If this view proved to be correct, it was a discovery of the first magnitude, and it would almost certainly be found that reducing gases also affected the properties or behaviour on casting of carbon steel and cast iron castings, since of all the metals cast iron had the greatest opportunity of absorbing gases when it was in the cupola.

### Notch Brittleness

Another line of investigation which appealed to him as being of extreme importance was known as notched brittleness. This had been brought to his notice generally in connection with steel rather than with cast iron; but he thought it was of equal importance in either case.

By pulling a tensile test-piece of steel it stretched out and finally broke. If, however, instead of having a smooth tensile test-piece, a notch was put in it, the ductility might not be apparent, and there might be a perfectly "brittle" fracture. The same thing occurred in the case of a transverse test-piece with a notch. An interesting point in connection with the Izod test was that it was the "notch" that was the real feature of the test. Whether the test was made slowly or by impact or whether the stress was applied directly or by bending was relatively unimportant. A tensile or a transverse test on cast iron, by virtue of all the graphite flakes in che case iron, was really a notch test, and the characteristic fractures of cast iron were due not to the brittleness of the ferrite or the pearlite, but to the fact that the notches gave sharp local concentrations of stress. The point was a somewhat complicated one because if the notched bar tests were carried out at different temperatures in respect to ferrous materials there was a point at which the material would change very suddenly from a tough to a brittle condition on cooling down. In the case of nickel-chrome steel it had been found to be very easy to bring about the brittle condition at normal temperatures.

### Molybdenum Additions Advocated

Silicon tended to produce the brittle condition at normal temperatures since it raised the temperature at which the change from a tough to brittle state occurred. Molybdenum, on the other hand, tended to lower the temperature of the change and was therefore beneficial. The speaker was sorry to find that molybdenum had not been given more attention by the lecturer. If any one element should ever be alloyed with cast iron it was molybdenum, and if the composition or heat treatment of the iron could be so adjusted as to reduce the notch-tough–notch-brittle change to below atmospheric temperature it might be that really ductile cast iron tests would be realised—not such an impossible idea as it might sound at first.

Dr. Doeherty, of London, had carried out some extremely interesting work in that respect, discovering that the effect was not merely one of composition but also of the size of the test pieces. With a large test piece brittle fracture tended to occur more readily than with a small one. Possibly this was a point which might not be generally interesting to ironfounders, but from a general metallurgical point of view he had no hesitation in stating that this sort of phenomenon was of perfectly general application, and would, in time, be found to apply to cast iron as well as to any other ferrous alloy.

### A Confusing Terminology

Another point which might be mentioned was the size of test bar. He noticed that the lecturer was careful to state how big his test bars were whenever he mentioned a test figure. People who were not foundrymen often became very confused over such points. It appeared to be an idea that a 1.2 in. bar, or some other standard bar, would represent the conditions of a similar section of a casting. This did not seem to be quite correct. The feature which governed the physical properties of a test bar was the rate at which it cooled down in the mould. The rate at which it solidified was governed by the amount of surface area compared with volume. It was obvious that a square test bar had twice as much surface area compared with its volume as a slab of the same thickness. Furthermore, to obtain the same rate of cooling in the mould, the test bar would need to be twice as much in diameter (or thickness if of square section) as the thickness of the wall or plate it represented. When advising people who had to use cast irons, and who had to design machinery, it was only fair to make it quite clear what was meant when it was stated that an iron was an 18-ton iron or a 20-ton iron. Furthermore, it behoved reputable ironfounders to have a clear idea themselves about such points.

### Thermal Shock and Temper Brittleness

Mr. Russell quite appreciated that troubles occurred in the case of alloy cast irons which were not encountered with ordinary cast irons. He had referred to some of them in the Paper. For instance, supercooled graphite was harmful if there was thermal shock.

The question of temper brittleness had been dealt with quite recently by Mr. J. E. Hurst, who had contributed an article to the Press advocating the use of molybdenum for the purpose of avoiding temper brittleness in heat-treated cast iron. As Mr. Benson had pointed out, the graphite flakes constituted such extensive notches that there was a considerable masking effect with ordinary cast iron.

A question had been raised as to why pearlitic iron was heat-resisting. Perhaps he had made a mistake. An iron was not heat-resisting because it was pearlitic. It should be fully pearlitic and as close to the cementite limit as possible. He was afraid he could not advance any theoretical consideration in that respect, but his experience of iron was that it should be wholly pearlitic if it was to be pearlitic at all.

The subject of gases in metals was receiving a considerable amount of attention nowadays, particularly by the Research Association. The structure of Silal was due to the fact that its graphite formation was almost entirely dependent upon gas reaction. He fully appreciated the significance of the remarks with regard to size of test bars.

Mr. T. Makemson (secretary, Manchester Association of Engineers), expressed his deep appreciation of the valuable information imparted by the lecturer, and thanked the Lancashire Branch for their kind invitation to the members of the Manchester Association of Engineers to attend the proceedings.

### Price of Raw Materials

In reply to a question raised by Mr. A. Sutcliffe, Mr. Russell expressed the opinion that if people would not pay for good materials they were not worth working for. It might be possible to mix any kind of iron from a No. 3 basis downwards in silicon but not upwards. Incidentally, in the case of alloy cast irons of any particular value, particularly from a heat-resisting point of view, hæmatites and steel were the basis. Outside scrap in alloy irons was ruled out; foundry re-melt could be used, but outside scrap of unknown quality was never used.

### Relative Conditions

Mr. A. Jackson thought that foundrymen would regard the Paper in three ways. First of all, they had to melt the cast irons. When they were melted they had to consider how they would run into the moulds, and, lastly, after casting how they were going to set into the solid cast iron. Once castings were passed out of the foundry, the foundryman considered he had finished with them. Then there was a second stage in which the castings were machined and tested; if they were alright they were passed, but if they did not stand up to the tests then the foundryman was told what was the matter with them. A third stage was that the castings had to be sold.

Would Mr. Russell state what was the variation from the ordinary cast iron in the running and the setting, and what the additional cost per cwt. was of an alloy cast iron mixture?

### Minimum Production Difficulties

Mr. Russell said he had purposely refrained from speaking about alloy cast iron production, because the previous Paper he had presented to the members of the Institute of British Foundrymen dealt very fully with that aspect of the question. The ordinary nickel-chrome cast iron, with 1.5 per cent. nickel and 0.5 per cent. of chromium was no more difficult to produce than the corresponding grade of cast iron from the foundry point of view, either in running or setting, and it made little difference to the shrinkage, except that when using cold alloys there was a cooling of the metal. There must be carefully controlled melting conditions giving the maximum possible temperature out of the cupola. Personally, he had found so much difficulty in melting, etc., now that he used the rotary furnace almost exclusively for melting alloy cast irons. It was not only a case of difficulty of temperature, but also the difficulty of separation of alloys from ordinary irons. If it was intended to make one brand of alloy cast iron exclusively then the cupola was still far the best means of doing so.

One per cent. of nickel cost 2s. per cwt., chromium about 8d. per cwt., while molybdenum was more expensive but there was not so much of it required. The results obtained were well worth the extra cost.

### Chromium Irons

Mr. A. Phillips said that in the production of chromium cast irons, hard patches were sometimes found, due, probably, to incorrect melting or the incorrect introduction of the chromium. If such irons were re-melted in the ordinary cupola, difficulty was sometimes experienced in re-dissolving these chromium carbide areas, with the result that there were hard spots in the casting. Could the lecturer furnish any information in regard to this?

The lecturer had certainly dealt with typical industrial applications of the special alloy cast irons, and he agreed that price was not the primary consideration. It was a question of service.

### Austenitic Cast Irons

In the production of some austenitic cast irons produced in the cupola, there was apt to be a liberation of "kish." In such cases certain elements were added, such as aluminium or copper to prevent this. Could the throw-out of the "kish" be avoided without the use of aluminium or copper? An illustration had been given of a pot for a die-casting machine. The chief problem with regard to that type of die-casting machine was the plunger, or the material for the plunger, and not the pot itself. With ordinary cast iron, erosion of the plunger took place, whereas with certain alloy cast irons this could be avoided. What did the lecturer consider to be the most suitable material for a plunger in a die-casting machine of the type described? Had the lecturer experienced any trouble when he had austenitic cast irons which could be machined quite readily, but which, when machined, were found to have developed hard martensitic surfaces owing to increased speed in machining?

Information with regard to Ni-Tensyl irons and their loads was most interesting; but he ventured to say that it would be of greater interest to most of those present if the loads were also stated in lbs., with the size of the bar as well as the transverse rupture stress. It was fully appreciated that the transverse rupture test gave the figure which was comparable for every size bar. In the impact tests detailed in the Paper, ordinary machinery cast iron gave 28.3 transverse rupture stress with 15 tons tensile. Nicro-Resist in that particular case only gave 27.2 rupture stress, and 13 tons U.T.S. This showed a lower tensile test and a lower transverse rupture stress. Was this intended so as to give a higher impact value, or was it the usual test obtained with a Nicro-Resist iron?

Another point upon which he would like to touch was the prevention of porous parts. An illustration had been shown of a large feeding head on a casting. What was the lecturer's view concerning the use of a feeding rod, which was a common practice in the foundry when producing ordinary cast iron? Personally, he had found great difficulty in using a feeding rod for austenitic cast iron.

### Avoiding Hard Spots

Mr. Russell said that the problem of carbide areas in chrome irons had been dealt with very extensively in published literature. It was undoubtedly possible to get carbide areas in metal produced by cold additions at the spout due to improper dissolving. It was a question very largely of the choice of a ferro-chrome of the correct melting point. The carbon must neither be too high nor too low; and, in his experience, about 5 per cent. carbon was the best grade. If the hardness persisted on re-melting, it would be because the iron was rather above what he had termed the pearlite limit and free cementite existed. When free cementite occurred in the presence of chromium, it tended to occur not in a distributed form, but in a localised form. This was not, in his opinion, due to the chromium not being added, but to the mere fact that it was present.

He was very glad to hear Mr. Phillips mention that service was the main factor to be taken into consideration. He had no experience of carbon coming out of austenitic cast irons as "kish"; his experience on austenitic irons had been entirely limited to irons that were mixed in the cold, and melted as one. It was probable that if the additions were added in the liquid form, "kish" would arise.

A point had been mentioned with regard to die-casting machine plungers. Ni-Resist had proved to be of definite advantage. In the case of ordinary cast-iron pots, the coefficient of expansion must be borne in mind, and extra clearance had to be allowed for in the cold. The plungers undoubtedly did wear rather more quickly than the pots, the ratio being approximately about two plungers to one pot.

### Minimising the Martensitic Hazard

He had had a certain amount of experience with regard to austenitic irons becoming martensitic on machining. It would undoubtedly occur if the alloy contents were low; but he always made it a practice, if possible, to keep the alloy contents at least 2 per cent. above the minimum.

MR. PHILLIPS: Do you mean the graphitiser of the alloys?

MR. RUSSELL said he was referring to the martensitic breakdown. The minimum was 12 per cent. He did not produce anything under 14 or 15 per cent. With that proportion, he had attempted to produce hardness and failed, and similarly with Nicrosilal, which was about 17 per cent. In that way the work hardness was overcome, although it was probable that the iron was not so good in resisting the abrasion of sand. It was a great advantage that annealing was so simple. If work hardness occurred, it could be annealed back by heating up to 800 or 850 deg. C., and cooling it down again, whereupon the work hardness disappeared. The load on an inch square bar in Ni-Tensyl would be 4,000 to 4,800 lbs. He could not give any 2 by 1 figures, because he had never made them.

Mention had been made of 13 tons on Ni-Resist. He was aware that most people claimed 16 tons. His own experience had been that to produce satisfactory castings for soundness, and ease of machining, 13 tons was the most which could be normally guaranteed. By trying to get higher strengths, one would be running into difficulties of machining.

### Feeding Rods Denounced

Feeding rods for austenitic cast iron were definitely unworkable, and similarly in the case of low carbon iron, such as Ni-Tensyl, because the iron had such a short melting range, and the action of the feeding rod tended to pull metal out of the casting rather than to push it in. All feeders must be of the self-feeding type.

### Shrinkage Allowances

Mr. J. H. D. Bradshaw referred to the production of austenitic castings. Mr. Russell had spoken concerning feeding, but another important factor to the foundryman was that shrinkage in austenitic irons was much greater than with ordinary types of iron; the foundryman should therefore make the necessary allowances in his pattern. He was not quite certain whether he had understood Mr. Russell correctly regarding Ni-Tensyl; the analysis he had thought Mr. Russell had given was: total carbon 2.8 to 2.9 per cent.; silicon 1.8 to 2 per cent., and nickel 1 per cent. He understood the lecturer to qualify that by saying that the iron would, if cast without a nickel addition, cast white. He suggested that if the figures were correct, iron, cast normally, would be grey.

Mr. Sutcliffe said the lecturer had dealt very ably with the problem of carbide spots produced in chromium castings, but he would venture to suggest that the introduction of the chromium by means of a chromium pig would probably solve the difficulty. The difference in the fusing points of the two materials was very great. It was probably now well known that there was on the market a ternary alloy of chromium which had a fusing point not much greater than cupola iron so that there would be less loss of chromium.

Mr. Russell, referring to the point of the patternmaker's shrinkage in austenitic cast irons, said it would be in the proportion of three-sixteenths inch per foot. There was very much less linear shrinkage trouble than with ordinary cast iron, owing to the toughness.

With regard to the analysis of Ni-Tensyl, the figures given were for the ultimate result. The original metal was such as to produce a white fracture on a fairly thick bar about 4 in. square. This was then inoculated with ferro-silicon and nickel.

He agreed that the use of chromium pig was the best method to adopt.

### Work Hardening

Mr. J. A. Reynolds observed that work hardening seemed to occur in grinding or machining at excessive speeds, thus causing surface heating of the material. The metal did not get red-hot except just at the point of contact. The same thing occurred with malleable iron. There was intense surface heating, and in some cases the metal became non-magnetic, and invariably hard. It was, therefore, necessary to restrict the speed of grinding and the speed of machining, otherwise there would be trouble, particularly with thin sections.

Mr. Phillips had mentioned the formation of "kish" in austenitic cast iron. In melting austenitic iron in the crucible, particularly where there was a high percentage of manganese in the mixture, the manganese attacked the clay and released the carbon portion of the crucible, which came to the top of the molten iron, and might interfere with the running. The remedy was a special type of crucible. Aluminium was perhaps not a cure for "kish," but would make an austenitic iron better for running thin sections. He was not sure whether the trouble experienced by Mr. Phillips was due to "kish," or to sluggish running metal.

Mr. Phillips said he was referring to cupola melting and not crucible melting.

Mr. Reynolds wished to mention one or two points in connection with austenitic and nickel chromium irons. For one thing, a higher contraction should be allowed for by the pattern-maker. Another point was that the liquid shrinkage—not the solid contraction—was usually greater; and it was necessary in most cases to use better methods of feeding and various methods of dealing with shrinkage. For low silicon irons he had found 1.0 per cent. nickel was valuable. By adding that proportion of nickel to an otherwise unmachinable iron two results were achieved: (1) machinability, and (2) a harder matrix, and a stronger iron, despite the fact that it was easier to machine.

Mr. Russell said he might at some time try the effect of aluminium in Ni-Resist to see if it helped fluidity.

### Vote of Thanks

Mr. E. Longden, in proposing a hearty vote of thanks to the lecturer for his extremely interesting Paper, referred to the fact that he had been associated with the lecturer in the investigations of the Cast Iron Sub-Committee of the Institute of British Foundrymen. The work which had been done by the lecturer on that sub-committee was of the highest possible value and was much appreciated by the members of the Technical Committee and the Institute of British Foundrymen.

Mr. Norman Cook seconded the vote of thanks, which was carried unanimously.

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# Scottish Branch

## A PLEA FOR LOAM MOULDING

By R. Liddle (Associate Member)

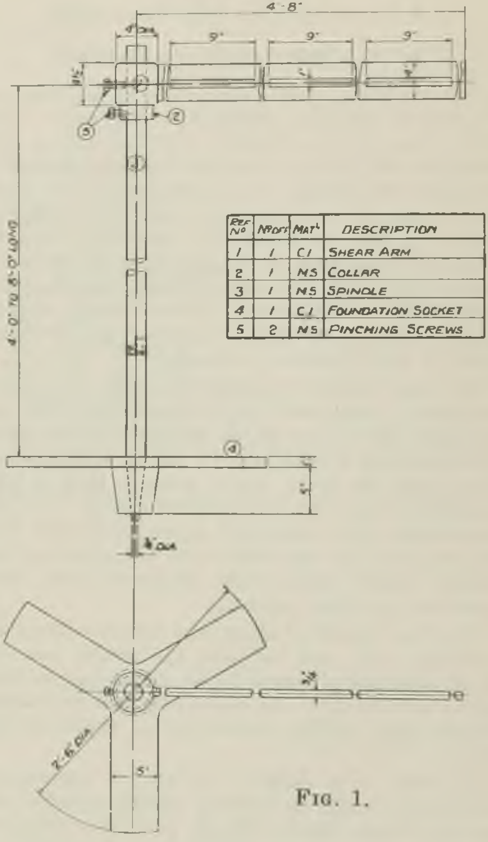
In preparing this Paper, the author has endeavoured to keep before him the very varied views that exist in foundry practice, but he does not offer an apology for the method adopted in treating this thesis. It is the belief of a great many men, who are closely related to the foundry industry, that so much has been said, and the changes have been so rapid within the past few years, that the problem of loam moulding has apparently disappeared. This results because of the scarcity of this particular type of craftsman in the foundries of to-day.

In the writer's opinion it is to be deeply regretted that this view should be held, apparently for very varied reasons, by so many distinguished founders. It would appear, however, that the main reason given is that in loam moulding the cost is considered high. At the same time it is generally agreed that this type of moulding is very safe, and the castings produced equally good, when compared with those moulded by other methods.

For the benefit of those who are not altogether familiar with this subject, the writer has had some sketches prepared in an endeavour to illustrate more clearly the plant required for casting simple jobs, having cylindrical or spherical contours.

In Fig. 1 is shown a group of components including crosses or footstep socket, spindle, and spindle arms which will at once be recognised by all who have even the slightest knowledge of foundry work.

It is desirable to stress how essential it is that the parts illustrated in Fig. 1 must be made from good quality steel. If they are not to be machined all over, bright bar steel must be chosen. Now in the manufacture of these component parts great care should be taken to ensure that all sizes are to gauge, so that, when




| REF No | No OFF | MATL | DESCRIPTION |
|---|---|---|---|
| 1 | 1 | CI | SHEAR ARM |
| 2 | 1 | MS | COLLAR |
| 3 | 1 | MS | SPINDLE |
| 4 | 1 | CI | FOUNDATION SOCKET |
| 5 | 2 | MS | PINCHING SCREWS |

FIG. 1.

assembled each part will fit properly to place and have only the predetermined clearances, otherwise, one could not rely on their being perfectly true. The producing of such parts as described is not costly, and provided reasonable care is taken, either, while in use or while lying in store, they will give many years useful service.

### Standardised Components

To eliminate the carrying of large stocks of this kind, sockets and spindles are made to stan-

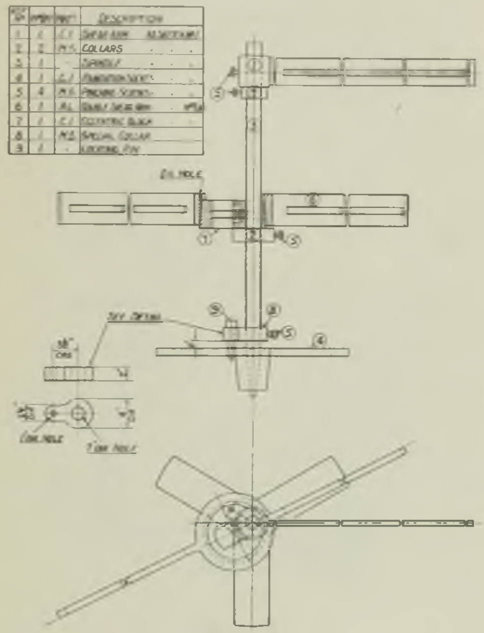



FIG. 2.

dard sizes. A master spindle should be kept as a gauge for sizes, so that in the event of replacements being required, the correct dimensions can be readily obtained.

The short spindles can be used as mandrels with which to cast sockets or crosses and makes the operation very simple: an open sand mould is made to the dimensions desired for the cross, then the mandrel cleaned, heated, coated with plumbago water, and dried and inserted into the boss of the cross. Care must be taken to have the mandrel plumb and passing through the bottom of the mould face at least 1 in. This, then, leaves a fine hole, hard wearing and

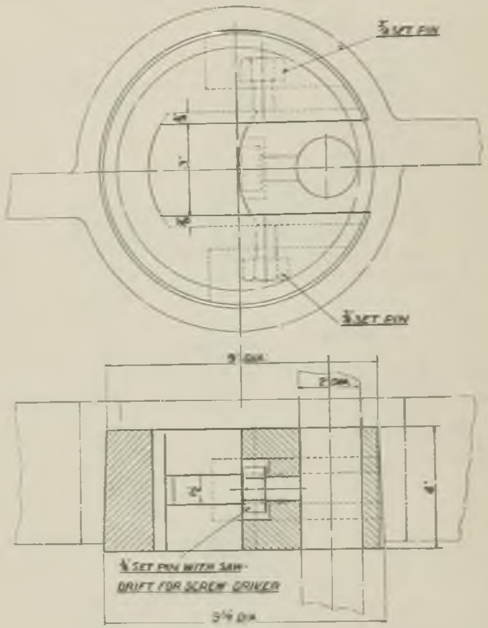



FIG. 2A.

definitely true. The boss should be purposely kept short, so that any spindle will fit, as when these parts are standardised, many hours are saved. Personal experience has shown that the lack of standardisation in some foundries is appalling, and much time is unnecessarily lost looking for the particular size or type of apparatus required. It will not be necessary to press any further the benefits derived from standardisation, as from the foregoing remarks in conjunction with Fig. 1, one can readily appreciate the time and labour saved.

In addition to the foregoing, and as shown in Fig. 2, an equipment is detailed which can be

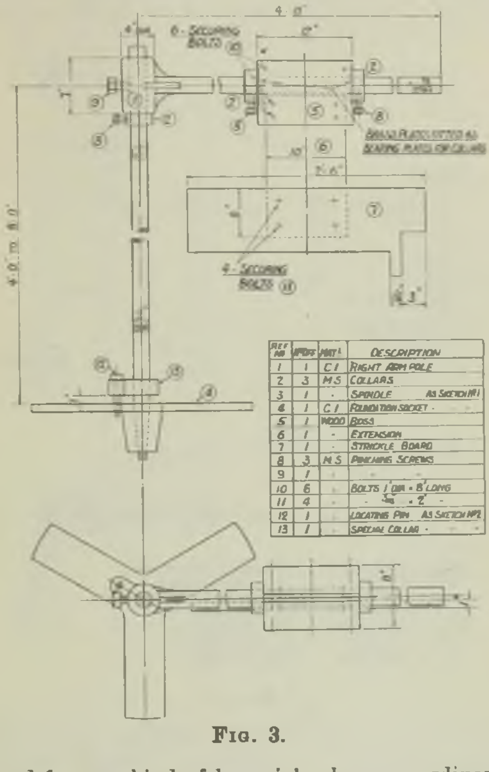
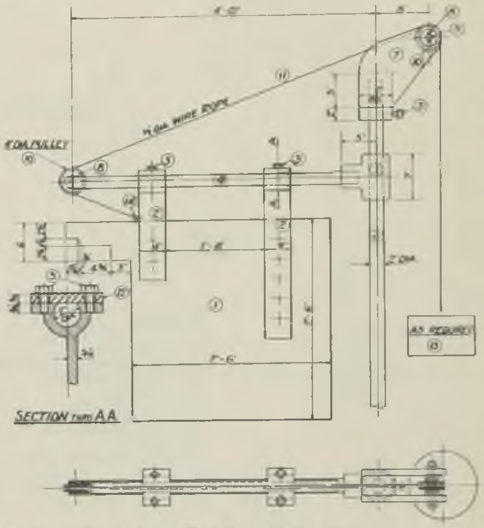



Fig. 3.

used for any kind of loam job where an ordinary spindle can operate, as well as strickle half-circles apart, extended sections of circles, and eccentrics. Detail of an eccentric block is shown in Fig. 2A.

As can be seen from Fig. 3, there is an added advantage in using the spindle, in so far that a number of parts can at the same time be assembled, such as a right-arm pole, or eccentric arm bearing, for the purpose of strickling-out branches or large facings on the core or mould as required. It is interesting to note that the right-arm pole can be set to any de-




| Ref No. | No. Req. | Mat. | Description | Ref No. | No. Req. | Mat. | Description |
|---|---|---|---|---|---|---|---|
| 1 | 1 | WOOD | BOARD | 8 | 4 | M.S. | SPLIT PINS |
| 2 | 2 | C.I. | SUPPORTING ARMS | 9 | 6 | " | WASHERS |
| 3 | 5 | M.S. | SET SCREWS | 10 | 2 | C.I. | PULLEYS |
| 4 | 1 | " | ARM SPINDLE | 11 | 1 | STEEL | ROPE |
| 5 | 1 | M.S. | TEE PIECE | 12 | 2 | M.S. | STRAPS |
| 6 | 1 | M.S. | SPINDLE | 13 | 1 | C.I. | WEIGHT |
| 7 | 1 | C.I. | HEADPIECE | 14 | 1 | STEEL | HOOK |

**Fig. 4.**

sired degree, and with the addition of a second pole, set from the first, any branch can be strickled, in almost any position, as is shown in Fig. 3.

Fig. 4 illustrates similar component parts which have greater utility. The arm faces and the other movable parts must be accurately machined to make a sliding fit. These parts are especially designed to sweep any shape or contour desired. The board being hung and balanced, can travel out or in along the line contour at bottom flange, or template, as required.

### Cylinder Moulding

Fig. 5 shows a cylindrical vessel, 12 ft. dia. by 10 ft. deep, and this, to some, would appear a

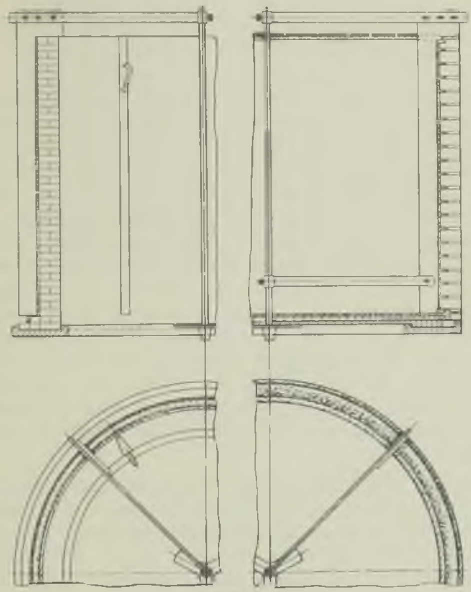


FIG. 5.

big proposition, but to moulders accustomed to this class of work it is a simple job, but expensive to cast, as the formation gives large dimensions for little weight, and to the founder this means maximum area to find, and weight to handle to produce such a vessel having a thickness of $\frac{3}{4}$ in. or $\frac{7}{8}$ in., with flanges $1\frac{1}{4}$ in. or $1\frac{3}{8}$ in. thick.

In Scotland, the method favoured is to build with the usual spindle and boards, but with a building ring inserted every fourth or fifth course, this being done to help resistance. It is imperative that the job is rammed up in a pit, or in cribplates. On the other hand, the practice adopted in England is to have rings with prods 10 or 12 in. long cast on, to hold the brickwork against casting pressure, which, of course, eliminates the need for ramming. However, it must be remembered that these rings are costly, and, if stored, take up a considerable amount of space. On a straightforward one-off job, no great saving can be accomplished; the only comparison to be made, as to these alternative methods, is that, by the English practice, ramming is eliminated, whereas in the Scottish method the rings can be produced at a lesser cost. In addition to the methods generally adopted in Scotland and England, another procedure is to set up the cope board in the usual way, and build, with a building ring on the line of the bottom flange, this being repeated after each layer of bricks. By this method 20 rings would be used in building a vessel 10 ft. deep, and this, it will be noted, is twice the amount required by the Scottish practice, and 12 more than required in the prodded or English procedure.

In the order stated the weight of metal would be 100 per cent. more and 20 per cent. less; the difference in time of manufacture would be 50 per cent. less and 100 per cent. more. The time required to build these three different types of mould would be approximately the same. The Scottish method requires ten rings, has a total weight of 48 cwts. and takes 17 hrs. The English system with eight rings (having prods) has a total weight of 105 cwts., whilst the time taken is 64 hrs. The third method, with 20 rings, has a total weight of 96 cwts., a time of 34 hrs., and to this, if one adds ramming and time required for digging out after casting, would involve 140 hrs., that is, about £7 extra on the Scottish method. This money cannot be recovered on the saving from the cost of a smaller number of rings used on the Scottish method. In the foregoing it is assumed that these rings are in the stock yard where the various methods mentioned are wrought.

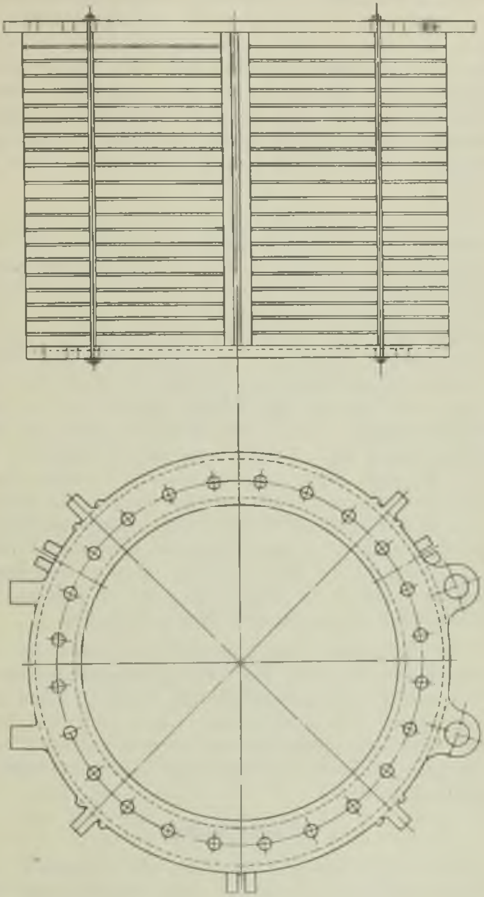


**Fig.** 6.

So far there would appear little saving on production costs, but then one must not forget to consider the time saved during ramming and digging, and also yard accommodation saved through reduced amount of tackle. In the event, however, of this being a job where two or more are required, the procedure would be slightly altered, in so far that it would only be necessary to build the core and cope once, as they are salved after first cast. It will be readily appreciated that time and money are saved by this method which can be easily accomplished if three joints are made on each section of the mould as is shown in Fig. 6.

It will be noticed that the cope ring is brought into line with the bottom flange, and the dual reason for this is, that it carries the completed cope to the stove, and keeps it intact until the casting is stripped from the mould. By taking the full depth of the flange, it is a check on the pressure at the greatest point. This is done by sweeping a joint at the level of the flange and having the lifting plates cast to the desired shape, so as to fit around a third of the circle, less 2 in. It must be done, however, so that it will clear any projections which may come in line, and each section should have four 1-in. lifters cast on them, and so arranged that the load will be evenly distributed when lifting. A lug should be cast on, 2 in. from each end, and at least 6 in. by $4\frac{1}{2}$ in., as it has to be utilised for tying the job firmly together.

The building rings should be made to fit exactly the shape of the lifting plates, and have holes cored in them sufficiently large to allow an easy passage during placing. Care must be taken that all rings are made up from the side of the hole to the lifters, as this helps to bind the complete building.

## Coremaking

The core is jointed in much the same way, a lighter plate or a heavy type of grid may be used, each section having four lifters cast on, the plates should be somewhat shorter so as to allow for three triangular easing bars about 2 in.

less than the length of the core to be built. Then to complete the gear required for the core, three further stiffening rings with dimensions as that of lifting sections and with cored holes to clear the lifters.

### Patternmaking

To build this job it would only be necessary for the pattern shop to supply the boards shown in Fig. 7. The plain bearing board is used for

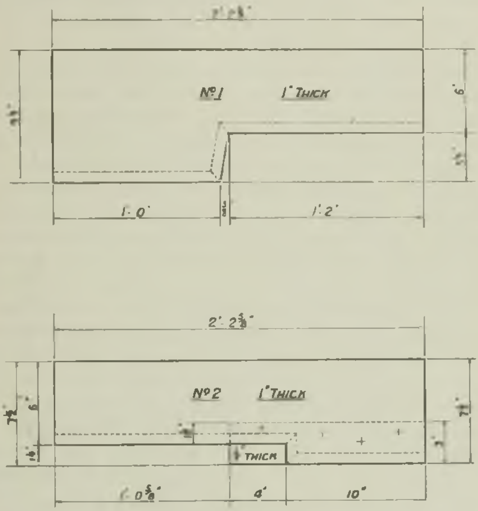



Fig. 7.

first casting only: the flange board is cut to sweep the flange giving the desired thickness for all castings required, and as no bearing-board sweeps the edge of the bottom flange, the flange board is set to size for doing this, and is cut to allow the stripping piece to be withdrawn as shown. A cope board has the top flange-piece formed on it, its length being equal to the depth of the casting minus the thickness of the bottom flange.

A core board should be the whole length of the casting, with a straight board forming the top, and this with cope and core gauge sticks, completes the necessary plant so far as the pattern work is concerned.

### Assembling the Mould

To assemble this job, proceed along usual lines, which are as follow:—A bottom plate is laid down with the cross and spindle fixed in the centre on a good level foundation, so that the spindle will be vertical. This plate must have four lifting lugs, and be at least 6 in. to 8 in. broad, but the shorter lugs should have a 2-in. square slotted hole cored on the edge of the plate at centre of the lugs. The object of these holes is to receive the bolts for binding before casting. In general these plates should be designed approximately 1 ft. 4 in. larger than the flange of the casting, and should be of robust design, as a considerable load may have to be carried on it, to and from the stove for drying purposes.

The bearing board marked No. 1 in Fig. 7 may be set and the section for cope ring finished. The cope ring is then set in place and bearing board marked No. 2, used to sweep the joint on the cope ring, which should clear the flange of the casting when completed. When it is sufficiently set, it can be swept to the desired thickness with either sand or soft brick, and then both the cope board and the first lifting plate set and the latter built up in the usual manner. Care must be taken, however, that all plant used is made strictly to given dimensions, so that the other sections will have sufficient space to accomplish easy fitting.

The first section now being completed, it is obvious that all other sections required, will be built in exactly the same manner, finished and strickled up. These sections have now to be bolted together, and in a job such as this, the proper size and number of bolts required should be in the store, ready for use, thereby saving time and trouble at a busy moment. This brings one to the point of how many bolts should be used in such a case as this, and to this the writer speaks from his personal experience. He has found it advisable to have quite a number of bolts and washers strong but light, so that one man can bind a section without assistance. When the bolts are effectively tightened the cope should then be skinned and parted, care being taken to mark the cope ring and the bottom section of the mould for assembly.

### Core Assembly

Work is now commenced on the core. The board is set, the lifting plates laid in position and kept sufficiently apart to allow the required space for the easing bars to be inserted, and it is advantageous to have these covered with brown paper, which should receive a coat of blackwash, as by this means an ideal joint is made, and the bars can be easily withdrawn from the core after casting. To complete the building is a comparatively easy job, and if the grids have been stayed at the lifters, these sections will be fit for use for quite a long time with very little repairs. Having now been strickled and allowed to set, it can be put into the stove to dry.

The top portion can now be considered, as it still has to be built. The plate for this section should have $2\frac{1}{2}$-in. prods and be of the same size and shape as the bottom one. It should be covered with stiff loam, $\frac{1}{2}$ in. in excess of length of prods. This is now ready for the stove, and when dried is placed on a socket or jig to strickle up a level face. Circles of the core and cope diameter can be drawn on the face and the gates marked off and passed through the top to complete the building.

### Finishing Operations

When drying is completed the bottom plate with core may be bedded in a pit for assembly. and if set level there should be no cause whereby trouble can arise. It is necessary that the cope should hang definitely vertical, so that it can be lowered gently to the marks already referred to. The thicknesses should be examined and, if correct, the cope can be lifted to ascertain that no crushing has taken place, and when correct relaid in place.

The top is now turned over and the inlets on the top side of the plate made up to suit the gate pins to be used in forming the head. If the gates are checked and found correct, the top can be put in place, the joints sealed up, and finally the top plate bolted tightly to the bottom with six $1\frac{3}{4}$-in. dia. bolts, fitting into the slots already described. To complete the head, it is necessary to use crib plates on the outside, and two rows of bricks built on end, in the inside, and when this is completed the job can be cast.

### Stripping

The easing of the casting can be carried out in approximately 30 to 45 minutes later, and, with the aid of the crane, the bars can be withdrawn from the core. The cope section may then be eased under the top flange by removing the top layer of bricks from the cope.

The following morning all binding material can be removed to allow the sections to be taken apart. The core sections can be lifted out and laid on the floor, and the cope parts can also be set, either on the top part or on a suitable temporary site, then the casting sent to the dressing shop. This leaves the bottom bearing with the cope ring in position, which has not been disturbed. The loam face, if taken away leaves the brickwork in perfect condition to strickle up, this can be done with the aid of No. 2 bearing board, as shown in Fig. 7. The stripping piece removed allows the flange to be strickled to the desired thickness. The cope board is now checked for size, and the sections forming the cope are placed and examined for positions by trying the board round each section as laid down before the crane is taken away. If the operation is done with the aid of marks on the cope ring, it becomes a comparatively simple job. The difference in time on, say, a three-off job, as against three castings made under usual foundry practice is very considerable and really worth while.

It is to be understood, that many other types of castings other than those produced by the equipment already described, are made by other

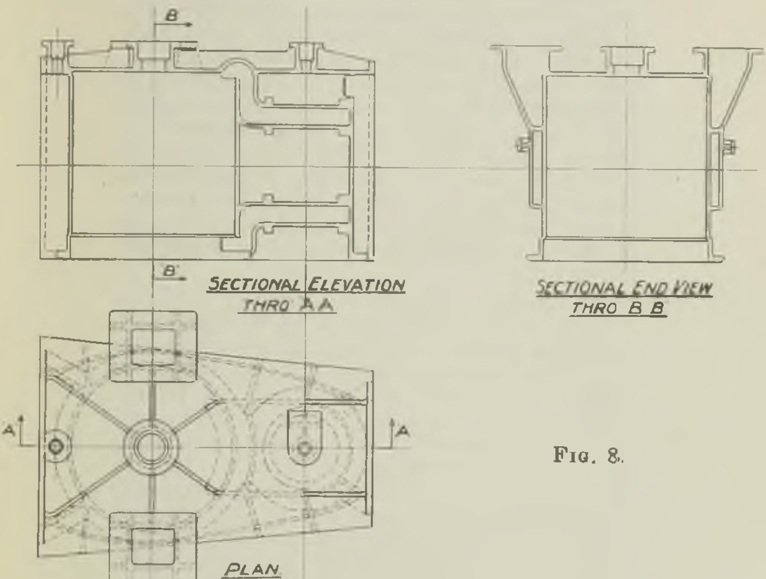



Fig. 8.

methods, and still retain the advantage of not requiring a complete pattern, such as is required, when being cast by a sand medium.

## High-Pressure Cylinders in Loam

The writer also wishes to deal with the class of work which is really intricate, and has a great labour value, because of the time spent on producing such castings no matter what type of moulding is adopted. The present custom followed by most executives in large engineering firms to-day, is to endeavour to determine whether it is cheaper to make a pattern or cast in loam, but their lack of knowledge and experience in loam practice, generally weighs the balance in favour of a sand casting.

From Fig. 8, *et seq.*, the writer is desirous of showing how that the saving from loam moulding should be greater than from jobs where patterns have to be made and cast in sand. Fig. 8 shows a sectional arrangement of a high-pressure cylinder when cast, and this in conjunction with the following sketches will help to show the method of producing such a casting. Fig. 9 shows a group of templates required for making a high-pressure cylinder, and it is to be noted that the more intricate it may be the cheaper will become its final cost, as in ordinary circumstances, longer time would be allowed to produce a more difficult casting, than a straightforward one.

The method adopted in moulding such an article as this, would be to use a spindle to sweep the bearing or print, and bottom mould-face. Care must be taken that the spindle is truly vertical and the foundation or bottom moulding plate, perfectly level. This plate must be at least 12 in. greater, each side, than the size of the job to be cast. Fig. 10 shows the bottom of the mould mounted on the bottom plate. The larger lugs on the sides are required in order to lift the load built thereon, including the casting contained in the mould, and it is obvious therefore, that in determining the thickness of these lugs, a fairly high safety factor should be employed throughout all calculations. The smaller lugs shown are for binding purposes. The face is strickled to correspond with the face of the board, which has been shaped to suit the particular job in hand. When completed, the centre lines should be carefully marked off on this face.

A section of the pattern forming the flange, having a uniform thickness all round is then put in place, and the stripping piece on the board should be withdrawn so that the bottom joint can be strickled, and this board removed. The main core board can now be set, and the core built up and strickled complete. The practical moulder may consider the method wherein the main core remains stationary to be unorthodox, but nevertheless it has a dual advantage in that (1) if, when the plate is being designed, a sufficiently large hole is allowed for the gas to have free escape then there is no need to fill the cavity of the core which is usually done in standard practice, and (2) it ensures a much truer centre on which to assemble the

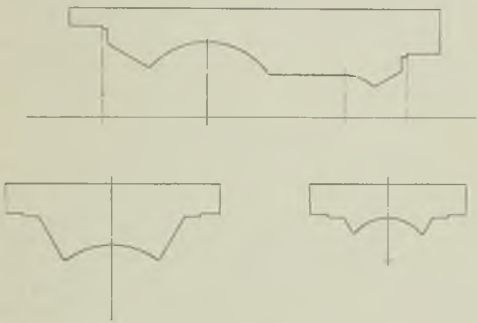


Fig. 9.

cores and other parts of the mould. The wood flange being withdrawn this section can be stiffened or dried in the stove, it may then be finished and finally dried. The centre lines can now be drawn lightly over the full length of the core, and if proved correct, it could be left until required.

Before dealing with the building of the core and cope for the other sections the author would like to mention that it is beneficial to have work on all sections proceeding at the same time, and this is especially true when the job on hand is required for urgent delivery.

Fig. 11 shows the side plate in position to commence building, the dimensions of the plate should be 2 ft. longer than the cylinder, and approximately 2 in. less than the distance between the inside top and bottom flanges, so as to allow freedom to carry out smooth working in setting operations and in closing or assembling. As in the case of the plates already described, this one also has lifting lugs, which are so arranged as to distribute the load evenly in any reasonable position and at any time. When casting the plate, the necessary holes have to be cored as would be required for bolts passing through the plate for bolting purposes, and also for vents for the escape of gas, etc. Six or more 1-in. wrought-iron bars are cast in, near the top and bottom edge of the plate to facilitate the fastening to the plate of any grids that may have to be secured at certain positions. This is done by inserting the bars in the cores made in the plate.

### Template Details

As shown in Fig. 9, the parts required from the patternshop for these two sections or sides of the mould, are two templates, having their working faces the same size and shape to correspond with that between the flanges of the cylinder. They are held in position by two vertical flanges coinciding with the valve face and receiver end of the cylinder. All other projections are placed on bars which extend across the mould face, and which are securely fastened in place and marked. Drain bosses and supporting webs to be cast on flanges are placed in their correct positions on the template. This frame is quite like a corebox of skeleton design, and can be easily set with the aid of a spirit level, or checked at any time while in use. The most convenient method in setting such a job is to have a bar so placed on the outside of the templates that a level laid across them will immediately show if alignment is correct. The frame is then laid on the plate the required distance apart.

The length of the templates is the same as the side plate, and this being 2 ft. longer than the cylinder it accommodates a 12-in. bearing or joint at each end of the mould. In cutting the template at least 6 in. of wood should be left to give strength on frame to strickle the face of the joints and moulds. In building the procedure is, as is common in loam moulding, to bolt the built-up material, with the aid of grids, to the lifting plate, where vents or cores have to be placed. This can be simply accomplished owing to the open and easy access to this mould section. When this section has been strickled up, the templates and other projections removed and dressed, it is then allowed to stiffen before being dried and finished in the usual manner.

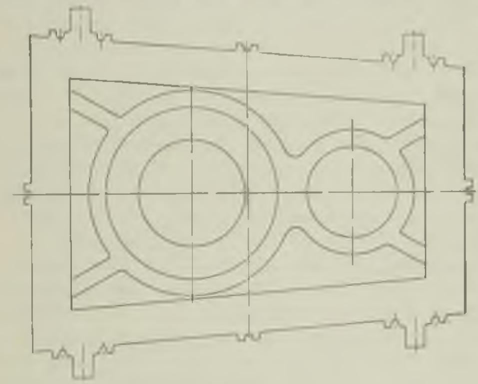


Fig. 10.

The receiver end section is carried out in the same manner but it is simpler and a smaller part to mould. Two templates are required (as shown in Fig. 9) the exact size and shape to coincide with the inside wall of this part of the cylinder, and like the sides are the depth of the cylinder apart. They are held together with bars, the bottom one of which is made longer to enable the setting of frame to be accomplished easily over the plate on which it is built. Stool brackets or other such projections are placed on bars as on the side frames, previously described. The lifting plate for this section will differ slightly in design as compared with the one used for the side plates. On this plate wrought-iron handles replace the lugs: these handles should be designed similarly to a semicircle and made from $1\frac{3}{4}$-in. dia. bar, and when designing them they must be sufficiently large to allow the hook of a lifting chain to pass through it without difficulty. Fig. 11A shows the end plate.

It is advantageous to have one or two large holes cored in the plate, as this allows a certain amount of freedom to fasten up and seal the core-vent arrangement of jacket cores. Other smaller holes, for bolts, etc., should be cored in such positions as found most convenient. Obviously it will be necessary to have two $1\frac{1}{2}$-in. lifters inside the plate to enable it to be lifted on end, and also to balance the load in closing this section. With the slide valve face as with the piston valve chamber the method of building is the same, but the assembly is slightly different. The slide valve face is fastened on to the end moulding-plate complete: this, by the way, is common practice on the North-East coast.

In assembling the piston valve the cores are built to place as is indicated by the centre line already drawn on the main core. It is checked by a side template cut exactly and marked off to the centre line on the main core, and from Fig. 8 the advantage of this method can readily be appreciated, as thicknesses, etc., can all be inspected, thereby preventing any mishap which might occur if one could not see each core as the job was being built.

### Method for Top Part

In respect to the top part the method which should be adopted is to set up a cross and spindle, and a level bearing is strickled up. Its size is approximately 18 in. larger on each side than the flange of the cylinder. It is essential that the bearing is level, as from this the pattern is set. In this case the pattern would be a complete section of the top cylinder flange, including all stools, bosses, etc., attached to it in the usual manner. All screws, nails, etc., should be driven in from the bottom side of the board, as when this is done, the whole thing can be turned over after it is built. This ensures both a good lift and top part.

The pattern is then set up on the bed previously prepared, the centre lines of the pattern and of the bed coming into line. The moulder can be confident that, providing sufficient weight is placed on top of the pattern, it will remain in its true position. As an additional check, the spindle which is still in a central position can be used to determine any dimension in respect to branches, brackets, bosses, etc.

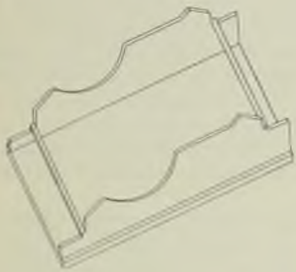


Fig. 11.

Fig. 11a.

The building of the top may now be started, and at this stage the position of the gate pins marked off, also any risers or vents passing through the lifting plate. The lifting grid may be tried in place, fitted, and all pins set to their correct positions. This action is built up to the top of the stool flange, so as to allow a joint to be made if required. In the event of such a joint being found unnecessary, it is considered good practice to complete these stool flanges before finally placing the top plate. In some instances it may be found more convenient, or even necessary, to have block cores or a drawback round the stools to allow closing and placing of stool cores. With this now completed, we proceed to assemble the parts of this cylinder and mould as follows.

The bottom plate is set on a suitable site, and this, from experience, would be a pit of depth sufficient to allow ease in casting. If, however, such a site is not available, a job of this description can be cast almost as easily on the floor (since ramming is not required), with the aid of a suitable scaffold.

### Bottom Section

It is essential that the bottom section be set absolutely level, and in any convenient manner secured, so that movement cannot take place during the assembly of the various remaining sections or while being cast. When the job is finally assembled, it should be inspected for injury, the centre lines again checked, the cores forming the valves placed in position, and each proved with the aid of the template and depth stick, the vent connections properly arranged in the placing of each core until the top one is in position. This can be easily visualised by the practical moulder.

The receiver end, if found in order after a careful inspection, is then placed in its true position with the aid of the template already used for the valve end.

The side sections, which have previously been prepared, should now undergo final inspection; if found correct, they should be turned up, one at a time, and placed in position. When in position, it is advisable to check that the prints of the cores correspond with those on the other sections. If there be any doubt that possible injury has occurred during this operation, then the section should be lifted, re-examined, and, when found entirely satisfactory, replaced in its true position, on which there should also be a final check. The side section remaining may now be set, and, when found correct, the cope and the mould should be bolted together. By adopting this procedure, no breakages can possibly take place without its becoming apparent, and therefore a good job can be guaranteed. Vents can now be made up with absolute safety, and by the use of mirrors the complete mould can be inspected in a comparatively short time.

The top section being previously prepared with cores in position, can now be tried to place, the thickness checked and, if found correct, it can be bound to the bottom, along with the securing of any vents to be brought through the top part.

The job is then completed, when, having formed the head in the usual manner, the casting operation then takes place. The moulder's art should, and must, be demonstrated by the result of a good, sound and perfectly-shaped casting. In conclusion, the author wishes to express his thanks to Mr. J. T. McNair for his assistance in preparing the Paper, and for preparing the drawings from which the slides had been made.

# Scottish Branch

## CONTRACTION

By W. Machin (Member), and M. C. Oldham (Member)

It has frequently occurred to the authors that contraction, with its associated problems, is deserving of closer attention than is devoted to it. The problems referred to in this Paper are those experienced not only in the foundry, as manifested by hot tears and cracks, but also in the machine shops, to which all engineering castings are ultimately delivered for machining.

One has frequently heard the statement that nearly all castings contain contraction faults, *i.e.*, cracks, stresses or strains, to some degree. The statement may be true in many instances where care has not been taken by the maker to prevent them, as such faults are known to be caused by many of the operations associated with the varied stages of manufacture.

All cast metals are subject, in varying degree, to the laws governing expansion and contraction, and it is disturbing to note how little attention seems to have been devoted to this subject by research workers on foundry operations. It is no uncommon experience, for example, for some castings that have been machined to be considerably different in dimensions from drawing sizes, the discrepancies occurring sometimes only after a few days standing. Such results arise from release, to some extent, by machining operations, of previously " locked up " stresses, and in view of the modern demand for fine dimensional accuracy such stresses may be the cause of very serious trouble.

It was decided, therefore, that consideration could usefully be given to a few of the factors involved which might be of general interest to foundry workers, metallurgists and engineers.

All phases of casting production to which the founder gives his attention lead up to that critical stage where contraction takes place from the plastic condition to the solid at atmospheric temperature. Castings of iregular section, such as handwheels, for example, which are designed with thin spokes and thick rims, may fly in two or more parts. More often than not, breakages of this kind are the direct result of sudden release of high stresses produced during contraction. A breakage of this kind may be

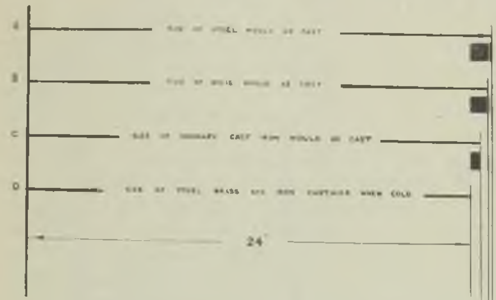



Fig. 1.—Relative Sizes of Moulds and Casting.

brought about by so commonplace an incident as the tap of a small hammer.

### Cause of Faults

Mainly, the causes of contraction faults which occur during the change from the plastic to the cold condition are: irregular thickness of design, method of construction of mould and core, temperature of mould, uneven cooling, or cooling of the casting too quickly. Some of these causes are also associated with other types of defects in castings, but it must be appreciated that the authors in this Paper are dealing only with those caused by contraction.

All workmen and supervisors in the foundry have as their sole objective the production of a shape in metal, to a specified design, which it would be almost impossible to machine or carve out of the solid block, even if it were economical to do so. A bulk of metal cast into a mould of the required interior shape is nothing more than a useless molten mass, and even when it is passing through the plastic stage it contains none of the attributes for which it is useful when cold.

The casting must cool gradually to atmospheric temperature, and during this cooling period complicated reactions take place and the points mentioned require the careful study and attention of all associated with production.

In Fig. 1 is shown a diagram relating to the dimensions of moulds for a casting 24 in. long, just at the point of solidification, and also of the castings after they have cooled to atmospheric temperature. It will be seen that the expansion of each of the metals consequent upon the elevated temperature during melting has made it necessary to make patterns larger than the actual finished article, so that the mould or moulds made from them will produce a casting accurate to the designed size when cold. The size of a mould for a piece of metal 24 in. long to receive the expanded metal in liquid state is as shown at A, B, C, and the same metals when in the cold state have contracted to the bottom line "D."

It is not intended to deal in this Paper with the metallurgical changes that take place during the liquid to plastic stage of the metal, nor is it intended to deal with the question of shrinkage between the liquid and plastic condition. These two subjects are variable according to the metal composition, and each of them, as is well known, is of very great importance regarding other problems connected with castings manufacture. They are, however, not actually considered the cause of such serious defects in a casting as is the period of movement from the plastic to the solid condition.

The line on the diagram at "A" is the widest one, and the metal in this instance is for cast steel, "B" is for brass, and that shown at "C" is for cast iron. The first gives the foundryman most trouble on account of the short freezing range, and the fact that cast steel

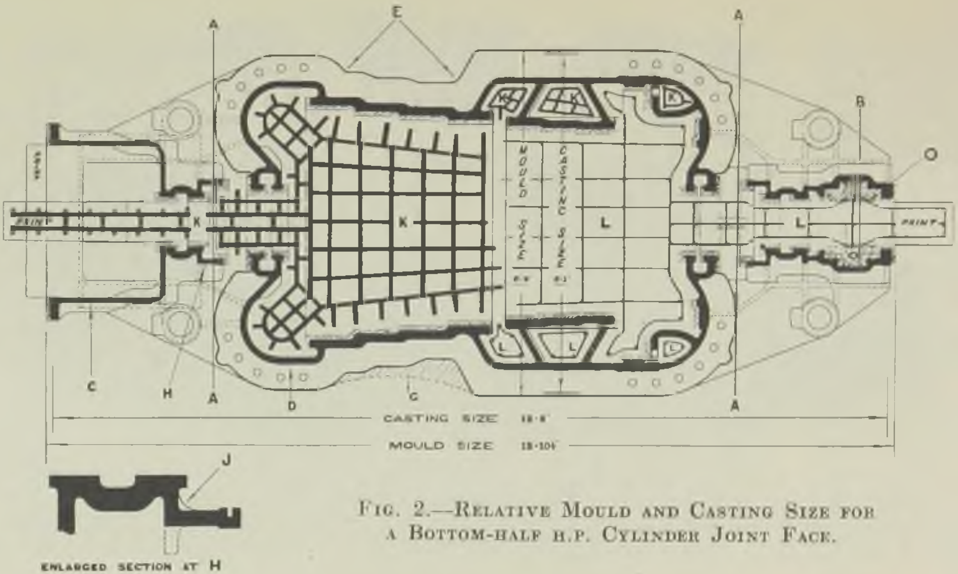



FIG. 2.—RELATIVE MOULD AND CASTING SIZE FOR A BOTTOM-HALF H.P. CYLINDER JOINT FACE.

travels the greatest distance in contracting to the " D " line. This diagram was drawn with the intention of showing in the simplest possible manner the extent of movement of the metal in a mould. This movement is a fundamental property of the materials, and if prevented or retarded in any way, trouble in the form of hot tears or invisible trouble in the form of strains occur.

### Cast Steel

The type of defect which is considered by all inspection authorities as serious (and rightly so) is what is described by the foundryman as a " hot tear." In order to define some of the causes of this, reference is made to Fig. 2, which shows the design of a bottom-half h.p. cylinder-joint face. This particular design has been chosen because of the complicated difficulties associated with contraction during its manufacture. Frequent reference, therefore, will be made to it to illustrate the various points connected with this subject.

The length of this casting is 12 ft. 8 in., but the pattern size from which it was produced was 12 ft. $10\frac{1}{2}$ in. The movement of contraction in this case, therefore, is $2\frac{1}{2}$ in., *i.e.*, the cold casting was that amount shorter than the mould from which it was cast.

The design of this component is not ideal from a foundryman's point of view, and, although many suggestions have been put forward by him for improvement, the designer has not yet found it possible to embody the suggested alterations, so the foundryman must face the risk and do his utmost during manufacture of mould and core to produce a casting free from hot tears. The contraction problem in this instance would have been simplified considerably by casting the bearing blocks separately and joining them to the body of the cylinder with a joint shown at " A." The movement in the casting would then only have been $1\frac{1}{2}$ in. instead of $2\frac{1}{2}$ in.

In addition, the designer could have helped the foundryman considerably by making the thin

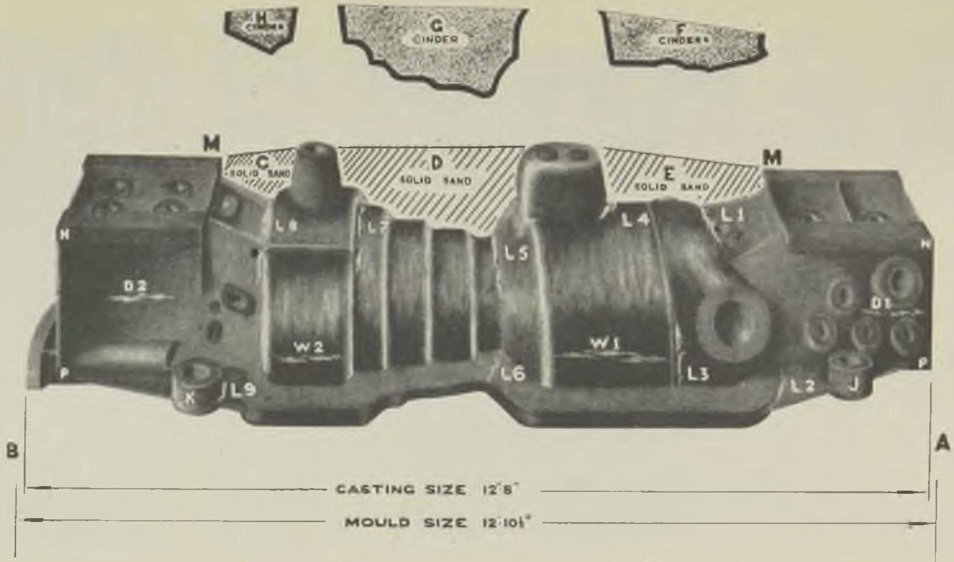



Fig. 3.—Opposite Side to Fig. 2.

walls of metal shown at "B" and "C" equal to the body thickness of the cylinder shown at "D." This alteration would have assisted in keeping the cooling rate of the casting more uniform.

The steelfounder has to commence his study of the method of manufacture by an examination of thicknesses, so that he can make an effort to control the cooling rate. He usually does this by runner and feeder distribution, but it is not intended to enlarge on these subjects now. The

FIG. 4.—MOULDING BOX DESIGN RELATED TO CONTRACTION.

cooling of the casting, however, is considered extremely important, in order to obtain, as far as possible, a condition whereby all parts of the casting commence to contract at the same time.

### Mould Temperature

The temperature of moulds is another important point, and the hotter these are when cast, the easier they crush when contraction takes place, as in this condition the moulds are weaker. If it were possible to have a mould as high in temperature as the casting metal, one would then obtain a much improved condition, although there would still be some resistance of the sand arising from its lower coefficient of contraction. At the present time, this is not possible, as no refractory materials are available to do this, and the moulds must be heated as much as is possible.

Hot moulds, besides being in themselves easier to crush, also delay contraction, and, owing to the delayed cooling of the metal, are in a better condition for crushing owing to the time afforded for heat conduction from the metal. A further advantage obtained here is that the delayed cool-

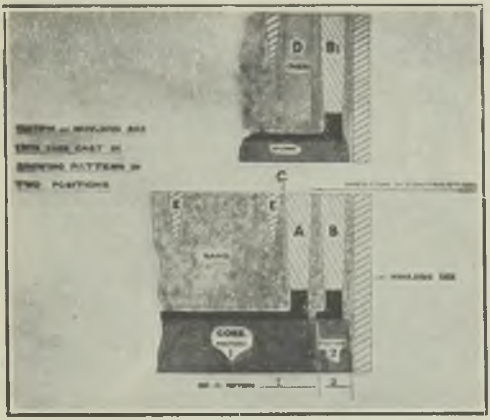


Fig. 5.—Section through Moulding Box shown in Fig. 4.

ing of the metal gives better opportunity for heat distribution through the casting.

Sharp corners and abrupt shapes are also considered a real danger to good results, two of these parts being seen at " E," Fig. 2. These parts of the casting would have facilitated contraction if the designer had made them to the dotted line " G." Then, again, the shape at " H " would have contracted much easier if it had been designed with a curve as seen in the enlarged section view of " J." Designers are therefore counselled to observe that curved shapes—easy curves, of course—are better than abrupt corners, as the latter are a source of real difficulty and anxiety to the foundryman.

Another item which is considered of very great importance is mould and core manufacture; by this reference is made not to the design side, which is in the designer's hands, but to the manipulation and choice of materials. The core for a casting of the type previously described must not be made rigid; if it is, cracks are certain to appear in the casting.

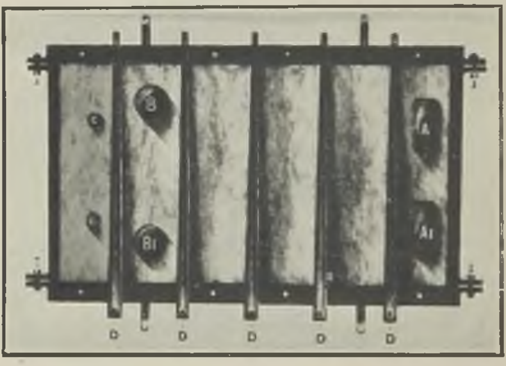


Fig. 6.—Moulding Box Made from Loose Sides without Bars Cast In.

In the making of cores, therefore, the use of cast-iron grids should be eliminated as much as possible. The reproduction shows the grids referred to marked "K," and it will be seen how core irons of this kind can retard contraction. The method of using cast-iron grids is much easier for the coremaker than that of manufacturing the cores with loose irons, as is seen at "L," but the latter is undoubtedly the correct one. The loose iron method is not so rigid, and therefore the core more easily collapses when contraction commences to crush it.

Another important point is in connection with the bearing core shown at "O." This core is better made separately and afterwards fitted round the main core. The reason is to permit it to slide through the main core when contraction commences to take place. If this core were made as part of the main core it would naturally

Fig. 7.—Propeller Shaft Bracket Casting after Easing.

become more resistant, as the core irons in it would be secured in the main core instead of being separate.

Fig. 3 is not a reproduction from an actual casting, but was taken from a freehand drawing of the pattern so that the various points relating to the subject could be conveniently added. It is the opposite side to Fig. 2 and was moulded in the lower half of the mould which was, as mentioned, 12 ft. 10½ in. long. The lines marked "A" and "B" again show, as in Fig. 2, the amount of contraction or travel which takes place in the casting during cooling. The portions shown at "C," "D" and "E," are parts of the mould which need to be made weak, *i.e.*, these parts must not be made with solid sand, neither must any reinforcement with heavy iron material be carried out.

The correct way to facilitate the contraction taking place is to build these parts of the mould as shown at "F," "G," and "H," where it will be observed that the sand, shown by a thick line, follows the pattern profile and the

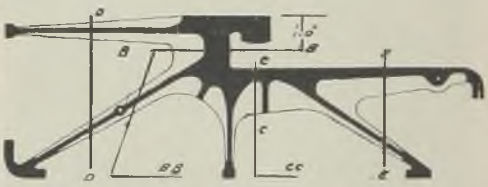


FIG. 8.—PART SECTION OF A CASTING 24 FT. WIDE.

centre is filled with cinder material. If this mould were made as shown at "C," "D" and "E," the parts of the casting at "M" would be propped and contraction would be retarded. The result of such a procedure would probably be tears at one or other of the places marked "L" 1-2-3-4-5-6-7-8-9, all these parts show tears which can be caused by retarding longitudinal contraction. The two bosses also marked "J" and "K," could cause the tears "L" 2 and "L" 9 to occur, if the mould in front of them were too rigidly constructed.

The two tears marked "W" 1 and "W" 2, could occur by the casting being core-bound, *i.e.*, by making the core as shown in Fig. 2, with heavy core grids incorporated instead of loose irons wired together. Also if the core were made with too large a thickness of sand, it would cause hot tears to occur. The two tears shown at "D" 1, and "D" 2, could be caused by up or down contraction, between the points marked "N" and "P." It is, therefore, important to manufacture moulds on flimsy lines, so that they may crush when contraction commences to take place.

The foundry operator who has had years of practice and has closely studied his craft knows all the small but important points which lead up to trouble in connection with this subject. A few of these points have already been referred

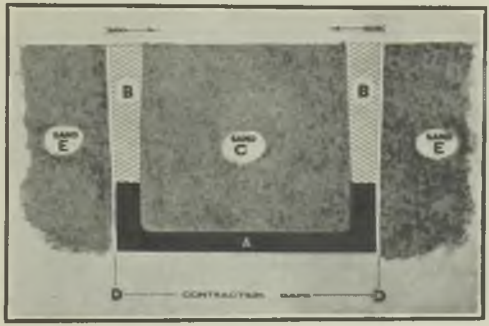



Fig. 9.—Contraction on a Simple Casting.

to, but there are many others that can often be noted in practice which militate against the production of good results in the finished article.

It will be appreciated by all that the ability of moulders varies considerably, and whilst it is admitted that some are perhaps 100 per cent. efficient, it may be safe to say that these men are well in the minority. The craft has recently been assisted a great deal in certain instances by moulding machines of various types, but for classes of castings which have to withstand high pressures and temperatures, moulding machines are of little use, as, by this method of moulding, moulds cannot be made sufficiently weak to allow contraction to take place.

The craftsmen required for this type of work are not so proficient or so numerous to-day as they were 20 to 30 years ago. A suggested reason for this is that boys do not appear to be coached in the important points as used to be the case. Another point in this connection which is also very noticeable is that teachers of students taking foundry courses are not sufficiently experienced and do not emphasise these important matters.

Consequently, for bringing forward one or two simple examples which combat good results in this connection, the authors hope to be excused.

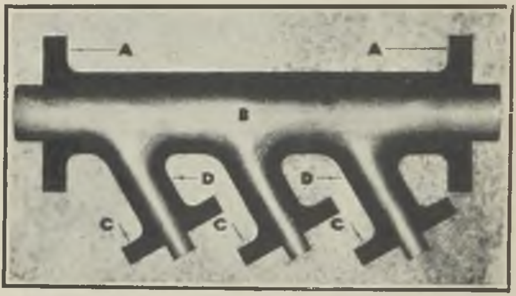



Fig. 10.—Easing Operations on a Flanged Casting.

It is known, and will be appreciated, that these examples require the operator's attention at all times, but it has been noticed even at the present time the correct method is not always put into use.

The first example of the methods referred to will be explained by Fig. 4. This view shows a moulding box with bars cast in it, and everyone will no doubt agree that a moulding box of this type is much easier to utilise than is a moulding box without bars.

The contraction on the casting inside this moulding box is in the direction of the arrows as shown at "A." The feeders on the casting are as seen at " B," " B1," " C," " C1," and the runners are at " D " and " D1." The space of sand marked " E," between these feeders and runners and the moulding box bars, will be seen to be too narrow. This condition is considered very bad practice, as, unless the sand is removed before contraction commences, the casting will be anchored at the ends and hot tears will probably be caused.

It will be seen that these feeders and runners

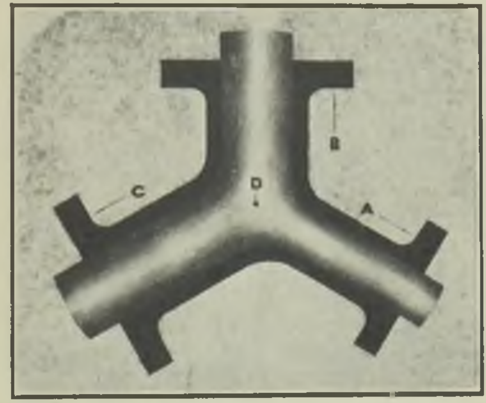



Fig. 11.—Easing Operations on a Flanged Casting.

should have had more room in front of them, so that a cavity for cinder or other loose material could be placed between them and the bars. It will be appreciated that the sand shown at positions " E " would be extremely difficult to remove unless such precautions were taken.

Fig. 5 is a part sectional view of the moulding box seen in Fig. 4, and will enable a clearer explanation to be made. In Fig. 4 it was shown that the feeder positions were very close to the moulding box bars, and in Fig. 5 there is a clearer view of the point raised. It will be seen in position 1 that without forethought the moulder could have made this item so that feeder " A " would be very close to the bar " E," leaving only the small clearance for sand between " A " and E " shown at " C." The direction of contraction will be noted by the arrow, and the importance of this clearance will be appreciated.

The moulder, with a little forethought, could have altered the position of his pattern to

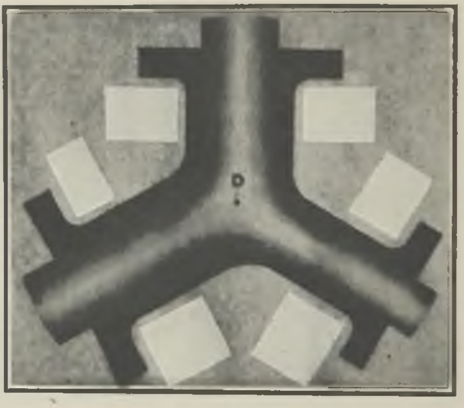


Fig. 12.—Method of Dealing with a Flanged Casting.

position 2, when he commenced to mould this item. By doing this it will be seen that the feeder position shown at " B " would give more room at " C." This would enable the moulder to carry out the correct method as shown at " B1 " and " D," where it will be seen that a cavity of cinders is in front of the feeder in the direction of contraction. The operator must consider these points, especially with dry-sand moulds, otherwise good results cannot be expected.

A type of moulding box which is considered a better one to use for steel casting production is the one built up with loose sides, and is shown in Fig. 6. The moulding box bars in this instance are all loose and are laid on top of the box. The feeders and runners are shown at "A," "A1," "B," "B1," "C" and "C1." The moulding box bars shown at "D" are all tapered so that they can be easily pulled through lifters or gaggers. A tap from a hammer on the small end allows the operators to pull these bars away very quickly, and liberate castings more quickly from obstructions. The simple points raised in connection with the last three figures

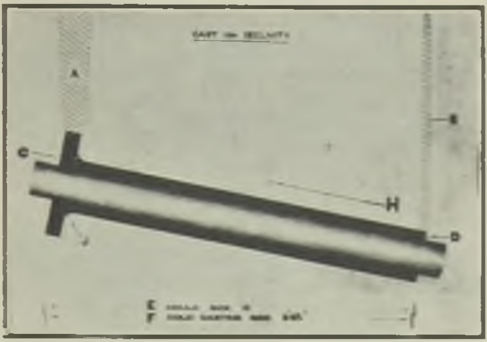



FIG. 13.—PIPE CASTING CONTRACTION PROBLEM.

are the cause of many hot tears and strains in castings.

**Easing Castings**

Having described the importance of weak mould and core construction so as to permit the full amount of movement to take place another process might be mentioned which assists in this direction. This process is what is known in practice as easing the casting. This term really signifies stripping away parts of the mould and cores likely to hinder contraction just at the time the metal has become solid in the mould. In this connection, in Fig. 7 is shown a propeller shaft bracket casting just after easing has been completed. It will be seen here how the whole of the mould in front of the light end of the casting has been removed. This has been done to enable that part of the casting to move in towards the heavy boss without being retarded.

The operation of easing takes place after the mould has been cast, and is a useless one unless carried out at the proper time, and at the correct places. Parts of the mould to be broken

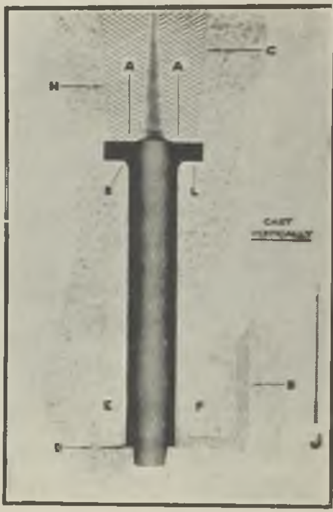



Fig. 14.—Contraction Problem when a Pipe is Cast Vertically.

away to give ease of contraction must also be removed without any great effort, a condition which can only be obtained by anticipating this point during the moulding operation and making the moulds and cores weak.

The easing operation must be commenced at the parts of the mould near to the casting where cooling first takes place, leaving the other parts which cool later until a more appropriate time.

The moulder who is working correctly always commences this operation by moving away the mould from the inside of runners, feeders, or other projections on the casting.

Fig. 8 shows a diagram of a rudder frame casting. In this design the ends of each arm

Fig. 15.—Contraction Stress Crack.

on this casting have a hooked shaped section, which is used to join up the outside of the frame with forged steel bar. These sections in the castings are only ¾ in. thick on the edge compared with the thickness of 18 in. in the thickest part of the same casting, shown in the vicinity of section "BB." It will be appreciated, therefore, that these light parts of the casting on the ends of the arms will be cooled very quickly after the mould is cast. This being the case, the easing operation must commence early in front of the hooked shaped pieces so as to allow these parts to travel towards the thick sections of the casting shown at " BB " and " CC."

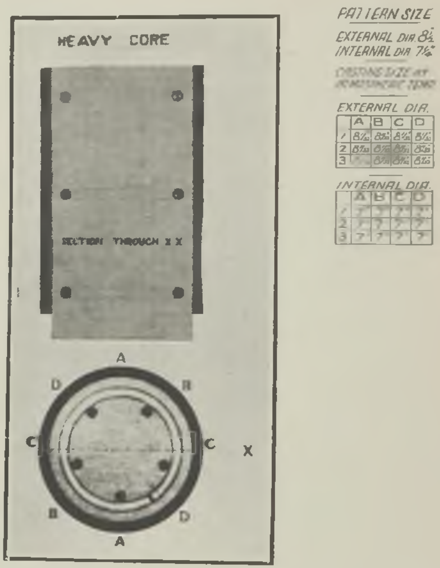



FIG. 16.—DIMENSIONAL CHANGES IN BUSH CASTING.

The supervisor or moulder, therefore, who is responsible for the manufacture of such a mould must anticipate these points during the moulding operations by making the moulds sufficiently weak so that the parts are easily removed a short time after the mould is cast. Serious contraction cracks may otherwise develop in the junctions adjoining the thick sections due to the contraction or travel being retarded.

The direction of travel during contraction of any casting is always inward, as was shown by Fig. 1, so that it is useless moving away parts of the mould which the casting is leaving during its contraction travel. In Fig. 9 a simple example is shown of a casting, marked " A," with two risers attached, which are shown at

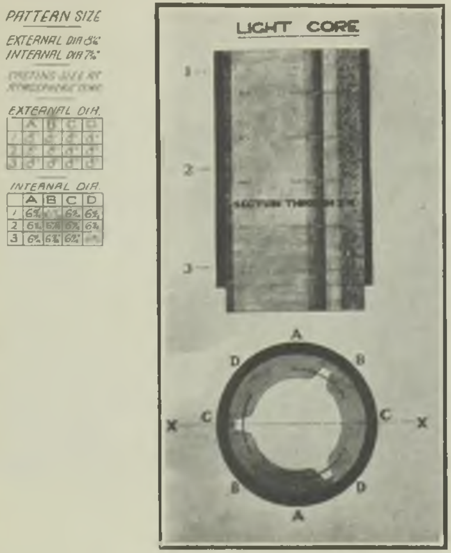



FIG. 17.—DIMENSIONAL CHANGES IN BUSH CASTING.

" B," " B." The contraction in a case of this kind would be from each end in the direction of the arrows. The sand which is shown at position " C," therefore, should be taken away first so that the movement in the direction referred to is not obstructed.

The contraction gaps left by the casting as shown at " D " will be seen to occur on the outside, and this occurs on every casting which is made in any class of metal, and to move away the sand shown at " E " becomes a useless procedure in practice, and is a waste of time.

The particulars just described are well known by the majority of foundry workers to be correct; but it is regrettable to have to say that there are still workers in some foundries who do not carry out the operation correctly and thereby cause their supervisors much trouble. It is suggested that such workers take careful

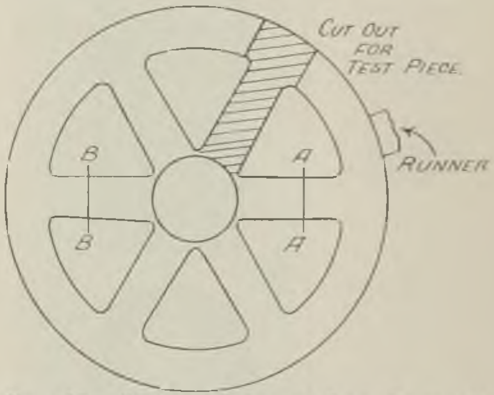



FIG. 18.—CASTING MADE TO TEST INTERNAL STRESSES.

note of this simple explanation, as it is considered to be of great importance to the quality of the finished product.

Further examples to give an idea of the commencing and finishing points when easing a casting are shown in Figs. 10 and 11. In a design of this kind the moulder should first ease away the sand in front of flanges " A," and whilst this is proceeding the coremaker should be removing the core " B." The sand in front of flanges shown at " C " should then be removed and almost at the same time sand obstructing the two points " D " must be taken away. The contraction travel to be attended to in turn by the operators are from " A " to " A," " C " to " B," and " D " to " D." It is important, therefore, to remove the parts of the mould (as near to the casting as possible) in front of these points.

In Fig. 11 another example is shown, and again the points at " A," " B," " C " should be removed all round the flanges, so as to allow them to move inwards to the point shown at

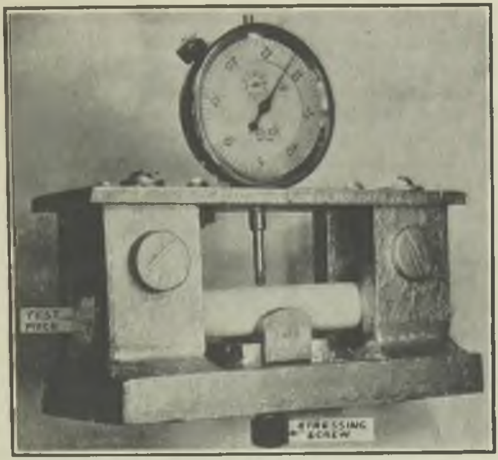


FIG. 19.—SPECIAL STRESS TESTING MACHINE USED.

" D." To facilitate removal at the parts mentioned in the examples shown in Figs. 10 and 11, it is essential during manufacture to construct the mould at these points on weak lines.

Fig. 12 shows the essential points in front of each flange. The cavities seen here are carried all round the flanges, and holes are linked up from them to the outside of the moulding box. This condition enables the operator to ease the sand away from the parts concerned without any great effort, and as a result without loss of time, which is an important matter.

The contraction movement in any casting always starts from the point where cooling commences. To explain this so that it will be more clearly understood, a sectional view of a pipe is shown in Fig. 13, cast on a declivity. The mould is 12 ft. long, shown at " E," and the cold casting size is 11 ft. 9¾ in. long, shown at " F," the contraction movement therefore being 2¼ in. It will be seen in this view that a feeder at " A " is used on the flange 4 in. thick, and the opposite end of the casting has a vent cast on it 2 in. dia. at " B," whilst the body thickness of the pipe is 2½ in. thick.

The casting is run at the position " C " so as to have the hot metal close to the feeder. It will be observed that this method brings about an immediate condition of two cooling rates. The reason for this is the extra bulk of metal at " A " and the runner point " C," causing a hot spot at that end of the casting. The first point to commence cooling is obviously the one at " D," so that the direction of commencement of movement is firstly in the direction of arrow " H."

It might be thought by those not acquainted with the foundry that the movement would not occur uphill, but this does actually occur. The end of the casting at " D " proceeds to leave the mould first, and it does so whilst the other end (*i.e.*, the feeder end) is in a plastic condition. The critical part of the mould to break away or ease first in a case of this kind is the sand in front of the vent " B," and if this is not removed before " D " commences to move, a contraction tear is almost certain to occur at the position shown at " J."

The same job cast in a vertical position could be run at positions which are shown in Fig. 14. The runner in this case might be used at positions " A " or " B," with a feeder at " C." The hottest portion here is therefore at the feeder end, especially if it were run at " A." If a joint happens to be made in the mould at the lower end, as is the case in many instances, it is possible to obtain a fin shown at " D." The first movement of contraction under the method described is in the direction of arrow " J," again on account of that being the first end to cool. The fin " D " at the bottom of the mould might in this instance cause a contraction tear to occur at " K " on account of the sand at " E " preventing the fin moving with the casting.

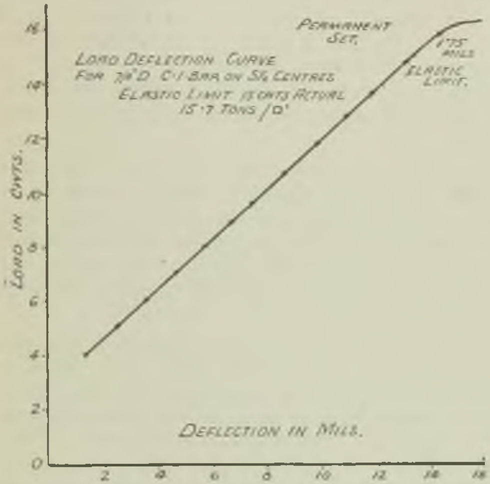



Fig. 20.—Load Deflection Curve for $\frac{7}{8}$ in. dia. Cast-Iron Bar.

It will be appreciated that this fin would be thin and therefore stronger than the rest of the casting on account of its earlier cooling. Thus a small fin can be an anchorage and again cause the trouble under consideration. The other position of running this job might be at " B." This method would cause a hot spot at the bottom of the casting, and so somewhat delay the commencement of movement from that end, as compared with position " A." This being the case, one must attend to removing the sand at positions "H" and "L" where two retarding points occur.

At "H," the sand under the taper in the feeder is sufficient to cause trouble at "K," and the other position "L" is obstructed by the sand between that part and "F." The obstructed parts referred to, where it is necessary to remove the sand, are as shown in Fig. 7. The light end of the casting has been released by the removal of the sand, so that this part will move first as a result of it cooling earlier than the other end, which is much thicker in section. If such a precaution were not taken the hot tear difficulty would be almost certain to occur.

In addition to the form of crack described in the foregoing, another crack known as a split is occasionally seen in steel castings, and these are also caused through contraction stress. Such stresses are mainly produced by cooling the casting too quickly, or by local heating, welding, etc., and afterwards cooling in the air.

This form of crack, shown in Fig. 15, is sharper and better defined than the hot tear. Such a crack can also be caused by stress in some parts of the casting, due to contraction being propped by the use of heavily reinforced cores. This kind of crack, however, is more easily diagnosed than is the case of the hot tear, and the stresses producing it are easily removed by suitable heat-treatment. This is done on many occasions on castings which are designed with light sections of metal between two heavier sections, both in cast iron and steel.

Only recently a small investigation was carried out to illustrate how contraction can be held by using heavily reinforced cores. This consisted of making two cast-iron bushes, one with a heavily reinforced core and the other with a very light core. In Fig. 16 is shown one of these bushes, which is 12 in. long, the mould size, external diameter $8\frac{1}{16}$ in., and the internal core diameter $7\frac{1}{16}$ in. At A, B, C, D, the external and internal diameters were taken as shown at points 1, 2 and 3, indicated in Fig. 17.

This casting was made with what was considered a very strong or heavy core which was purposely reinforced with core irons. For this investigation five straight irons and three rings were used in the core as shown in the section and plan view. The casting was carefully measured after removal from the mould at the parts mentioned, and it is shown by the internal

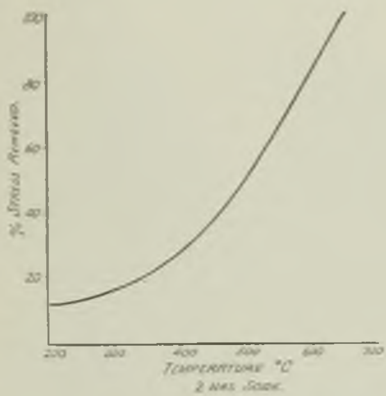


Fig. 21.—Stress Removal Related to Heat-Treatment.

measurements that it has contracted $\frac{1}{16}$ in. A further bush was made from the same pattern and a core was made which had three grooves in it. A few light pieces of iron were used but much lighter than in the heavy core, Fig. 16. The core irons referred to are as seen in the section and plan view in Fig. 17.

It was found on measuring this casting that it had contracted $\frac{1}{8}$ in., *i.e.*, double the amount of that shown in Fig. 16. The cause of this is obviously the core shown in Fig. 17, allowing the casting more ease of movement than was the case with the core shown in Fig. 16. The measurements show that less contraction stress will exist in the casting made on the lines as indicated in Fig. 17 than will be the case in that shown in Fig. 16, because if the natural property of contraction is restrained, a stress must exist in the material.

In order to obtain natural contraction movement in any casting one must assist all parts to move at the same time. This condition is more easy to talk about than to obtain, especially where thicknesses vary so much in the many different shapes a foundryman has to contend with. If it were possible to design every part of a casting in even thickness, the foundryman could then control the cooling rate very easily.

It has often been stated that a casting designed on these lines sometimes gives more trouble than another with varying thicknesses. It is difficult to see how this can be possible, providing an attempt is made to obtain even contraction by keeping the cooling even. This would be possible by equal runner distribution, but this method cannot be carried out accurately where sections vary.

Good examples of this have been noted in the works where the authors are employed, during the manufacture of large gunmetal liners. These castings are always made in the horizontal position and give few contraction troubles. The method of manufacture is to have the runners spaced equally over the full length of the casting, with the object of keeping the metal at a uniform temperature throughout the length. These liners have been cast up to a length of 38 ft. and although the casting is made in gunmetal, trouble could easily be experienced if the contraction was not evenly maintained.

The method of runner distribution is to set them out on the lines of equal cooling over the whole length.

The contraction on the liner casting was 6 in. so that the mould in which it was cast was 38 ft. 6 in., the casting size in cold condition being 38 ft. It has been mentioned only recently in a modern technical book that the contraction troubles in castings can be eliminated only by the designer fully appreciating basic principles. This is not altogether true, as however easy a design may be, to obtain good contraction the method of manufacture in respect of the running of the moulds, feeding, and the strength of moulds and cores have infinitely more to do with good results than has the question of design.

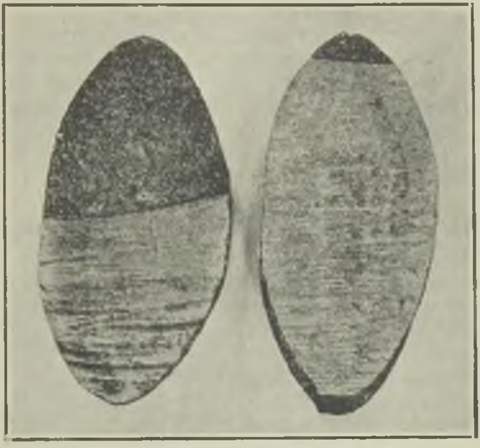


FIG. 22.—SECTIONS OF THE STRESSED AND UNSTRESSED SPOKES.

The example which has just been described of a gunmetal liner 38 ft. long is a tube of metal of even thickness throughout its length. It will be appreciated therefore that such a design is all that could be desired, and a perfect casting should be produced. Nevertheless, a good casting cannot be obtained unless the foundry supervisor makes the casting cool evenly by means of equal runner spacing.

Again, serious contraction faults can be caused in the foundry by anchorage of the casting at the ends through fins, or runners and risers not being eased by the removal of sand in front of them. The removal of sand needs to be carried out in front of the runners and risers first right on the extreme ends of the casting, and then each one in turn until the centre of the casting is reached.

This method of easing has already been described in Figs. 9 to 12, but in a case of this kind, every down runner from each end to the centre of the casting must be eased, otherwise the casting is almost sure to give trouble on water test. The trouble referred to is a result of microscopic tears due to uneven contraction from the ends to the centre. There is no doubt that this occurs because it has been proved during manufacture in the works where the authors are employed.

## Casting Strain Research

In connection with the subject of strains an investigation was recently carried out by the authors on a wheel which was made in a dry-sand mould and cast from metal of the following composition:—T.C., 3.35; Gr., 2.57; C.C., 0.78; Mn, 0.51; Si, 1.78; S, 0.11; P, 0.39 per cent.

The wheel referred to is shown in Fig. 18, and it will be seen that the runner position is as shown on the rim and no risers were used on any part of the casting. The casting was allowed to cool to shop temperature before it was removed from the mould, so that no undue stress would be added by the casting cooling quickly in the air.

To obtain the maximum amount of stress which existed in the spokes of this wheel it will be appreciated that it was necessary to carry out the investigation regarding this point immediately. Accordingly the casting was sent into the research department where it was taken from the mould. The method adopted to ascertain the nature of the stresses was to make two cuts which are shown at "AA" and "BB." At "AA" two marks were made which were 0.748 in. apart, and at " BB " two marks 0.750 in. apart.

After cutting, the marks at " AA " opened to 0.774 in. and " BB " to 0.765 in. Thus the spokes were in a definite state of tensile stress, as the increase at " AA " was 0.026 in. and at " BB " 0.015 in. As could only be expected, the stress having been partly released due to

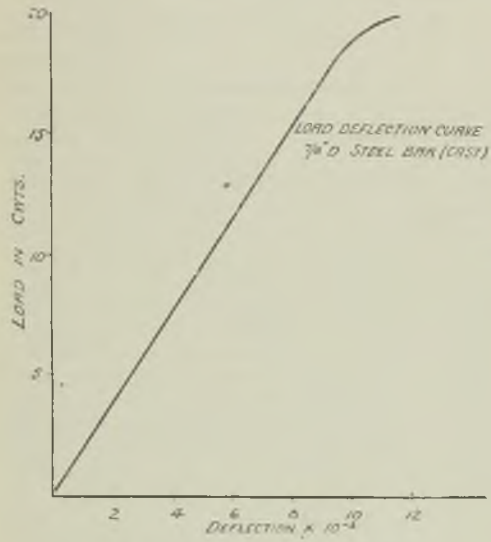


Fig. 23.—Load Deflection Curve for $\frac{7}{8}$ in. dia. Cast-Steel Bar.

" AA " being cut first, the stress was less at " BB." The cutting of these spokes was done very slowly, and when this operation had been partly carried out the inherent stress was sufficient to break the remainder of the section. The total area of the section of the spokes was 0.67 sq. in. and the fractured area was 0.28 sq. in. It will thus be seen that the stress in the spoke was sufficient to fracture a bar of the material 0.28 sq. in. section.

It was decided after this had been done that a test-bar should be cut from one of the spokes of the same wheel, which is shown shaded in Fig. 18. The U.T.S. value of this spoke returned 14.4 tons per sq. in.; therefore the force in the area which fractured

$$= 14.4 \times 0.28 \text{ tons},$$

and the stress in the spoke

$$= \frac{14.4 \times 0.28}{0.67} = 6.01 \text{ tons per sq. in.}$$

## Stress Reduction

With a view to determining the correct heat-treatment temperature to eliminate or reduce such strains a further investigation was undertaken. When the wheel was cast a number of test-bars were cast at the same time and these were machined to 0.875 in. dia. One of these bars was used for a load deflection test set up in the apparatus shown in Fig. 19.

In this machine a pin was substituted for the screw so that a measurable load could be applied directly to the bar and measuring could then be done on the instrument shown. Small increments of load were applied to enable a stress strain curve to be prepared. This graph is shown in Fig. 20. It will be seen that the elastic limit in transverse was found at a load of 15 cwts., and the stress in the bar at this load was

$$f = \frac{WL}{4Z} = \frac{\frac{3}{4} \times 5\frac{1}{2}}{4 \times \frac{\pi}{32} \times 0.875^3} = 15.7 \text{ tons per sq. in.}$$

This stress corresponded to a deflection of 0.013 in.

The bars were then given a deflection of 0.008 in. by means of the screw shown in Fig. 19, this deflection corresponding to an induced stress of 10.5 tons per sq. in. The bars still held in the apparatus were then individually heated to progressively increasing temperatures and the elastic deflection remaining was measured. The results are set out in Table I.

Each bar was maintained at the stated temperature for 2 hrs., after which it was slowly cooled in the furnace. The figures show that a temperature of 650 deg. C. was necessary before the stress was completely removed, as is shown in Fig. 21.

In order to verify the conclusions arrived at it was thought advisable to cast a second wheel exactly similar to that shown in Fig. 18, and the same conditions were carried out so far as moulding practice was concerned, and this casting was heat-treated to 650 deg. C. and slowly cooled on exactly the same lines as the test-bars. After this operation had been completed, it was marked

TABLE I.—*Stress Removal by Thermal Treatment.*

| Temp. | Bar No. | Initial def. | Permanent def. | Per cent. stress removed. |
|---|---|---|---|---|
| Deg. C. | | In. | In. | |
| 200 | 1 | 0.008 | 0.001 | 12.5 |
| 300 | 2 | 0.008 | 0.0012 | 15.5 |
| 400 | 3 | 0.008 | 0.0018 | 22.0 |
| 500 | 4 | 0.008 | 0.004 | 50.0 |
| 600 | 5 | 0.008 | 0.0065 | 81.0 |
| 650 | 6 | 0.008 | 0.008 | 100.0 |

in exactly the same way as the wheel which was untreated had been and the amount of spring measured.

The original distance between the marks was 0.976 in., but after treatment this increased to 0.981 in., which is an increase of 0.005 in. This is compared with the increase of 0.026 in. on the untreated bar. The section of the cut and fracture were again measured with the following results—

Total area, 0.71 sq. in.
Area of fracture, 0.03 sq. in.

This represents a residual stress of $\frac{0.03 \times 14.4}{0.71}$ tons per sq. in. = 0.61 tons per sq. in.

In Fig 22 the two sections of the spokes cut from the wheels can be seen. The one shown with the large fracture is without treatment and the other showing the small fracture occurring after treatment. From the investigation carried out on these two wheels it would appear that satisfactory strain relief in cast iron is obtained by heat-treatment at 650 deg. C. followed by slow cooling in the furnace.

The danger of shock load on any casting which contains strain of the type just referred to is the development of defects such as that which is shown in Fig. 15. It is admitted that the contraction stress in the cast-iron wheels which have been used for this investigation is one which may be associated with design, but such stresses can appear in a perfectly designed casting made in cast iron by using heavily-reinforced cores as illustrated in Figs. 16 and 17.

### Casting Strains in Steel Wheels

After the investigation referred to had been carried out on the cast-iron wheels, it was thought that useful information could be obtained from the same pattern of wheel in cast steel by taking the stress existing in same before any heat-treatment was done. It was decided, therefore, to cast another two wheels in steel on exactly the same lines as those made in cast iron, together with the same number of test-bars. The analysis of the steel used for this purpose was as follows:—C, 0.28; Mn, 0.73; Si, 0.23; S, 0.042; and P, 0.038 per cent.

As before, two marks were made on one spoke, 0.75 in. apart; the spoke was then cut between the two marks, and, after careful measurement, it was found that it had extended to the extent of 0.022 in. In order to determine a suitable heat-treatment temperature to remove the strain in the second cast-steel wheel, the test-bars similar to those employed in the case of the cast iron were loaded with strain in transverse and afterwards treated at various temperatures.

The load deflection curve prepared from one of the bars is as shown in Fig. 23. This indicates the limit of proportionality at 0.009 in., and the bars for treatment were therefore loaded to give 0.007 in. deflection. From the results of treatment on these, a further curve (Fig. 24) was prepared, which indicates complete strain relief after a heat-treatment at 650 deg. C. After the treatment of these bars, the second wheel was then heat-treated to 650 deg. C., and it was then found that the strain existing in the casting was negligible.

This investigation clearly proved that the strain relief was entirely removed at 650 deg. C., similar to the case of the cast-iron wheels.

Thus it is suggested that all castings made in


FIG. 24.—THERMAL STRAIN RELIEF CURVE FOR CAST STEEL.

any metal are likely to have contraction faults in them, and, unless correct methods are used during the moulding stages, these faults appear in a greater degree. In addition, it is very important that the designer should give his careful thought and attention to the foundry requirements, as only by these means, coupled with careful heat-treatment processes, can hot tears, cracks and strains in castings be avoided or removed.

The authors would like to mention that the defects caused by contraction in the casting or castings in any metals are associated with many other subjects which have not been entered into in this Paper. Many of these subjects were briefly put forward in a previous Paper.*

In conclusion, the authors would like to thank the directors of Vickers-Armstrongs, Limited, especially Sir Charles Craven, Mr. Callander and Sir Robert Beeman, for their kindness in allowing them use of some of the photographs reproduced, and also for the stimulating interest they have taken in the preparation of this Paper.

* "Castings." W. Machin and M. C. Oldham, Proceedings, Institute of British Foundrymen, Vol. XXVIII, p. 361.

# Sheffield Branch

## CAST-IRON PIPES

By W. Woodhouse, F.I.C.

### Introduction

Cast-iron pipes are used chiefly for the conveyance of water, sewage and gas; they are also used for steam and other purposes. To-day they are an essential part of any civilised country.

Previous to the introduction of cast-iron pipes, pipes for the conveyance of water were made of clay, examples of which have been discovered at Nippur in Mesopotamia. Terracotta water and drain pipes have been found in the Palace of Minos at Cnossus. These date from about 2000 B.C., and examples are shown in Fig. 1. During the advanced civilisation attained by the Greeks in the centuries preceding the Christian era, an extensive use was made of clay pipes glazed inside and jointed with lead.

Metal pipes were first used by the Romans, who made water mains of sheet lead folded into tubular form and soldered at the edges, examples of which are shown in Fig. 2. These pipes were usually 10 ft. long and ranged from 5 in. (60 lbs. per length) to 100 in. (1,200 lbs. per length). During the occupation of this country by the Romans, both lead and wooden pipes were used. Examples of these have been found in the Roman cities of Caervent (Gloucestershire) and Uriconium (Shrewsbury). The use of wooden pipes (Fig. 3) made from bored tree trunks continued in England to the beginning of the 19th century. The timber used for the pipes was mostly elm and fir. Later on stone pipes (Fig. 4) were introduced. The Manchester Water Works Company used these in 1813. Owing to the porosity of the stone and consequent heavy water leakage, the use of this class of pipe was soon discontinued.

### Cast-Iron Pipes

Cast-iron pipes were first manufactured over 250 years ago. The earliest authentic record dates back to 1664-1668 when cast-iron mains were installed at Versailles to supply water to the celebrated Fountains in the Palace Gardens. Many of the original pipes are still in service and often cited to prove the "life" of cast iron. These pipes are 3 ft. 4 in. long and vary in diameter from 20 in. to $12\frac{3}{4}$ in., and from

FIG. 1.—GREEK AND ROMAN POTTERY PIPES.

observation they were moulded and cast in a horizontal position.

### Bank Pipe Foundry

About the middle of the 19th century the practice of horizontal casting was suspended by a system of oblique casting on inclined beds, called a "bank." Such a foundry is illustrated in Fig. 5. In this process the moulding boxes are divided into top and bottom halves. The moulds are placed at an angle of approximately 30 deg. Sand is bedded in the lower half of the mould and then sufficient sand is removed with a strickle, so that the pattern is at the correct depth when bedded in. The mould is prepared in green sand. The facing sand has the following composition:—Erith weak loam $33\frac{1}{3}$, floor sand $33\frac{1}{3}$, and pond duff, $33\frac{1}{3}$ per cent. (Pond duff is coal from the bottom of settling ponds or tanks, and contains water 16-30, ash 18-36, vol. 15-22, and carbon 24-36.) Sand is now rammed down the side of the pattern and

FIG. 2.—ROMAN LEAD PIPES.

scraped off. Parting sand is sprinkled on the mould and the top half is put on and rammed. The top is lifted off and the pattern removed.

The core is "swept up" in loam and, when set in place in the mould, a chaplet is put in the top half to give the required thickness. The top half, provided with runner and risers, is then clamped in position and the metal poured into the upper end of the mould.

The metal requires to be hot and fluid, about 1,350 deg. C. The metal lifts the core to give correct thickness, but if it is "sluggish," the core does not lift, and thick and thin pipes are produced. Casting by this method, there is a tendency for blowholes in the pipes due to insufficient venting or damp moulds; there is also a liability to lack of concentricity in the pipes. Pipes from 2 in. to 6 in. dia. in 9-ft. lengths are made by this method.

FIG. 3.—WOODEN PIPE UNEARTHED IN PICCADILLY.

### Vertical Pit Casting

In 1846 Mr. D. Y. Stewart, of the Links Foundry, Montrose, obtained a patent for a method of producing vertically-cast iron pipes. According to a local legend, Mr. Stewart conceived his process while in church, the root idea being suggested by the vertical columns in front of him.

When vertical casting was first introduced, it was customary to form the socket at the upper end of the moulding box, but it was later discovered that by casting with the socket downwards, the metal became denser and stronger

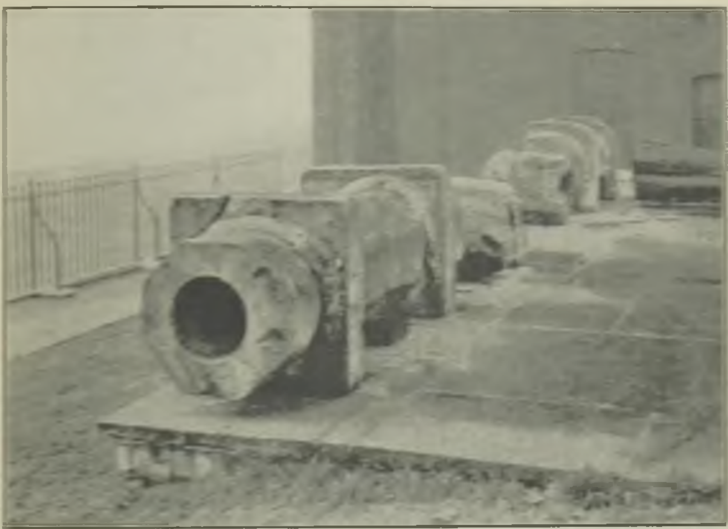


FIG. 4.—OLD STONE PIPES, BELIEVED TO HAVE BEEN USED BY THE OLD WEST MIDDLESEX & GRAND JUNCTION WATER COMPANY IN 1807.

due to the head above it, thus strengthening the pipe in the most desirable place. This method also permits of casting a head on the spigot end of the pipe, into which sand, scum, etc., can rise. This head is afterwards cut off in a lathe.

In the manufacture of vertically sand-cast pipes it is usual to range the moulding boxes round the sides of circular, semi-circular or rectangular pipe pits. They are illustrated in

Figs. 6 and 7. The moulding boxes are belled at the upper and lower ends and open on slides or hinges to enable the socket to be withdrawn. Sizes from 1½ to 2 in. to 75 in. diameter are cast in this class of pit. For sizes up to 27 in. the cores are made on perforated barrels. For the larger sizes to 75 in. dia. collapsible core-bars are used.

FIG. 5.—GENERAL VIEW OF A BANK PIPE FOUNDRY.

## The Ardelt Process

A more recent construction is to fix the moulding boxes to circular turntables such as is carried out in the Ardelt process. In the circular and rectangular pits the ramming is done by hand, but in the Ardelt process by mechanical means. The sequence of moulding is common to both types of shops, so that a description of the Ardelt process will answer for both processes.

Pipes produced by the method of vertical moulding are cast to dimensions within fine limits. Iron patterns, accurately machined and having a smooth finish, are used to form the outer part of the mould for the body and socket of the pipes, the bore of the pipe and socket being formed by cores. All tackle used for

FIG. 6.—CIRCULAR VERTICAL PIPE PIT.

casting pipes in this way is machined to gauges so that the components of a mould are readily interchangeable.

The "Ardelt" pipe foundry belonging to the Stanton Ironworks Company, Limited, is one of the most up-to-date plants in this country for the production of vertically-cast iron pipes made in dried-sand moulds. The moulding boxes are fixed to circular turntables, so that the bottom of the boxes are a few feet above floor level. This necessitates a high building (60 ft. high) having two floors. On the ground floor all work in connection with the *sockets* is done. This consists of preparation of the sand, making and drying of the socket core. On the upper floor, the moulds are rammed, central cores prepared and the pipes are cast and stripped from the mould.

### Moulding Plant

The building contains three cylindrical tables or drums 19 ft. in dia. by $7\frac{1}{2}$ ft. deep, which are

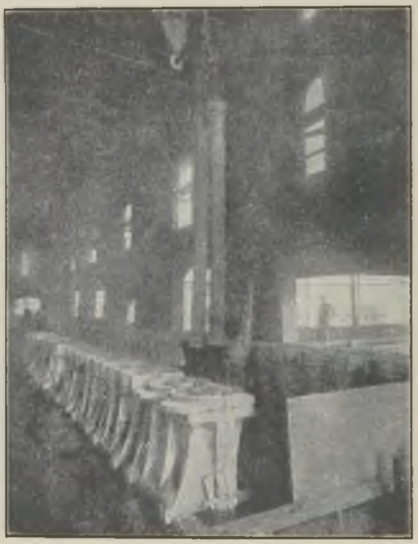


Fig. 7.—Rectangular Vertical Pipe Pit.

built up of steel sections encircled by steel plates. These are mounted on two cast-iron rings which carry the vertical moulding boxes. The tables, one of which is shown in Fig. 8, are supported on massive cast-iron bases and are revolved by electric motors operating through three sets of gearing. When the table is fully loaded the total weight is approximately 90 tons, but as this is carried on a ball bearing having $2\frac{1}{2}$-in. steel balls, the 6-h.p. "series-wound" motor turns it without difficulty.

Tables 1 and 2 carry 36 boxes each, and each table has a 5-ton electric centre crane and is capable of turning out 144 4-in. pipes 12 ft. long per 10-hr. shift. Table No. 3 carries 28 boxes, has an 8-ton centre crane and can produce 98 pipes either 8, 9, 10 or 12 ft. per shift.

A ramming base to which the socket pattern is attached is fixed on the bottom of the mould

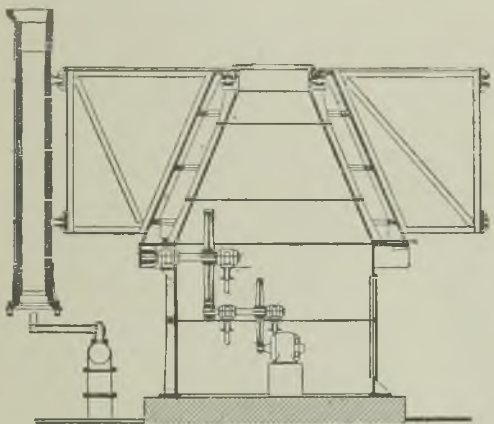


FIG. 8.—SECTION OF TABLE CARRYING BOXES.

and the lower end of the pattern drops into a tapered joint in the socket pattern (Fig. 9).

"*Bottom Sand.*"—A specially-milled sand, somewhat stronger than the floor sand, is supplied for ramming the mould to about a foot above the socket. This sand gives a higher mould strength at a point where the liquid metal exerts the greatest tangential force. The sand mixture used is best red moulding sand 45 per cent., black sand 50, and manure 5 per cent.

"*Floor Sand.*"—The remainder of the ramming is carried out with floor sand. No direct addition of new sand is made to this floor sand. The strength is maintained by the "bottom-sand" additions and clay water up to 5 per cent. After stripping the moulds, the sand is knocked out on to the floor and is fed into a

FIG. 9.—PLACING THE SOCKET PATTERN IN POSITION.

vertical bucket elevator enclosed in a sheet-steel casing, which takes it up to the top floor, all the sand passing through a rotary sieve before being delivered into the storage hopper situated at the side of the ramming machine.

The ramming of the moulds is done by an electric ramming machine (Fig. 11), which is an important feature of the Ardelt plant. The four blades revolve, shown in Fig. 11, and the rammer

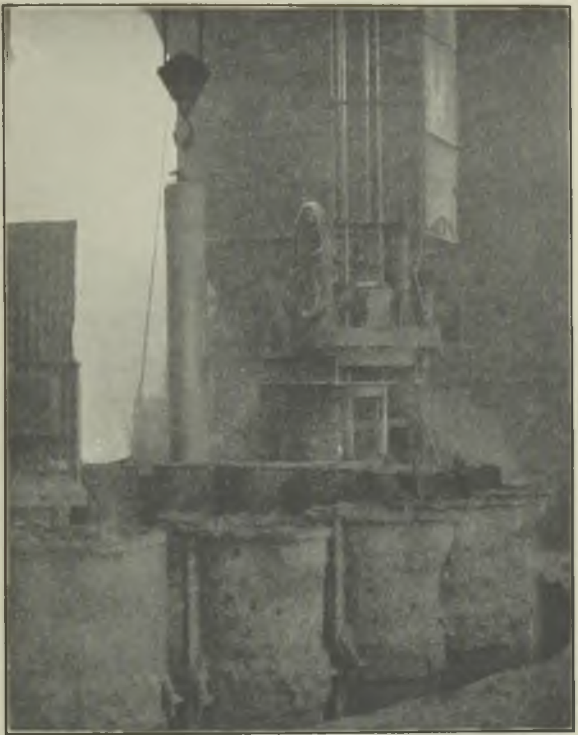


FIG. 10.—LOWERING IN THE PATTERN FORMING THE BODY OF THE PIPE.

is mounted on a table, which swivels over the mould. The table is revolved by a pinion drive engaged with a gear wheel running round the table. There are four blades, and rods pass through four guide holes in a square plate. The centre piece is worked up and down by a crank action. A split fibre brush in each guide hole is fitted with a spring, and the rammer rods are held in the brush when descending and slip through when ascending. This machine is almost human in its imitation of hand ramming, except that it always strikes a uniform blow, thus ensuring a mould with a ramming density constant throughout, and from mould to mould. This constant ramming density gives a pipe of uniform section throughout. The time to ram a 4-in. mould is $2\frac{1}{4}$ min., whilst for a 12-in. mould it is $3\frac{3}{4}$ min.

When the ramming is completed, the pattern is withdrawn, and the table is moved round the pitch of one box. This mould (No. 1) is then blacked, while another mould (No. 2) is being rammed. When the table is moved again, No. 3 mould is rammed, No. 2 mould blacked and No. 1 mould is brought over No. 1 of a series of nine gas jets set at a distance round the table corresponding to the pitch of the boxes. Fig. 12 shows the drying of the moulds with gas.

Thus, nine boxes are rammed, blacked and brought over the burners; these are then moved from the burners and are now ready for "coring," whilst a similar procedure is carried out with a further nine moulds. Whilst this ramming has been carried out, the striking of the main cores in special loam has been proceeding.

### "Body Cores"

The body core is "struck" on a perforated cast-iron bar, with special loam to give the correct dimension of the pipe. Different sets of core-bars are provided when making the various sizes of pipes, 4, 6, 8, 10 and 12 in., but for classes A, B, C and D, in which each size of pipe is made, the difference in metal thickness is adjusted by altering the loam thickness on the bar.

A necessary function of the core is that it should yield or give at the time of casting, under the pressure of the contracting pipe, so that the core-bar may be removed without

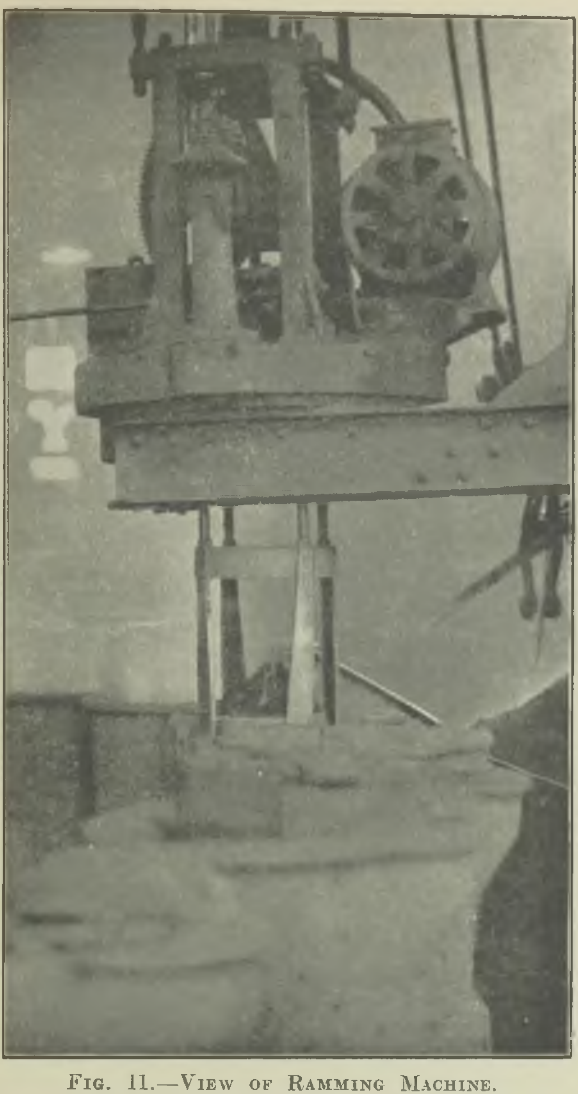


FIG. 11.—VIEW OF RAMMING MACHINE.

difficulty. To attain this, the hot core-bar is splashed with a slurry composed chiefly of horse manure, well ground in the loam mill. This "roughing" forms a spongy mass on drying, which later easily compresses under the contraction of the cooling pipe.

When this roughing is dry, the core is struck up with loam. The core-bar is placed in sockets at either end of the core table and the core is

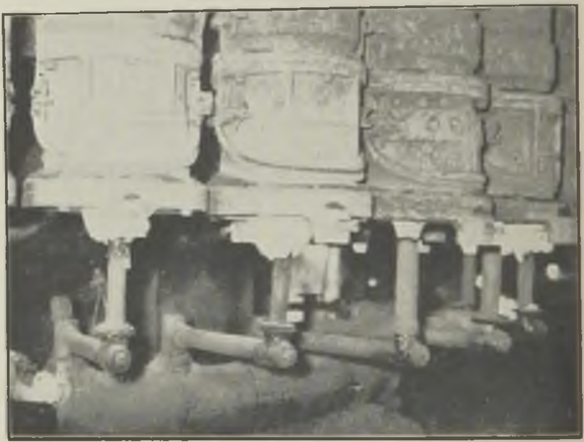


FIG. 12.—DRYING THE MOULDS WITH GAS.

revolved by the wheel seen at the left-hand side of Fig. 13. In front of the bar is a long shelf on which is the loam, and this is worked by hand on to the bar and strickled off to the correct diameter. The loam is prepared in a mill having a stationary pan, in which run a roller and a serrated chopping wheel.

The loam mixture consists usually of 60 per cent. spent core sand; 30 per cent. new red moulding sand, and 10 per cent. manure to which is added 24 per cent. of water. This mixture varies somewhat according to the qualities of the new sand. These loams are tested every day for tensile and permeability. The tensile strength runs from 35 to 40 lbs. sq. in. and the permeability varies from 150 to 200 secs.

A loam of this character meets the heavy demands made upon it and is sufficiently permeable to allow of the ready escape of the gases. The cores when struck are passed into the drying stoves to dry preparatory to being

Fig. 13.—Striking up the Main Core. The Finished Cores at the rear are seen entering the Drying Stoves.

placed in the mould. Each casting table is provided with two core making tables and two drying ovens. The core stoves are provided with recording thermographs for controlling the heat in the stove, which is round about 400 deg. F.

**Socket Cores**

These are prepared on the ground floor and are made with a sand having a high dried-bond strength. They are made from good red moulding sand, 66; clay, 20, and manure, 14 per cent. This is milled for 5 minutes in an edge runner type of mill and is delivered to the socket-core-makers' benches in hoppers running on light-gauge rails.

The body and socket cores are both blacked and dried previous to putting them into the mould.

FIG. 14.—HYDRAULIC TESTING OF CAST-IRON PIPE.

The number of core-bars necessary for ensuring a continuous cycle of operations is 72 for tables 1 and 2 and 56 for table 3. The number of " kellets " for the socket-cores is the same.

The system of working, length of time in drying, etc., of all work on the sockets is made to coincide exactly with that of the body cores, so that a set of each cores is ready at the same time. The mould is now dried and ready, the socket core is raised into position by means of a hydraulic lift, situated in a position on the ground floor exactly corresponding with the position of the rammer on the upper floor. The body core is lowered into position, the tapered end fitting into the recess in the socket core. Casting cakes are placed in position at the top of the mould and casting is proceeded with. When the metal is set, the core-bars are loosened and removed, the moulds are opened and the pipes withdrawn.

The pipes run down an incline to the gantries on the ground level outside the moulding shop, where they are fettled. From here they pass on

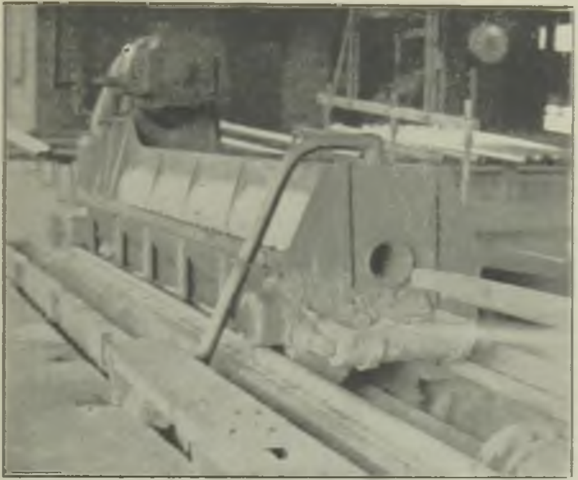


FIG. 15.—WATER-BOX CONTAINING THE MOULD.

to the lathes where the casting head is cut off. They are then tested by hydraulic pressure to 100 per cent. over the working load and during this pressure-test they are hit by a 2-lb. hammer at various places along their length. This operation is shown in Fig. 14. This load varies with the diameter and class of pipe. After testing and inspection, the pipes are coated and are then ready for despatch.

The complete cycle of operations on the table are: ramming, blacking, drying, coring, casting, stripping, through which course the table makes one revolution. The methods in the other types of vertical casting are similar to those already mentioned, with the exception that the moulds do not rotate and that the ramming is not mechanical.

### Centrifugally-Spun Cast Pipes

The application of centrifugal force to the casting of metal is the subject of patents dating back as far as 1809. The first inventor, however, to develop a system of centrifugal casting with commercial possibilities was Mr. Seusaud de Lavaud, a French engineer, who began his in-

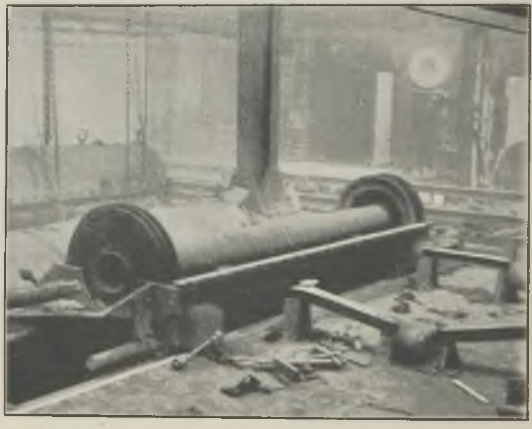


Fig. 16.—Machine with Top Half of Water-Box removed.

vestigations in Brazil in the year 1914. The Stanton Ironworks Company, Limited, developed the De Lavaud system of centrifugal pipe casting from the experimental stage and began producing pipes by this process in a small plant in 1922. A large plant was put into operation in 1924 and has been considerably extended since that time and is still increasing.

Considerably over 16,000 miles of De Lavaud centrifugally-spun pipes have been supplied by the Stanton Company up to the present time. These pipes are produced in sizes from 3 in. to 21 in. diameter up to 18 ft. in length, and are also made in metric sizes for export. Since the establishment of the spun plant at

FIG. 17.—FALL SPOUT, AND FILLING OF TILTING HOPPER.

Stanton, the De Lavaud system has also been adopted by important firms in the United States of America, Germany, France, Belgium, Canada, Australia and Japan.

The plant is designed on the straight-flow principle. All raw materials enter the works at a high level at one end and the finished pipes, gravitating through stages, leave at the other end. At this plant there are eight cupolas, each having a continuous melting capacity of 10 to 15 tons per hour, and each cupola on blow runs continuously for 20 hours. There are four cupolas blowing each day. These cupolas are mechanically charged.

The pig-iron and scrap charge is apportioned on analysis to give the requisite silicon con-

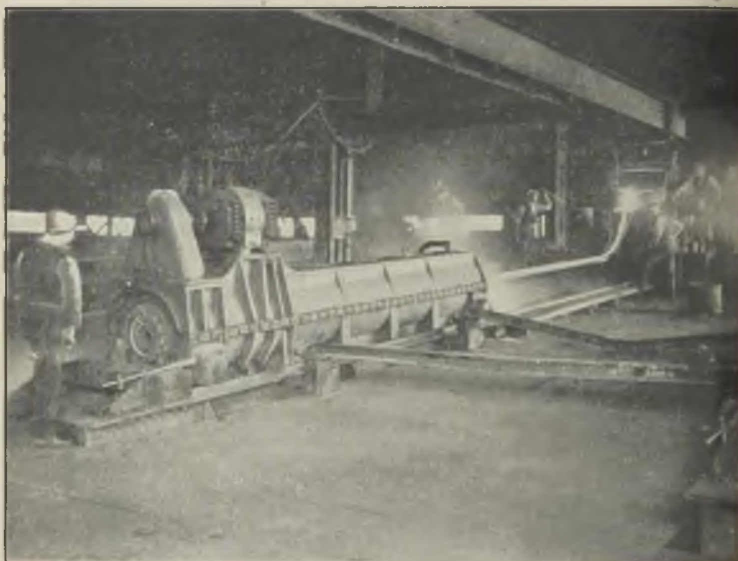


FIG. 18.—FINISH OF CASTING.

tent in the molten metal, whilst all charges of iron, coke and limestone are weighed. For further control samples of the molten metal are taken every $1\frac{1}{2}$ hrs. and analysed for silicon and sulphur, and the phosphorus, manganese and carbon contents are ascertained every 6 hrs.

The blast volume and pressure are controlled with a Wilson blast recorder. This analytical control of cupola supplies and resultant metal applies to all the cupolas at the various foundries belonging to the Stanton Company.

The molten metal at a temperature of 1,400 deg. C. is run into 50-cwt. casting ladles which are conveyed into the casting shops by overhead electric telpher cranes. The plant consists of two units, one for the manufacture of pipes up

FIG. 19.—WITHDRAWING PIPE FROM MOULD.

to 4 metres long the other for pipes up to 18 ft. in length, each unit being capable of working independently of the other. With the exception of a short socket core no sand or loam moulds or cores are used. This automatically obviates the risk of certain defects, which cannot always be avoided in sand casting, such as sand holes, blowholes, cold shot, etc.

Briefly, the molten metal is introduced into a revolving water-cooled steel mould and the centrifugal force holds the metal against the sides of the mould. As the mould requires no preparation, casting is practically continuous, enabling output to be increased in comparison with the sand-cast method by eight times per head of labour employed.

In the casting shop batteries of machines are situated on either side of a central platform.

FIG. 20.—GENERAL VIEW OF CASTING SHOP.

The overhead telpher track for carrying the ladles of molten metal is located in such a position that the ladle is in alignment with the head of each machine.

The casting machine, shown in Fig. 15, consists of a water box containing a steel mould rotating on friction rollers and driven by an electric motor. This mould is accurately machined, the inside diameter conforming to the outer profile of the pipe. These moulds are manufactured of special steel. Fig. 16 shows the mould in the bottom half of the water box. This water box containing the mould is mounted on rollers and is traversed along a steel track on the machine bed, which is slightly inclined.

This movement is actuated by means of a hydraulic cylinder and ram, the latter being attached to the underside of the water box. The speed is controlled within very narrow limits

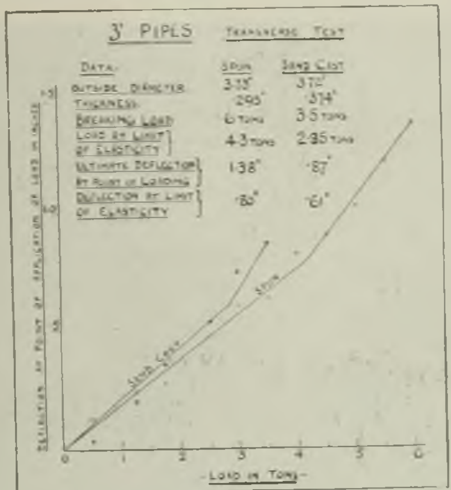



FIG. 21.—CURVES SHOWING DEFLECTION OBTAINABLE ON SAND-CAST AND SPUN PIPES.

by means of a fine adjustment valve. At the upper end of the inclined bed is a frame to which is attached at the back a tilting hopper, which has a metal carrying capacity just sufficient to cast one pipe. On the other side of this frame is a fall spout (Fig. 17) leading to a long cantilever pouring trough. The tilting hopper, which is hydraulically operated, is shaped so that during casting the molten metal is discharged to the mould at a uniform rate.

The procedure for casting a pipe is as follows: A sand core, to form the inside of the socket, is inserted in a taper seat at the socket end of the mould, and the water box is then moved up to the top of its track. The mould is revolved and the hopper, which has been previously filled with molten metal, commences to tilt. A uniform stream of iron flows down the

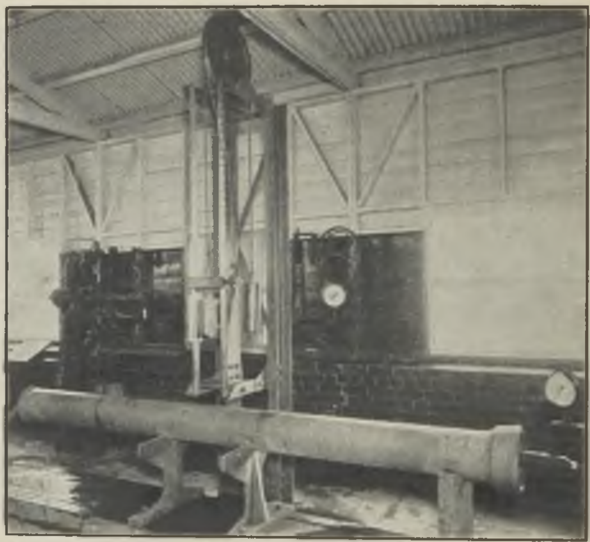


FIG. 22.—IMPACT TESTING MACHINE.

fall spout and trough, and is projected into the mould at the socket end. When the socket portion is full, the water box travels in a downward direction.

Due to the combination of the axial and circumferential movements, a continuous spiral of molten metal is deposited on the inside of the mould, and knits together, thus forming the pipe. The finish of the casting process is shown in Fig. 18.

It will be realised that a true pipe can be formed to any required thickness by the adjustment of those three movements. For instance, having determined the correct peripheral speed of the mould, *i.e.*, that which exercises sufficient centrifugal force to hold the metal against the wall of the mould, and knowing the rate of discharge of the tilting hopper, the speed of traverse is adjusted to suit the thickness of the

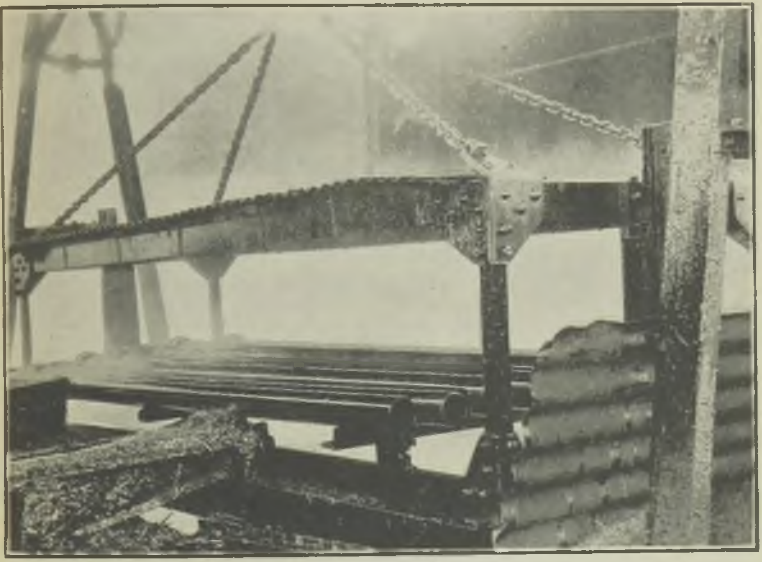


FIG. 23.—COOLING SPUN IRON PIPES.

pipe. This speed of traverse varies with the size of pipe.

After removing the socket "kellet," the pipe is discharged from the mould by inserting internal grip tongues into the socket end of the pipe and moving the machine once again to the upper part of the track. This is shown in Fig. 19.

During this operation arms automatically function, temporarily supporting the pipe until it is picked up by a transfer mechanism and deposited on to an adjacent gantry, and this operation is shown in Fig. 20. The pipes roll along this gantry over a weighing machine to a normalising furnace.

As the pipes are cast in metal moulds a slight chill is formed in the outer skin. This chill is minimised to a large extent by sprinkling the inside of the steel mould with a predetermined amount of powdered ferro-silicon. The object of this normalising is two-fold, to remove the last traces of chill and to eliminate any casting strains. The pipes are kept at a temperature of 955 deg. C. for 15 min. in the hot zone and then gradually cool to a temperature of 315 deg. C. at the exit of the furnace.

The transit of the pipes through the normalising furnace is controlled by a conveyor which also keeps the pipes revolving. The furnace is heated with producer gas and the temperature is controlled by means of thermocouples and radiation pyrometers coupled to recording instruments. After leaving the furnace the inside of the pipe is scrubbed by a pipe scouring machine, after which it is inspected and passed to the dipping tanks where it is coated. It is then hydraulically tested, after which it is ready for despatch.

The time for casting a spun pipe, of course, varies with the size. From putting the socket in place to removing the pipe to the gantry a 4-in. dia. pipe takes $2\frac{1}{2}$ min., whilst a 15-in. dia. pipe takes 8 min. The sockets are struck up with a special mixture of sands, clay and a cereal binder to give a good strong socket.

The centrifugally-spun process subjects the metal to the influence of two important factors:—(1) Centrifugal force, and (2) rapid rate of solidification. Both of these enhance the structure and strength of the metal. Metal when cast in sand giving a tensile of 10 tons per sq. in. has a tensile strength of 15 to 20 tons per sq. in.

when spun in a water-cooled metal mould—depending on the thickness of the pipe. This improved strength is primarily due to the effect of rapid cooling, the centrifugal force contributing about 25 per cent. to the total improvement.

The rapid solidification of the metal causes the formation of a fine crystalline structure in which the graphite is evenly distributed in a very fine form. Centrifugal action prevents the formation of blowholes or other cavities in the section of the casting, any gases formed being expelled by this action. Owing to the improvement in the mechanical properties of the spun metal, it is possible to manufacture the spun pipe some 25 per cent. thinner in section than the corresponding sand-cast pipe and at the same time to produce a higher factor of safety.

Apart from the increased tensile strength of the spun pipe, tests representing various stresses, such as shock, external loads along the pipe, external loads transverse to the pipe—prove that the spun pipe is in all instances equal or superior, despite its reduced thickness, to sand-cast pipes. The normal tests specified for testing of the metal used in sand-cast pipes are transverse and tensile. As similar bars would not represent the metal in a spun pipe, a ring test has been devised and adopted for the determination of the tensile strength. Rings 1 in. wide are cut from the spigot end of the pipe and pulled in a testing machine in a similar way to testing the link of a chain. From a formula which has been evolved from many tests, the tensile strength of the metal can be calculated.

Fig. 21 shows the comparative deflections on sand-cast and spun pipes of 3-in. dia.

Comparative bending tests on 3 in. spun and sand-cast pipes show that, in the case of the spun pipe, the breaking load is greater by 71 per cent.; limit of elasticity is greater by 51 per cent.; elastic deformation is greater by 30 per cent.; total deflection is greater by 60 per cent.

## Impact Testing Machine

The impact test gives a good indication of the resistance of cast-iron pipes to shocks received in transportation and in actual service. The pipe is held firmly in the machine, shown in Fig. 22, in 24-in. supports. A hammer weighing 50 lbs. is dropped on to the pipe, which is under an internal hydrostatic pressure of 65 lbs. per sq. in. The initial height of the hammer is 6 in., and succeeding blows are from heights increased by 2 in. The blows are all struck at the same point. The number and height of the blows are increased until the pipe fails. The height at which the first crack and first leak occur is noted. From an empirical calculation the impact is found in foot-pounds.

## Coating

All pipes, bends and specials are coated before leaving the works. The pipes are heated either in a hot-water tank or oven before going into the dipping tank. In the case of spun pipes (Fig. 23), the residual heat in the pipes coming from the normalising furnace is sufficient without any further treatment.

The coating mixture consists of special refined tar containing 10 per cent. bitumen to which is added at times strained anthracene oil to control the consistency. The tar acids are kept as low as possible in this mixture, about 3 per cent. The mixture is kept at 150 deg. C. in the dipping tanks which are all controlled with recording thermographs. The pipes are kept in the dipping tank from 5 to 15 minutes according to size, when they are withdrawn and allowed to drain.

When extreme adverse conditions are expected, such as aggressive soils containing magnesium sulphate, calcium sulphate and other salts a special thick coating is put on the pipes. This consists of bitumen to which is added an inert filler and asbestos fibre to give additional strength. This coating is from $\frac{1}{16}$ to $\frac{1}{8}$ in. thick and is put on in a special machine.

When tubercule incrustation is encountered, the iron pipes are lined with centrifugally-spun concrete.

The Paper has now traced the various methods of making cast-iron pipes and arrived at the stage where they are ready for transit to be despatched to their various destinations all over the world.

In conclusion it seems desirable to quote the words of Mr. Henry S. Stilgoe, M.Inst.C.E., late Chief Engineer to the Metropolitan Water Board.

" I can always say of the cast-iron water-main that it is a well-tried, faithful and honest servant of the water engineer." This quotation is taken from an interesting book " Cast-Iron Pipe. Its Life and Service," published by the Stanton Ironworks Company, Limited.

The author wishes to thank the directors of the Stanton Ironworks Company and Mr. P. H. Wilson, foundry general manager, for permission to give the Paper.

# Scottish Branch

## MANUFACTURE OF LOCOMOTIVE CASTINGS

**By H. Lowe (Associate Member)**

This Paper mainly refers to the production of locomotive castings at the St. Rollox workshops of the L.M.S. Railway Company. There is a definite necessity for the chemical analysis of pig-iron, and the only way in which good results can be obtained is to analyse all the materials and carefully control the proportion of the charges that go into the cupola. To ensure correct results, check analyses are made of samples of the iron as received.

The method is to take three or four pigs from different parts of the truck, break them and take drillings from the centre, care being taken that no sand from the outside becomes mixed with the drillings. They are then put into envelopes and carefully marked with the number of the truck and such other information as will serve to identify this particular lot of iron, and then submitted to the chemist. If it is found that the material is not to specification, a full report is sent to the makers, and the wagon marked " rejected." The same procedure is adopted with all other materials such as coke, lime, shell, and moulding sands.

### Furnace Charges

The furnace charges are put on a board on the charging platform, which shows the amount of charges and the different mixtures for the day. At the tapping spout on the wall there is an indicator showing the different classes of metal that are being tapped. This is a guide to the metal carriers, who then know to which section of the shop the metal should be taken. There are four different mixtures melted in the furnaces each day, for castings such as brake blocks, signal castings, cylinders, engine details and axleboxes.

Cylinders, cylinder covers, piston heads, piston rings, piston valve liners, slide bars, motion plates and all high-pressure castings are manufactured by the dry sand process.

Dry sand moulding is essentially the same as in green sand except in respect to the actual manipulation of the sand used, as the composition and general properties of the two sands are very different. For dry sand moulding, the

Fig. 2.—Core Racks.

mould requires to be thoroughly dried in a suitable stove before it can be cast successfully. Dry sand mixture such as 90 per cent. floor sand and 10 per cent. Leavenseat sand containing 12 per cent. clay, incorporates no combustible substance, such as coal dust or blacking, but these are used in the green sand mixtures. They are much stronger, however, and more binding, but too close and compact when in the damp state to permit of the escape of gases generated by the heat when casting. After being thoroughly dried, the moulds become harder and stronger. These and other factors make the dry sand process more reliable, especially for larger and more important work.

In green sand moulding there is a much greater tendency to honeycombing and the production of unsound castings. Honeycombing which usually appears at the top side of the castings, is often due to the water arising from the dampness of the green sand, being evaporated into steam, which for the want of a freer escape finds its way through the liquid metal where it has become entrapped. By hammering or

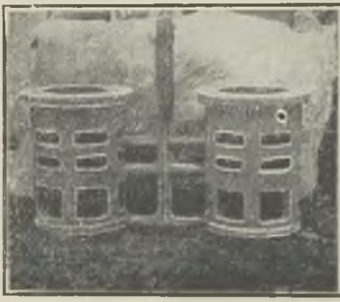


Fig. 1.—Method of Gating Piston Valve Liners.

Fig. 5.—External Core Assembled for Cylinder.

breaking up, such defects are all the more liable to occur in the vicinity of the studs or chaplets, especially those placed on the top for holding down cores. This again is due to steam vapour being in the first instance condensed on these metal surfaces and then evaporated by heat of the molten metal, in contact with it during the casting process. The sand in a green sand mould is much weaker than by the dry sand mixture and is therefore more readily broken by the wash of the metal, and any portion thus separated will cause sand holes or scabs.

Having regard to all the circumstances and the very important fact that these castings are made by semi-skilled labour and are machine moulded, more success is obtained in the dry sand than the green sand process.

### Operations Performed by Moulding Machines

Owing to the increased competition in founding, coupled with the large and growing demand for castings, much time and ingenuity have been expended in devising mechanical devices that will replace, to some extent, the manual labour involved in the foundry, particularly in such classes of work as loose patterns and plate moulding.

FIG. 10.—PLAN VIEW OF ASSEMBLED CORE.

FIG. 11.—CLOSED READY FOR RAMMING HEADS.

The result of the employment of such devices has been to cheapen and increase the output, at the same time securing a more uniform and higher quality of work. While these good results will continue to obtain in repetition or standard work where the objects are of a more or less simple form, there will always be a demand for skilled moulders to deal with the many special lines of work which will continually recur, and which it will not be commercially possible to attempt to handle by machine.

With the exception of the locomotive cylinders all the engine detail castings are moulded on a large Osborne jarring machine by semi-skilled labour—two men and a boy. One man closes the moulds, and the other blacks the moulds and assists the boy at the machine. After a time on the machine, these men become very efficient and competent at their work, and when exceptional circumstances arise, such as a man being off duty, it has been found to be good policy to put an unskilled man on the machine. It is always giving him a certain amount of knowledge of the machine, and will make him ready

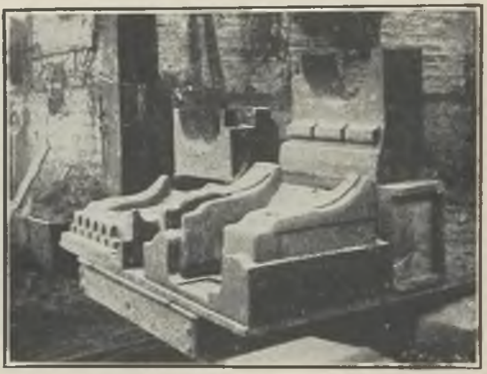


FIG. 3.—THE CORE PLATES USED ARE MACHINED.

to take over when there is a vacancy for a machineman. It also serves the purpose of maintaining the output and keeping the core-making and fettling sections in the department fully employed.

## Gating

The gating is a very important factor in the manufacture of good clean castings. All gates are placed on the moulding boards by the patternmaker to the instruction of the foreman moulder, who gives the sizes and direction of all rates and risers. As shown in Fig. 1 for the piston valve liners, the gates are so placed that the metal runs directly below the ports and exhaust. This method clears away any scum or dirt that may lodge in this section during the casting operation. It is very important that these parts should be clean and free from scum or dirt, as the ports are cored out leaving $\frac{1}{16}$ in. machining allowance, and the least spot or mark would cause these castings to be rejected.

Piston heads are run with two drop gates on the rim and the riser placed on the highest part.

FIG. 4.—FIRST CORE ASSEMBLED FOR OIL SAND MOULDED CYLINDER CASTINGS.

With the dry sand process, and by paying attention to the proper method of gating and pouring the metal at a high temperature, say from 1,320 to 1,340 deg. C., good high-pressure castings can be obtained.

### Core Making

This section is a very important part of the foundry department. The core shop has conveniently-placed portable racks (Fig. 2) with ample storage capacity readily accessible to the core makers. They are placed between the core benches, with a passage of 3 ft. on both sides. These racks consist of a series of open and narrow shelves which allow the cores to be deposited on the one side by the core makers; when these are filled up with cores, they are taken by a lift truck, with a capacity of 2,500 lbs. and $1\frac{5}{8}$ in. lift, and placed in the drying store.

### Core Plates

The cores are made in half and are supported on iron plates. These iron plates, known as core plates, have a true-planed surface. If warped plates were used for drying the half of jointed cores, it would be found necessary to rub the faces of the cores together until they make

Fig. 6.—Internal Cores in Position.

a good joint, but this is a bad practice, as it will be found that such cores are usually out of shape, and consequently will not produce satisfactory castings. It is therefore good practice to have all core plates with a true planed surface (Fig. 3).

### Sand Mixtures Used

All cores are made in oil sand. There are three different mixtures of core sand: for cylinders and engine detail cores a mixture of 150 lbs. sea sand to 8 lbs. of linseed-dextrene mixture is used; for axle boxes and less important cores a mixture of 150 lbs. of sea sand to 5 lbs. of linseed-dextrene mixture is used. All brake block cores are made with 150 lbs. of reclaimed sand to 5 lbs. of No. 2 binder, L.M.S. specification.

The core sand is mixed in the pan mill, the sand being first measured into the mill, and the oil and other binding materials then added. When mixed it is taken and distributed to the core makers at their benches, particular attention being paid to the green sand bond, which gives some idea as to the quality of the sand. As far as possible, the same men are retained for sand

FIG. 7. DRAG MOULD OF A CYLINDER MADE FROM OIL SAND.

mixing. The millman has in his possession the standard mixtures and no mixtures are altered unless authorised by the works metallurgist or foreman. Continuous application enables these men to become expert at this work, and the result is a very uniform core sand.

The savings obtained from a good oil-sand mixture are not only to be associated with a simple method of making all cores, due to the cores being made in half, but also are due to the elimination of all cast-iron core-irons.

### Oil Sand Cylinder Moulds

An experiment was made recently in manufacturing a locomotive cylinder in oil sand without the use of the ordinary pattern. Three core boxes were used to make ten external cores, by transferring the parts required to each corebox. The method adopted was to make a level bed on the drag part of the moulding box, and place the bottom core on the centre lines, the cores being made 4 in. clear of the inside of the moulding box, and all runners and risers rammed in the cores. When the five bottom cores were in position, the mid-part of the moulding box was lowered over them and ordinary floor sand

FIG. 8.—SHOWS SPACE AROUND THE ASSEMBLED CORES FOR SAND RAMMED BETWEEN THE CORES AND BOX.

rammed round the cores to hold them in position. There was no danger of the cores being rammed out of position as the joints had been checked in the cores to prevent any shift when ramming. The bottom part of the mould, when completed, was ready to receive the cores for the internal surfaces. Care was taken in locating these cores in order that their distances from the adjacent sand surfaces and the ultimate thickness of the metal mould be uniform. When all the internal cores were in position, the remaining five external cores were placed in position, and the mould closed up. The top part of the moulding box was lowered over the cores and rammed up similarly to the drag part.

The mould was then prepared for pouring in the molten metal. A runner box connected the two down gates through which the metal would flow. These holes were plugged with two pieces of tin with a ½-in. hole in the centre. This allowed the runner box to be filled with metal before the metal passes to the mould. The two down gates fed the casting equally from the two corners. The process is shown in Figs. 4-11.

The casting referred to was an 18 in. by 26 in. freight engine cylinder, the weight of which was

FIG. 9.—END VIEW OF FIG. 7.

23 cwts., but 28 cwts. were required in the process of casting. It took two days for the metal to cool sufficiently to allow the casting to be taken to the dressing shop. This was necessary to prevent uneven stresses which would be set up in the casting if allowed to cool quickly and prevented any chilling and hardening effect on the surfaces to be machined. When taken to the dressing shop the casting was easily fettled, all the external cores falling off, leaving a very clean surface. The benefits obtained from this process are that it is a simple method, there is no danger of scabbing of the mould, as the whole mould is perfectly dry, there are no crushes in

the mould when closing, there are good joints, and the mould is visible through the whole process of closing. Twenty of these cylinders have been made and machined and the results have been satisfactory.

Axle boxes and carriage and wagon castings are manufactured by machine moulding by the green sand method. The preparation of sand for green sand moulding involves the following: The facing sand is made from 80 per cent. floor sand, 10 per cent. Levenseat sand and 10 per cent. coal dust. This sand is milled in the pan mill, giving the sand the bond strength for facing the moulds. The floor sand is put through a Royer sand machine, which not only gives a good mixing, but aerates the sand, and imparts a high permeability. For heavy and light jobbing castings made in green sand, the facing sands are shovel mixed with a percentage of floor sand, rock sand, Belfast sand and coal dust.

A series of tests on the moisture content of moulding sand in various parts of the foundry has been made by the works metallurgist, by means of a Speedy moisture tester. The results show a variation through the foundry of the moisture content in the sand. In green sand, the tests showed the moisture from 7 to 9 per cent., and in dry sand 9 to 10 per cent. by weight. The result of these tests shows the importance and need for mechanical control of all moulding sands.

### Casting Temperature for Cast Iron

As a result of a discussion with the works metallurgist as to what was the correct temperature at which cast iron should be poured, the results of some tests recently made in the iron foundry, St. Rollox, to determine the effect of casting temperature on the mechanical properties of cast iron are detailed below.

A series of 2 in. by 1 in. section test bars was cast in dry sand moulds from the same bogies at temperatures of 1,330, 1,320, 1,280, 1,250, 1,220 and 1,180 deg. C. The metal used was cylinder quality, and three 42 in. bars were cast at each temperature. Each bar was tested in transverse between 36 in. centres. The test was repeated on the broken pieces between 12 in. centres, and result was made equivalent to the tests on the 36 in. centres. In this way nine results were obtained for each temperature, and the averages of these are given in Table I.

TABLE I.—*Effect of Casting Temperature in Mechanical Strength.*

| Casting temperature in deg. C. | 1330 | 1320 | 1280 | 1250 | 1220 | 1180 |
|---|---|---|---|---|---|---|
| Average transverse breaking load (cwts.) | 34.9 | 32.3 | 34.8 | 34.5 | 29.7 | 25.8 |
| Average deflection (in ins.) | $\frac{11}{32}$ | $\frac{11}{32}$ | $\frac{11}{32}$ | $\frac{9}{32}$ | $\frac{8}{32}$ | $\frac{9}{32}$ |
| Average Brinell hardness | 222 | 218 | 222 | 219 | 222 | 220 |

It will be seen that, whereas the deflection and Brinell hardness are barely affected by casting temperature, there is a marked loss of strength in bars cast below 1,250 deg. C. This was confirmed by the increased number of flaws discovered in the bars cast at the low temperatures.

It is concluded that for castings of 1 in. section, temperatures below 1,250 deg. C. are to be avoided in the interest of mechanical strength and soundness. For castings of greater section than 1 in. lower temperatures may be permitted, but sections under 1 in. will require even higher temperatures than 1,250 deg. to ensure the best results.

Co-operation of the practical and technical knowledge in the St. Rollox foundry is a great contribution to the success of the foundry. Work of this kind should always go on, and the machinery made as up to date as possible, but there are always the men upon whose performance of their duties the structure depends.

In conclusion, the author wishes to thank the management for the facilities for giving this Paper, and would also thank the few friends who were responsible for providing the illustrations.

# NAME INDEX

# SUBJECT INDEX

THE TECHNICAL COMMITTEE OF THE
INSTITUTE OF BRITISH FOUNDRYMEN
IN COLLABORATION WITH
THE BRITISH CAST IRON RESEARCH ASSOCIATION

# TYPICAL MICROSTRUCTURES OF CAST IRON

## INCLUDING MALLEABLE CAST IRON

Series II. 1936.

This second series of photomicrographs has been prepared to amplify those given in the first series. Both series have been assembled for the purpose of enabling metallurgists to have some common standards with which their own observations of microstructures might be compared.

The specimens have been collected to show characteristic structures, and are not necessarily the best or only structures permissible in the class of casting from which they have been obtained. In view of this declared purpose, compositions have been purposely omitted.

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The best thanks of the Committee are due to Messrs. L. W. Bolton and A. A. Timmins, who have been responsible for the collection and photography of the specimens.

## POLISHING AND ETCHING SPECIMENS FOR MICROSCOPIC EXAMINATION

Full notes on the preparation of samples for microscopic examination were given in Series I (see also I.B.F. Proc., 1933-34, Vol. XXVII, p. 667) and the British Cast Iron Research Association Research Report No. 105. The etching notes given in Series I are now repeated and amplified to cover the range of materials included in this Series.

### Etching Reagents for Normal Grey and White Cast Irons and Malleable Iron.

*Picric Acid.*—For revealing the structure of normal cast iron, including white irons and whiteheart malleable, the most generally used etching reagent is a solution of picric acid in alcohol (rectified spirits). A 4 per cent. solution is recommended, but, owing to ease of preparation, a saturated solution is often used. The time required for etching in order to reveal the ordinary details of the structure on microscopical examination varies with the character of the metal and the strength and temperature of the solution. With a saturated solution of 15 deg. C. 5 to 10 seconds' immersion is sufficient for a normal grey cast iron. With longer immersion this reagent may be used for developing the structure of low alloy content martensitic cast irons of the type shown in typical micro structures 12 and 13.

*Nitric Acid.*—A 2 per cent. solution of nitric acid in alcohol (Nital) is useful for developing the grain boundaries in ferrite, and for this reason is mainly used in etching wholly ferritic material, *e.g.*, blackheart malleable cast iron. The development of ferrite-grain boundaries by means of this reagent takes from 30 seconds to 2 minutes, and as a general rule this time is sufficient to over-etch any pearlite which is present.

The ferrite grains can be made to take on a colour contrast if the etching solution is heated to approximately 40 deg. C., and this will also shorten the time of etching.

This solution may also be used for revealing the pearlitic structure of ordinary grey cast irons.

(*Continued on page* 28)

## STRUCTURE No. 9.

Annealed Grey Cast Iron.

Medium-sized graphite flakes in a matrix of ferrite. Small manganese sulphide inclusions and lakes of phosphide eutectic can be seen with traces of pearlite near the phosphide lakes. Carbon from the breakdown of pearlite has been deposited on the graphite flakes.

## STRUCTURE No. 10.

Burnt Grey Cast Iron.

Graphite and iron oxides in a matrix of ferrite. Phosphide eutectic is also present. The oxidising gases have penetrated down the graphite flakes and begun to attack the metal. Small areas of oxide are distributed throughout the matrix.

STRUCTURE No. 9.

Etched. × 200.

STRUCTURE No. 10.

Etched. × 200.

## STRUCTURE No. 11.

Chill Changing to Grey.

(*a*) The top portion of the photograph shows the structure of the white part of a chilled casting. The pearlite dendrites are in a matrix of what was originally the austenite-iron carbide eutectic. The austenite part of this eutectic has become pearlite during cooling.

(*b*) The centre portion corresponds with the mottled fracture between the white chill and the grey back. Graphite flakes are present, the matrix being pearlite. Some eutectic cementite is present, the austenite (pearlite) part of the eutectic having joined up with the pearlite matrix.

(*c*) The bottom portion shows the structure of the grey part of the casting at the back of the chill. The graphite flakes are in a matrix of finely laminated pearlite. No free cementite is present. Small lakes of phosphide eutectic are to be seen. These are also present in the other two areas, but are not easily distinguishable owing to the presence of large quantities of free cementite.

STRUCTURE No. 11.

(a)

(b)

(c)

Etched. × 200.

STRUCTURE No. 12.

Martensitic Grey Cast Iron.

Graphite flakes in a matrix consisting mainly of martensite. Such a structure can be produced either by heat treatment or the use of alloying elements.

STRUCTURE No. 13.

Martensitic White Cast Iron.

Cementite in a matrix consisting mainly of martensite. No graphite is present. Such a structure is usually obtained by the use of alloying elements.

STRUCTURE No. 12.

Etched. × 500.

STRUCTURE No. 13.

Etched. × 500.

## STRUCTURE No. 14.

Grey Cast Iron containing Austenite and Martensite.

Graphite flakes in a matrix of austenite containing needles of martensite. Such a structure is usually produced by the use of alloying elements.

## STRUCTURE No. 15.

Austenitic Grey Cast Iron.

Graphite flakes in a matrix of austenite. No other constituent is present. Such a structure can only be obtained by the use of alloying elements.

The carbides shown in Structure No. 17 are usually also present in this type of structure.

STRUCTURE No. 14.

Etched. × 500.

STRUCTURE No. 15.

Etched. × 500.

## STRUCTURE No. 16.

Supercooled Graphite in Grey Cast Iron.

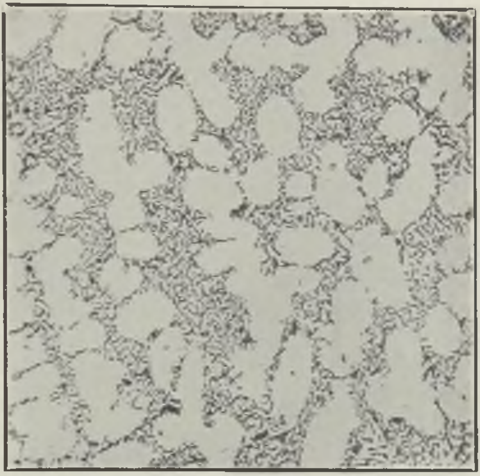
Graphite is present in the supercooled form, *i.e.*, thrown out of solution at a lower temperature than normal graphite. Dendrites of ferrite are isolated by the ferrite-supercooled graphite areas.

## STRUCTURE No. 17.

Supercooled Graphite in Austenitic Grey Cast Iron.

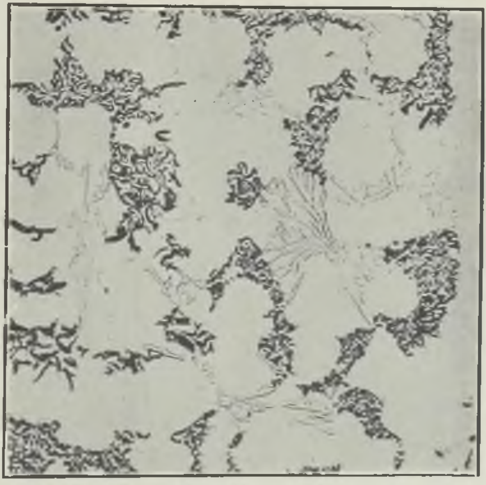
Graphite of the supercooled type, similar to that shown in Structure 16, in a matrix of austenite. Some carbide areas are also present. Such a structure can only be produced by the use of alloying elements.

STRUCTURE No. 16.



Etched. × 200.

STRUCTURE No. 17.



Etched. × 200.

In Structures Nos. 18 to 21 the specimens have been deeply etched to reveal the distribution of the phosphide eutectic. The specimens were all obtained from pearlitic cast irons containing no free cementite.

STRUCTURE No. 18.

Grey Cast Iron containing 0.1 per cent. Phosphorus.

Only a small amount of phosphite eutectic is present.

STRUCTURE No. 19.

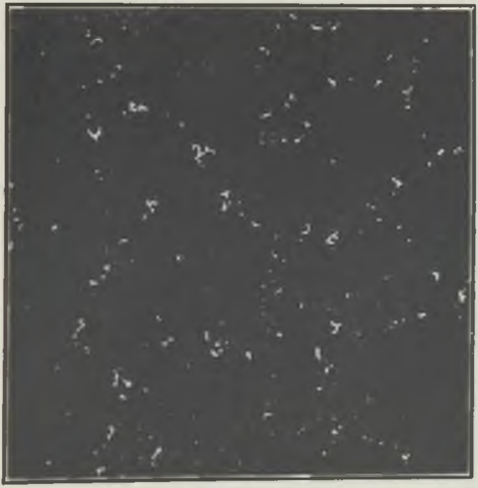
Grey Cast Iron containing 0.25 per cent. Phosphorus.

Shows the effect of the higher phosphorus content on the distribution of the phosphide eutectic. Phosphide is distributed round the grain boundaries in a network formation.

STRUCTURE No. 18.

Etched. × 25.

STRUCTURE No. 19.



Etched. × 25.

STRUCTURE No. 20.

Grey Cast Iron containing 0.75 per cent. Phosphorus.

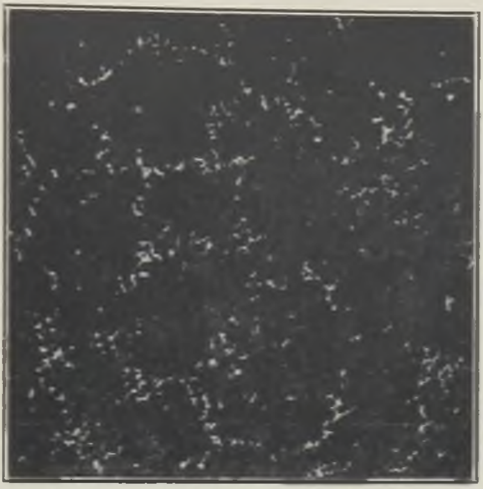
Shows a further increase in the amount of phosphide eutectic present. The network formation is more clearly defined.

STRUCTURE No. 21.

Grey Cast Iron containing 1.20 per cent. Phosphorus.

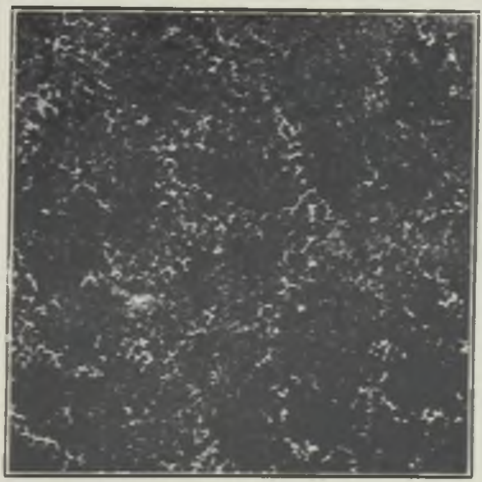
The crystal grains are now almost completely surrounded by phosphide eutectic.

STRUCTURE No. 20.



Etched. × 25.

STRUCTURE No. 21.



Etched. × 25.

STRUCTURE No. M1.

White Heart Malleable, unannealed.

Free carbon is absent, the whole of the carbon being in the combined form. The structure is Pearlite (dark) and free Cementite (light).

STRUCTURE No. M2.

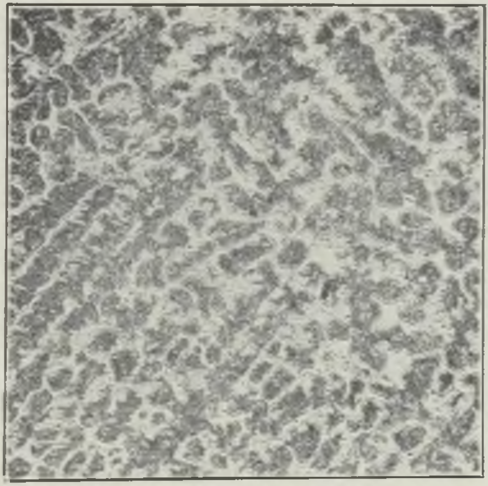
Black Heart Malleable, unannealed.

This structure is similar to M1 in being free from graphite and composed of Pearlite and Cementite, but the grain size is larger, and the ratio of Cementite to Pearlite is much less, due to lower Total Carbon content.

STRUCTURE No. M1.

Etched. × 50.

STRUCTURE No. M2.



Etched. × 50.

STRUCTURE No. M3.

White Heart Malleable, annealed. Taken from the centre of a well annealed 2-in. dia. section.

The black patches are temper carbon (graphite). They are surrounded by lakes of Ferrite (white).

The matrix is Pearlite (half ton), distinctly laminated in the left-hand top corner.

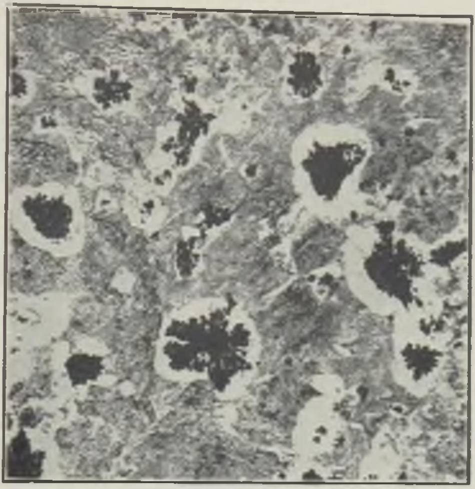
Sulphides are seen as grey particles in both Pearlite and Ferrite.

STRUCTURE No. M4.

Black Heart Malleable, annealed. Taken from centre of 3-in. dia. section.

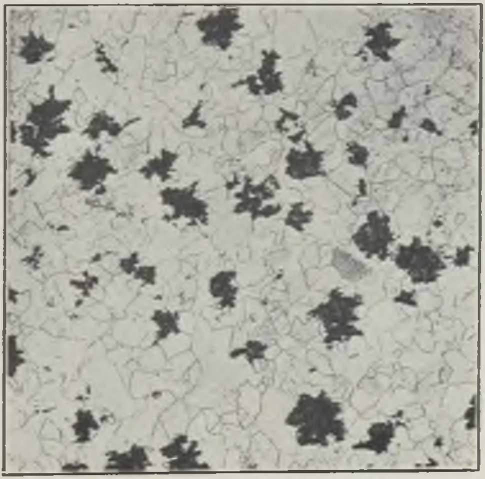
The structure is Ferrite and temper carbon. A few sulphide particles may be seen. There is no combined carbon present. Note that the grain size is larger than in M7.

STRUCTURE No. M3.



Etched. × 50.

STRUCTURE No. M4.



Etched. × 50.

STRUCTURE No. M5.

White Heart Malleable, annealed. Taken from edge of well annealed $2\frac{1}{2}$-in. dia. section.

There is a wide band of Ferrite next to the skin and this contains Sulphides (light grey), Oxides and Silicates (very small black particles), and Temper Carbon (large black patches). The structure within the surface layer of Ferrite is Pearlite and Ferrite, with some temper carbon and sulphides.

STRUCTURE No. M5.

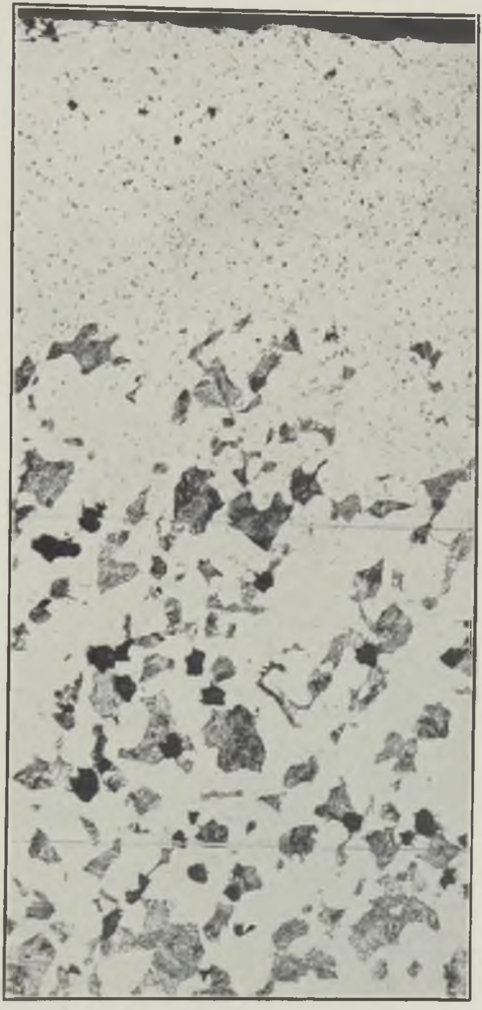
Etched. × 50.

STRUCTURE No. M6.

White Heart Malleable, annealed. Taken from edge towards the centre of a $\frac{5}{16}$-in. section.

The structure near the skin is similar to M5. Bounding the Ferrite edge is Ferrite and Pearlite, with temper carbon and sulphides. Note larger grain size than M5, and the increasing amount of Pearlite towards the centre.

STRUCTURE No. M6.



Etched. × 50.

STRUCTURE No. M7.

Black Heart Malleable, annealed. Taken from edge of $\frac{3}{4}$-in. dia. section.

The structure is Ferrite with temper carbon. Traces of sulphides may be detected with difficulty. There is no combined carbon present.

Etched. × 50.

STRUCTURE No. M8.

Black Heart Malleable "Rimmed" type. annealed. Taken from edge of $\frac{3}{4}$-in. dia. section.

The structure next to the skin is Pearlite with very little Ferrite. This changes to a mixture of Ferrite and Pearlite, the Ferrite forming lakes round the temper carbon Although some sulphide particles are present, the magnification is not high enough for them to be readily detected. Note the Pearlite is laminated.

× 50.

(*Continued from page 3*)



## Deep Etching Reagents for Revealing Phosphide Eutectic.

(See Typical Structures 18-21.)

The following etching reagents are recommended for deep etching when it is desired to examine the distribution of the phosphide eutectic. Usually, at least one minute's immersion is required to complete the darkening of the matrix.

*Ammonium Persulphate.*—A 10 per cent. aqueous solution of ammonium persulphate will darken both ferrite and pearlite, leaving phosphide eutectic and free cementite unattacked. This reagent will not keep indefinitely, and to obtain the best results it should be freshly made up.

*Nitric Acid.*—A 20 per cent. solution of nitric acid in water will darken pearlite, leaving the phosphide unattacked. Ferrite is not darkened to the same extent as with the previous reagent, and, if present, may lead to confusing results. Cementite is also unattacked by this reagent.

*Bromine.*—A saturated solution of Bromine in water will reveal the phosphide distribution, darkening pearlite and ferrite, the latter to a rather less extent than ammonium persulphate. Cementite is also unattacked by this reagent.

## Austenitic Nickel Cast Irons.

A 10 per cent. alcoholic solution of hydrochloric acid is recommended for etching high nickel austenitic cast irons of the type shown in typical microstructures, 14 to 17. This reagent should be used warmed to about 50 deg. C. and up to 5 minutes' immersion is required to develop the structure.

An alternative reagent is an alcoholic solution of picric acid containing a little nitric acid. This solution is prepared by diluting 30 m.l. of a saturated solution of picric acid in methylated spirits by 20 m.l. of methylated spirits and adding two to three drops of nitric acid. If the mixture etches too slowly, further small additions of nitric acid are made. This solution does not require to be heated.

For the examination of the carbide structure in austenitic cast irons an electrolytic etch in 10 per cent. aqueous solution of oxalic acid may be used. The specimen is made the anode and a platinum cathode is used, the current being 6 volts. About 15 secs. are required to develop the structure. This method tends to open up the graphite flakes.

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