MR. WESLEY LAMBERT, A.K.C.

President 1929-30.

Mr. Wesley Lambert is Manager of the Metallurgical Department of J. Stone & Company, Limited, Deptford and Charlton. He received his training at the Roan School, Greenwich, and King's College, London, securing the Associate's Diploma and various awards, including a Science Scholarship, the Jelf Medal and the Cunningham Prize. He became Assistant Metallurgist at the Royal Gun Factory, Woolwich, and later took an appointment as Metallurgist and Lecturer on Engineering Chemistry under the Imperial Ottoman Government. During his services with the Ottoman Government the Sultan conferred upon him the Order of the Medjidieh.

Mr. Wesley Lambert later became Chief Metallurgist at the Royal Gun Factories, Woolwich, and was invited to join the staff of the Sir John Cass Technical Institute as a special lecturer. He is a Fellow of the Chemical Society, and has contributed "Papers" to a number of societies to which he belongs, including the Institution of Civil Engineers, the Institution of Naval Architects, Institute of Marine Engineers, Institute of Metals, etc. He is a member of several Panels and Committees of the British Engineering Standards Association, and is a Member of Council of the British Cast Iron Research Association.

PROCEEDINGS
OF THE . .
INSTITUTE OF
BRITISH FOUNDRYMEN.

VOLUME XXII. 1928-1929.

Containing the Report of the International Foundrymen's Congress and Twenty-Sixth Annual Conference, held in London, June 10th, 11th, 12th, 13th and 14th, 1929; and also Papers and Discussions presented at Branch Meetings held during the Session 1928-1929.

Institute of British Foundrymen.

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THE INSTITUTE OF BRITISH FOUNDRYMEN.

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PRESIDENT:

Wesley Lambert, A.K.C., F.I.C., Messrs. J. Stone & Company, Limited, Deptford, London, S.E.14.

VICE-PRESIDENTS:

F. P. Wilson, J.P., "Parkhurst," Middlesbrough.
A. Harley, "Ashlea," Stoke Park, Coventry.

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R. Buchanan. (Deceased, 1924.) 1904-1905.
H. Pilkington. (Deceased.) 1906-1907.
F. J. Cook, M.I.Mech.E., 31, Poplar Avenue, Edgbaston, Birmingham. 1908-1909.
P. Longmuir, M.B.E., D.Met., 2, Queen's Road, Sheffield. 1910-1911.
C. Jones. (Deceased, 1923.) 1912.
S. A. Gimson, 20, Glebe Street, Leicester. 1913-1914.
W. Mayer. (Deceased, 1923.) 1915.
J. Ellis, 20, Lambourn Road, Clapham, London, S.W.4. 1916-1917.
T. H. Firth. (Deceased, 1925.) 1918.
John Little, M.I.Mech.E., 68, Rawlinson Road, Hesketh Park, Southport.
Matthew Riddell. 1920.
Oliver Stubbs, M.I.Mech.E., Openshaw, Manchester. 1921.
H. L. Reason, M.I.Mech.E., M.Inst.M. 1922.
Oliver Stubbs, M.I.Mech.E., Openshaw, Manchester. 1923.
R. O. Patterson, Pioneer Works, Blaydon-on-Tyne. 1924.
J. Cameron, J.P., Cameron & Roberton, Limited, Kirkintilloch, N.B. 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.
S. H. Russell, Bath Lane, Leicester. 1928.

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Messrs. F. J. Cook, R. O. Patterson, and Oliver Stubbs.

GENERAL SECRETARY AND GENERAL OFFICE:

Tom Makemson, Assoc.M.C.T., St. John Street Chambers, Deansgate, Manchester.
(Registered Office: 49, Wellington Street, Strand, London, W.C.2.)

AUDITORS:

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

GENERAL COUNCIL:

(Districts represented are shown in brackets.)

*J. A. Affleck, B.Sc., 21, Overdale Avenue, Langside, Glasgow. (Scottish.)

*A. W. G. Bagshawe, Dunstable Works, Dunstable. (London.)

†A. R. Bartlett, 1, Lower Park Road, Belvedere, Kent.

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†J. R. Hyde, "Hillcrest," Clayton Road, Newcastle, Staffordshire.

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

†J. Shaw, "Cartref," Parkstone Avenue, Southsea.

*J. N. Simm, 61, Marine Drive, Monkseaton. (Newcastle-upon-Tyne.)

*T. A. Spiers, "Delamere," Uppingham Road, Leicester. (East Midlands.)

*V. Stobie, M.I.E.E., Dunstan-on-Tyne. (Newcastle.)

*R. W. Stubbs, 209, Dickinson Road, Longsight, Manchester. (Lancashire.)

*S. P. Thorpe, 11, Devonshire Road, Middlesbrough.

*T. H. Turner, M.Sc., Dept. of Metallurgy, The University, Birmingham. (Birmingham.)

*B. H. Vaughan, 25, Holmes Street, Derby. (East Midlands.)

*F. J. Wares, 216, Cromwell Road, Peterborough. (London.)

*D. Wilkinson, 1114, Bristol Road South, Northfield, Birmingham.

†H. Winterton, "Moorlands," Milngavie, Dumbartonshire.

†D H. Wood, "Kingswood," Park Road, Moseley, Birmingham. (Birmingham.)

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

J. G. Pearce, M.Sc., M.I.E.E., British Cast Iron Research Association, 24, St. Paul's Square, Birmingham.

* Branch Delegates. † Elected at Annual Conference.

BRANCH PRESIDENTS AND SECRETARIES.

(Ex-officio Members of General Council.)

BIRMINGHAM.

E. H. Tyson, 269, Gillat Road, Edgbaston, Birmingham.
F. K. Neath, B.Sc., 24, St. Paul's Square, Birmingham.

EAST MIDLANDS.

J. Lucas, "Sherwood," Forest Road, Loughborough.
H. Bunting, 82, Otter Street, Derby.

LANCASHIRE.

E. Longden, 158, Manley Road, Whalley Range, Manchester.
H. Stead, 1st 36, Cheetham Hill Road, Stalybridge.

LANCASHIRE—BURNLEY SECTION.

T. Greenwood, 1, Schofield Street, Todmorden.
J. Pell, 17, Mersey Street, Rose Grove, Burnley.

LONDON.

J. W. Gardom, 39, St. Peter's Road, Dunstable, Beds.
H. G. Sommerfield, Charterhouse Chambers, Charterhouse Square, London, E.C.1.

MIDDLESBROUGH.

N. D. Ridsdale, F.C.S., 3, Wilson Street, Middlesbrough.
F. A. Harper, Station Chambers, Middlesbrough.

NEWCASTLE AND DISTRICT.

R. H. Smith, 16, Whitburn Road East, Cleadon, near Sunderland.
F. Sanderson, 1, Ellwood Gardens, Gateshead-on-Tyne.

SCOTTISH.

H. Winterton, "Moorlands," Milngavie, Dumbartonshire.
J. Bell, 60, St. Enoch Square, Glasgow.

SCOTTISH—FALKIRK SECTION.

R. Ure, Stenhouse House, Carron, Falkirk.
A. M. Cleverley, B.Sc., 24, York Street, Falkirk.

SHEFFIELD.

G. L. Oxley, Vulcan Foundry, Attercliffe, Sheffield.
T. R. Walker, B.A., 26, Castlewood Road, Fulwood, Sheffield.

WEST RIDING OF YORKSHIRE.

W. G. Thornton, 1081, Grangefield Avenue, Thornbury, Bradford.
S. W. Wise, 110, Pullan Avenue, Eccleshill, Bradford.

WALES AND MONMOUTH.

W. S. Kinsman, 116, Miskin Street, Cardiff.
J. J. McClelland, "Druslyn," 81, Bishop's Road, Whitchurch, Glam.

AWARDS 1928—29.

THE "OLIVER STUBBS" GOLD MEDAL

1929 Award to WESLEY LAMBERT, A.K.C.,
"in recognition of his long and valued services to the Institute of British Foundrymen and for his valuable contributions to non-ferrous foundry practice."

DIPLOMAS OF THE INSTITUTE

were awarded as follows :—

Mr. D. H. WOOD, for his Paper on "History of Ironfounding in the Midlands," given before the Birmingham Branch.

Mr. B. HIRD, for his Paper on "Coal Dust: Its Use and Abuse in the Foundry," given before the East Midlands and Newcastle Branches.

Mr. E. LONGDEN, for his Paper on "Some Interesting Moulding Jobs," given before the Newcastle Branch.

Mr. W. McCULLOCH, for his Paper on "Monel Metal and other Special Non-Ferrous Castings," given before the Scottish Branch.

CONTENTS.

PAGE

International Congress and Annual Conference, London:—

Papers Read at International Congress:—

PAGE

Papers Read before Branches:—

A Symposium on Steel Castings:—

The Institute of British Foundrymen.

TWENTY-SIXTH ANNUAL CONFERENCE and INTERNATIONAL FOUNDRYMEN'S CONGRESS,

LONDON.

JUNE 10, 11, 12, 13 and 14, 1929.

The Twenty-sixth Annual Conference was held in London from June 10 to June 14. This Conference also formed the third of the series of Triennial International Foundrymen's Congresses. Nearly 600 ladies and delegates were present, including about 180 members and ladies from Overseas Foundry Associations, representing 14 countries.

The opening meeting was held in the Grand Council Chamber of the Guildhall of the City of London, by permission of the Lord Mayor and Council, and the other meetings were held at the Institution of Mechanical Engineers, Westminster, by permission of the President and Council of the Institution.

The International Foundry Exhibition, organised by Messrs. F. W. Bridges & Sons, Limited, and the Foundry Trades' Equipment and Supplies Association, was held at the Royal Agricultural Hall from June 5 to 15, and this proved an additional attraction to the delegates.

Previous to the opening of the Congress, about 60 members of Overseas Foundry Associations, and their ladies, accompanied by the President-elect, Mr. Wesley Lambert, and Mrs. Lambert, took part in a tour of the principal industrial centres of Great Britain. and were entertained by various Branches of the Institute.

MONDAY, JUNE 10.

Annual General Meeting.

The annual general meeting of the Institute of British Foundrymen was held at the Institution of Mechanical Engineers, London, on Monday, June 10, Mr. S. H. Russell—the retiring President—being in the chair during the early portion of the proceedings.

On the motion of the President, the minutes of the previous annual general meeting, held in Leicester on June 12, 1928, were taken as read and confirmed.

The Report of the General Council for the year June, 1928, to June, 1929, was then formally presented, having previously been circulated, and, on the motion of the President, seconded by Mr. V. C. Faulkner, was adopted unanimously without discussion.

General Council's Report.

The General Council has pleasure in presenting their Report for the year 1928-29. The year has been one of steady progress, we are able to record an increase in the number of members, and an improvement in the financial position, whilst a step forward has been made in connection with the scheme for a national certificate in foundry practice, for the benefit of students attending either day or evening classes in these subjects.

It is within the knowledge of many members that from time to time the Institute has been seriously concerned by the need for a higher quality of recruit, and for better facilities for training them; but so far with but little result. It is hoped that better progress will now be made towards a solution of this very difficult problem. A sub-committee is considering the most desirable method of establishing an authoritative examining body, but much work has yet to be done before a definite scheme can be expounded.

The Board of Education Committee on "Training for the Engineering Industry" has applied to your Council for their views on "Foundry Apprenticeship and Training." The Literary, Awards and Education Committee has drafted and submitted a carefully-prepared reply to this request.

The duties allocated to the Literary, Awards and Education Committee become more numerous every year and it will soon be necessary to consider whether this Committee should not meet more frequently, so that greater progress can be made.

Much of the time of the Council has been spent in considering the arrangements for the International Congress to be held in London, and the entertainment of the Overseas Visitors during their visits to the various industrial centres of Great Britain.

Membership.

The number of members of all grades on April 30, 1929, was made up as shown on page 4.

It is with great regret that the Council announce the death of 10 members. Eight subscribing firms, 55 members, 70 associate members, and 30 associates have been elected to membership during the year, making a total of 163. Owing to various causes 116 names have been erased, giving a net increase of 47.

It is realised that there are many persons in the foundry industry who are eligible for membership and to whom membership would be of considerable value, but who are not yet associated with the Institute. The Council would appeal to all members to get in touch with such gentlemen of their acquaintance, and point out to them the advantages of Membership.

Junior Sections.

The Institute's own educational work has been continued through the activities of the five Junior Sections, all of which have completed successful sessions.

Membership of the Institute, June, 1929.

	Subscribing Firms.	Members.	Associate Members.	Associates.	Total.
Birmingham, Coventry, and West Midlands ..	2 (2)	88 (91)	95 (91)	19 (17)	204 (191)
East Midlands	4 (1)	40 (37)	83 (68)	2 (4)	129 (110)
Lancashire	9 (8)	115 (114)	197 (198)	9 (11)	330 (331)
London	4 (3)	139 (130)	87 (81)	11 (12)	241 (226)
Middlesbrough	5 (4)	26 (31)	34 (27)	6 (5)	71 (67)
Newcastle	10 (10)	59 (56)	49 (52)	89 (77)	207 (195)
Scottish	2 (1)	64 (68)	131 (143)	29 (30)	226 (242)
Sheffield	6 (7)	84 (84)	78 (84)	11 (11)	179 (186)
West Riding of Yorkshire ..	—	28 (29)	53 (56)	1 (2)	82 (87)
Wales and Monmouth ..	1 (0)	29 (25)	27 (22)	4 (4)	61 (51)
General	—	35 (34)	10 (8)	1 (1)	46 (43)
Total	43 (36)	707 (689)	844 (830)	182 (174)	1,776 (1,729)

The figures in brackets are for the Session 1927–28.

Oliver Stubbs Medal.

The seventh award was made in June last to Mr. J. W. Donaldson, B.Sc., F.I.C., of Greenock, for Papers presented to the Institute embodying his researches into cast iron. Shortly after the award of the medal, the University of Edinburgh conferred upon Mr. Donaldson the degree of Doctor of Science, and the Council wish to congratulate him upon this distinction.

Buchanan Medal.

The work of the Junior Sections has been stimulated by the establishment of the Buchanan Medals. These have been established by anonymous donors, who have invested a sum of money in the name of the Institute, the interest from which is to be applied to the purchase of a silver medal each year for each Junior Section, the medal to be awarded as the result of an essay giving a résumé of the session's work of the Junior Section with which the candidate is associated. The donors have also presented to the Institute the dies from which the medals are struck. The Council wish to tender their sincere thanks for these valuable gifts.

Diplomas.

Five diplomas were awarded in June last for Papers given before the branches during the previous Session. The recipients and the respective branches before which the Papers were given are as follows:—

A. J. Beck	East Midlands Branch.
A. Hudson	Scottish Branch.
W. H. Poole	Newcastle Branch.
N. D. Ridsdale... ...	Middlesbrough Branch.
P. A. Russell, B.Sc. ...	East Midlands Branch.

General Council.

Four General Council meetings and a number of sub-committee meetings have been held at Leicester, Weston-super-Mare, Birmingham and York; several sub-committee meetings have also been held in London and Manchester. At the

General Council meetings there has been an average attendance of 33.

The following members of the General Council retire at the General Meeting on June 10. All retiring members offer themselves for re-election :—Messrs. W. T. Evans, A. Firth, J. Haigh, A. Harley and H. Winterton.

Test Bar Committee.

This Committee has met four times during the year, and has devoted considerable attention to practical investigation of the Fremont Shear Test. It was felt desirable to examine this test fully, as it has repeatedly been put forward in various International exchange Papers. The report is not yet completed, but two members of the Committee have published Papers pointing out certain difficulties which have been encountered in connection with this test. It is expected that the results published in these Papers will be considered during the coming Congress, and your Committee will then be in a position to carry out further investigations if necessary.

The convener of the Test Bar Committee, Mr. John Shaw, desires to place on record his appreciation of the help the members have given during the twelve years the Committee has been in existence. It is not generally recognised that hundreds of tests have been made, the cost of which under ordinary conditions would considerably exceed £1,000, the work, however, has been done without any cost whatever to the Institute, and the thanks of the members of the Institute are due to the members of the Test Bar Committee, who have made considerable sacrifices of time and money.

Annual Conference, 1928.

The Twenty-fifth Annual Conference was held at the Association Hall, Leicester, in June, 1928, and was very well attended. Mr. S. H. Russell was installed as President. The General Council wish to express their appreciation of the arrangements made by the Convention Committee, and particularly the chairman, Mr. Sidney A. Gimson (Past-President of the Institute), Mr. H. H. Moore (treasurer), Mr. H. Pemberton (Branch-President), and Mr. H. Bunting (secretary). The Council also wish to tender their thanks to the Lord Mayor of Leicester and to the many firms in the East Midlands area who entertained the members and ladies at their works, and to the subscribers to the Conference Fund.

International Congress.

The next Annual Conference is being held in London from June 10 to 14, inclusive. This Conference should be a notable one, as it forms the third of the series of Triennial International Foundrymen's Congresses, the first of which was held in Paris in 1923, and the second in Detroit in 1926. A large number of members and ladies of American and Continental foundrymen's associations are expected to be present, and, previous to the Congress, a party of the overseas delegates and ladies will tour Great Britain under the auspices of the various branches of the Institute.

International Relations.

Your General Council still maintains very close relations with overseas foundry technical associations, as evidenced by the holding of the International Conference under the auspices of the Institute in June. Included in the Papers to be read at this Conference there will be several Papers officially presented by various overseas associations.

Exchange Papers have been presented on behalf of the Institute by Dr. J. W. Donaldson at the French Foundry Conference, October, 1928, and by Mr. F. Hudson at the Conference of the American Foundrymen's Association, April, 1929. Mr. T. Henry Turner, M.Sc., is preparing a Paper, on behalf of the Institute, for presentation to the next French Foundry Conference to be held in October next. The Institute is represented on the International Committee of Foundry Technical Associations by Mr. V. C. Faulkner, and your general secretary continues to act as secretary of this Committee.

British Cast Iron Research Association.

The work of this Association has progressed on normal lines during the year. There is a steady but slow increase in membership and income. In June, 1929, under present arrangements with the Department of Scientific and Industrial Research, the Government grant hitherto received by the Association will fall to one-half, and under these circumstances the Association will only be able to continue on its present scale with the aid of more subscribing members.

The work done during the year has carried a number of developments a stage further from the purely metallurgical side, and several advances of very great interest have been made. One of these, dealing with the influence of manganese in relation to sulphur, will be presented to the London Congress in the form of a Paper by Dr. A. L. Norbury. Other developments refer to relationships between structure and composition, alloy cast irons, heat-resisting irons and malleable iron. Work on moulding sands has reached a point at which particulars have been placed before members, of simple foundry-control tests, which will enable sand conditions to be related to troubles experienced, and to enable a minimum of new sand to be employed consistent with safety. Developments of an important character with respect to the cupola have also been made by Mr. J. E. Fletcher, and thus the Association is in a position to advise members in respect of moulding practice, melting practice and mixtures in directions which should result in economies much greater than the annual subscription.

Accounts.

The statement of accounts and balance sheet for the year ended December 31, 1928, are set out on pages 9 to 11.

It will be noted that the income has exceeded the expenditure by £300 5s. 6d. Your Council realised some time ago that rigid economy in working, together with increased membership and regular collection of subscriptions, was necessary to put the Institute's funds on a sound basis and they are happy to announce that the Institute's finances are in a more satisfactory condition than they have been for some time. In this connection they wish to acknowledge the co-operation they have received from the branches, and particularly the Branch-Secretaries. It is felt that if this policy is continued, sufficient funds will be accumulated to extend further the Institute's work and usefulness.

Branch Activities.

It is perhaps not generally recognised that the Institute owes a considerable debt to the readers of Papers and to the firms who permit the various branches to visit their works. In addition to the Papers presented at the Annual Conference, no less than 73 Papers have been given before the various branches, and a large number of works visits have also been arranged. In addition, each Junior Section has carried out a complete programme of Papers and visits.

To the authors of all these Papers and to the managements of the various works the General Council wishes to express its very sincere thanks.

S. H. Russell, *President.*
T. Makemson, *General Secretary.*

BALANCE SHEET, DECEMBER 31, 1928.

LIABILITIES.

	£	s.	d.	£	s.	d.
Subscriptions paid in advance				164	17	0
Sundry Creditors				389	2	0
The Oliver Stubbs Medal Fund :—						
Balance from last Account	203	10	8			
Interest to date	8	4	4			
	211	15	0			
Less Cost of Medal ..	9	10	0			
				202	5	0
The Buchanan Medal Fund				97	16	3
Turner Testimonial Fund						
Balance from last Account	72	14	4			
Less Cheque Professor Turner	70	0	0			
	2	14	4			
Sundry Receipts ..	11	9	0			
				14	3	4

LIABILITIES.—*continued.*

	£	s.	d.	£	s.	d.
Surplus at December 31, 1927	950	16	9			
Add: Excess of Income over Expenditure for the year ended December 31, 1928	300	5	6			
				1,251	2	3
				£2,119	5	10

ASSETS.

	£	s.	d.	£	s.	d.
Cash in hands of Secretaries :—						
Lancashire	21	8	9			
Birmingham	37	7	1			
Sheffield	147	7	9			
London	137	18	5			
East Midlands	22	7	2			
West Riding of Yorkshire	24	3	10			
Middlesbrough	11	18	11			
				402	11	11
Lloyds Bank Ltd. :—						
General Account ..	476	13	2			
Deposit Account ..	400	0	0			
				876	13	2
The Oliver Stubbs Medal Fund :—						
£342 5s. 7d. Local Loan £3 per cent. Stock at Cost	200	0	0			
Balance in hand, Lloyds Bank Ltd.	2	5	0			
				202	5	0
The Buchanan Medal Fund :—						
£125–£3 10s. Conversion Stock at £78				97	16	3
Turner Testimonial Fund :—						
Cash at Bank	12	16	5			
Cash in hand	1	6	11			
				14	3	4
Investments Account						
£450 5 per cent. War Loan at Cost				430	9	10
Furniture, Fittings and Fixtures :—						
Per Last Account ..	105	18	0			
Less: Depreciation 10 per cent.	10	11	8			
				95	6	4
				£2,119	5	10

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1928.

EXPENDITURE.

	£	s.	d.	£	s.	d
Postages				75	16	1
Printing and Stationery, including printing of Proceedings				525	3	0
Council, Finance and Annual Meeting Expenses ..				62	5	7
Medals for Past-Presidents				2	6	6
Branch Expenses :—						
Lancashire	111	14	9			
Birmingham	56	2	7			
Scottish	89	13	8			
Sheffield	54	11	10			
London	35	3	3			
East Midlands	36	13	7			
Newcastle	84	18	0			
West Riding of Yorkshire	33	3	0			
Wales and Monmouth	32	10	1			
Middlesbrough	25	6	6			
				559	17	3
Audit Fee and Accountancy Charges ..				12	12	0
Incidental Expenses				73	14	6
Salaries—Secretary and Clerk				468	0	1
Rent and Rates of Office less Received ..				77	10	4
Income Tax				6	16	0
Subscription to International Committee of Foundry Technical Associations ..				5	0	0
John Surtees Memorial Examinations Grants to Branches				22	18	0
Depreciation of Furniture				10	11	8
				1,902	11	0
Excess Income over Expenditure ..				300	5	6
				£2,202	16	6

INCOME.

	£	s.	d.
Subscriptions Received	2,132	9	10
Sale of Proceedings, etc.	9	1	0
Interest on War Loan and Cash on Deposit	39	7	8
John Surtees Medal Fund, Surplus ..	21	18	0
	£2,202	16	6

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 & COMPANY,
Chartered Accountants,
Auditors.

19 & 21, Queen Victoria Street,
London, E.C.4.

May 13, 1929.

Accounts.

The **President**, in presenting the accounts for the past year, expressed satisfaction that there was a balance of over £300 on the right side, the largest amount that had ever been shown as a credit balance in one year. The assets of the Institute, he pointed out, were represented by £450 in 5 per cent. War Loan. which had cost £430 9s. 10d.

The motion by the President for the adoption of the accounts was seconded.

Mr. Sutcliffe asked why a London firm of accountants was employed to audit the accounts when the general offices of the Institute were in Manchester. He also pointed out that two of the Branches were holding sums of £175 and £137 respectively, and asked what it was proposed to do with regard to this.

The **President**, replying to the first point, said he did not think there could be any serious objection to the employment of a London firm of auditors. The registered offices of the Institute were in London, although the general offices were in Manchester, and the firm in question was almost of worldwide repute. With regard to the amounts held by two Branches, as pointed out, the General Council had had that fact in mind, but it was not felt that the Council was in a position to ask for that money to be refunded. They were exerting such influence as they could to induce the Branches in question to use some of that money instead of asking for new grants, and the point raised by Mr. Sutcliffe would be borne in mind. He was informed by the secretary that the sums held by the Branches mentioned represented subscriptions.

Mr. Cook pointed out that the auditors had to be re-elected at the annual meeting, and therefore it was open to anybody to make a new nomination if they desired to do so.

The accounts were then unanimously adopted.

Alterations to By-Laws.

The President then dealt with some alterations to the by-laws.

The first resolution, he said, dealt with the election of the Council, the object being to have a postal ballot instead of electing the Council by voting at the annual general meeting, at which it was not always possible for some of those who took a keen interest in the affairs of the Institute to attend. As Mr. Cook had been responsible for the first resolution, he asked him to speak to it.

Mr. F. J. Cook said it had occurred to him that to elect the Council by postal ballot instead of by attendance of members at the annual meeting would be more satisfactory, because it gave everybody an opportunity to vote for their rulers in the Institute, which in this democratic country was what we desired.

The motion that the election of the Council in future should be by postal ballot was seconded and carried unanimously, it being explained by the President that the election on the present occasion would be by voting at the meeting.

The President said the second resolution, dealing with the by-laws, related to the application form for membership, and as it was necessary to get the permission of the Privy Council to the previous alteration, it was felt desirable to ask, at the same time, for any other alteration, thus reducing expense and trouble. The proposal was that, in the form for application for membership, the declaration that those proposing the applicant believed, to the best of their knowledge, that he was not of enemy or alien birth or interests, should be deleted. The Institute no longer wished to debar membership on the ground of nationality, but the other proposal in the resolution as sent out, to delete the words " nationality by birth or parentage," was due to a misunderstanding, because, although there was no desire to debar membership on account of nationality, it was desirable that the General Council should know the nationality of its members. Therefore, the deletion of these words would not form part of the resolution as put to the meeting.

Mr. F. Sanderson (Newcastle) said the resolution came from his district, and, as the President had pointed out, the second part of the resolution was due to a misunderstanding. He therefore moved the first part relating to the declaration as to the knowledge of those putting forward an applicant regarding his enemy or alien birth or interests.

The motion was seconded and carried unanimously.

The Oliver Stubbs Medal.

The President then announced that the Oliver Stubbs Medal had been awarded to Mr. Wesley Lambert, and in connection with the award he read the following recommendation from the London Branch:—

> "The General Council will require no detailed list of the innumerable services over a long period of years that Mr. Wesley Lambert has rendered to the Institute. There is scarcely a Branch before which he has not lectured, and I should think there is scarcely a Committee on which he has not served. Particularly as Convener of the Literary Committee has he contributed materially to the solid foundations of the Institute. In addition to having been the London Branch-President, he is now President-designate of the Institute, and the London Branch Council feel there could be no more fitting or qualified recipient this year of the award, and they sincerely hope the General Council will accept and endorse the recommendation of the London Branch."

Continuing, the President said the General Council, in making the award, had done so quite apart from any consideration of the fact that Mr. Wesley Lambert was being nominated as President of the Institute. It felt that it was quite time the non-ferrous section of the industry should be recognised, and they felt there was no worthier exponent of that branch than Mr. Wesley Lambert. The award had been made entirely on its merits. The actual presentation of the medal would be made the following morning.

MR. WESLEY LAMBERT, in expressing his appreciation of the award, said that such little work as he had been able to do for the Institute of British Foundrymen was done because he considered it one of the foremost, if not the foremost, of technical institutions in Great Britain. Another reason why he appreciated the award was that it was largely due to Mr. Oliver Stubbs that he had been induced to take a keen interest in the Institute, and he would value the award if only for the reason that it perpetuated the name of Mr. Oliver Stubbs.

On the motion of the PRESIDENT it was decided to send a message from the Institute to Mr. Oliver Stubbs expressing sympathy with him in his serious illness and wishing him a speedy recovery.

Diplomas.

The award of Diplomas was announced as follows:—

Mr. D. H. Wood, for a Paper read before the Birmingham Branch entitled "History of Ironfounding in the Midlands"; Mr. Ben Hird, for a Paper read before the East Midlands Branch and also the Newcastle Branch entitled "Coal Dust: Its Use and Abuse in the Foundry"; Mr. E. Longden, for a Paper read before the Newcastle, Scottish and Middlesbrough Branches entitled "Some Interesting Moulding Jobs"; and Mr. W. McCulloch, for a Paper read before the Scottish Branch entitled "Monel Metal and other special Non-Ferrous Castings."

Buchanan Medals.

The announcement was then made of the following awards of Buchanan Silver Medals to members of Junior Sections for resumés of the Papers read before the Branches during the year:—Mr. Norman Blythe (Scottish Junior Section); Mr. John Hird (Birmingham Junior Section); and Mr. J. Eric Garside (Lancashire Junior Section).

The New President.

The PRESIDENT said his next and last duty as President was to propose the election of Mr. Wesley Lambert as his successor. They had already awarded Mr. Lambert the Oliver Stubbs Medal, and it was difficult to find words to add to what had been said. A better choice could not have been made, because those who had worked with him for many years realised how great were his abilities and how great was his interest in the work of the Institute. He was one of the foremost men on the non-ferrous side of the industry, a side that was apt at times to be a little neglected. Mr. Wesley Lambert has had a very wide experience, wider and more varied than fell to the lot of many of them, and he was always prepared to place not only his knowledge but also the whole of his information at the disposal of any member of the Institute. He had placed himself at the disposal of all the Branches with regard to giving Papers, and as Convener of the Literary, Awards and Education Committee he had done remarkable work. When, last year, owing to the duties concerned with the International Conference, he found it necessary to resign, the Committee missed his help and advice very much indeed. He therefore moved with the greatest pleasure that Mr. Wesley Lambert be elected President of the Institute.

MR. F. J. COOK seconded the proposal, which was carried with acclamation.

MR. WESLEY LAMBERT then took the Presidential Chair, the retiring President promising him every assistance not only personally but by all the members of the Council and of the Institute.

The new PRESIDENT, in expressing his appreciation of the honour that had been conferred upon him, said he would not have gone forward as President if he had not been satisfied that he would have the support of everybody, as had so kindly been promised by Mr. Russell. Having worked for many years on the Council he could assure the general body of the members of the Institute that the men they elected to serve them on the General Council were very keen indeed, and knowing the keen feeling that existed he was looking forward to a very successful year of office. In connection with the International Conference, he said that the overseas delegates who were here were a fine body of men and gentlemen in every respect, and he appealed to the members of the Institute to make their visit here as pleasant and enjoyable as possible.

Continuing, the President proposed a hearty vote of thanks to the retiring President, Mr. S. H. Russell. The manner in which he had carried on the work of the Institute, he said, was seen in the fact that there had not been a single complaint of the way in which the business had been conducted during the past year. That was very great testimony to the tact and ability of Mr. Russell.

Mr. V. C. Faulkner said it was peculiarly fitting that he should be asked to second the vote of thanks because perhaps he had better opportunities than most members of the Institute in knowing the work of the President. He had been with him at most of the Branches and knew the amount of work and travelling, often on Sundays, in going round to the various Branches. He also felt that the vote of thanks should include Mrs. Russell and Mr. Russell's brothers, who had had a great deal of extra work thrown upon them during Mr. Russell's term of office.

The vote of thanks was carried with enthusiasm.

The **President** then handed Mr. Russell the Past-President's Badge.

Mr. Russell, acknowledging the vote of thanks, said he had really enjoyed being President, although it had involved a certain amount of hard though interesting work. There were two things he wished to refer to. He had hoped that by the end of his year of office he would have seen the question of the national certificate for the apprentices a great deal more advanced than was actually the case. Everything possible had been done, but progress was very slow, and there was a long way to go yet before their desires in that direction could be achieved. The other matter was one he had alluded to in his Presidential Address, viz., that the status of the Institute would be enhanced by some form of examination for membership. That was his personal view, but he was sorry to say he had come to the conclusion that it was premature to ask for that at present. Nevertheless he hoped to see it in the near future. He did not think it necessary to ask for a written examination; some other form of examination could be found, and he hoped that this would be possible in the course of the next few years. Any little success he might have had in business was undoubtedly due to the fact that he had always been keen on attending the Branch and annual meetings of the Institute, and he felt that in return it was only right that he should push forward the work of the Institute in every possible way.

Senior Vice-President.

The PRESIDENT then moved the election of Mr. F. P. Wilson as senior Vice-President for the coming year.

MR. J. T. GOODWIN, in seconding, said he had known Mr. Wilson for many years, and as long as 24 years ago, when the Conference was held in Middlesbrough, Mr. Wilson took a great part in organising the arrangements. Mr. Wilson was one of the progressive foundrymen in Middlesbrough, and had played a great part in the development of the Middlesbrough Branch.

The motion was carried unanimously.

MR. WILSON, acknowledging his election, said that, although he had not long been a member of the Council, he had been a member of the Institute for many years in a remote corner of the country, which, perhaps, was not much more than a name to many people. The Middlesbrough Branch, however, felt greatly honoured that he should have been selected for nomination as senior Vice-President, and when the Branch knew he had actually been elected it would be still more pleased. Looking at the past-Presidents, he realised what a brilliant body of men they had been, whereas he himself could only claim to be of the commonplace type and a representative of the commonplace people. At the same time he felt pleased that the commonplace people should be represented in this manner on the Council. He felt that he represented the rank and file of the Institute, among whom he counted many of his best friends.

Junior Vice-President.

Mr. S. H. Russell then proposed the election, as junior Vice-President, of Mr. A. Harley, whom he described as one of the most prominent foundrymen in the Birmingham district and one who had done a tremendous amount of work on different Committees of the Institute.

Mr. Cameron, who seconded the proposal, referred to Mr. Harley's association with the Daimler Company, and assured him that he would find the work involved in the office of junior Vice-President most enjoyable.

The proposal was carried unanimously.

Mr. Harley, in expressing his thanks for his election, said he also regarded himself as one of the commonplace people, like Mr. Wilson. He was a very commonplace man coming from a very commonplace family, most of whom had toiled and sweated in foundries. His father did so for 50 years, and there were two men whom he wished were present that evening. One was his father and the other was Mr. Robert Buchanan. When he joined the Birmingham Branch about 20 years ago Mr. Buchanan was kindness itself in receiving him, and before that, when he did not know Mr. Buchanan, one of his Papers had been a God-send to him when he was struggling with some of the problems of cupolas. He afterwards took the opportunity of telling Mr. Buchanan what a help that Paper had been to him, and it certainly was an example of the advantage to others that came from Papers given by men who had special knowledge on a particular subject. He himself was in Shropshire at the time he spoke of, out of contact with foundrymen generally, and he had a very vivid remembrance of the benefit he received from that Paper by Mr. Buchanan. He had actually intended to retire from the Council, but when it came to the point he could not bring himself to sever the friendships he had made. The members of the Council were a very fine body of men, not only from the foundry point of view but personally, and he could only hope that he would be able to carry out the duties of junior vice-president in a proper manner.

Members of Council.

A ballot was then taken for the election of five members of Council, for which there were six candidates, the result being announced at the opening of the International Conference the following day. The candidates elected were Mr. J. Haigh, Mr. W. T. Evans, Mr. H. Winterton, Mr. D. H. Wood and Mr. A. Firth.

Honorary Officers.

Mr. F. W. Finch was unanimously re-elected hon. treasurer.

Messrs. F. J. Cook, R. O. Patterson and O. Stubbs were unanimously re-elected trustees for the Institute.

Auditors.

Messrs. J. and A. W. Sully & Company, 19-21, Queen Victoria Street, London, were unanimously re-elected auditors.

Vote of Thanks to General Secretary.

On the motion of Mr. E. Longden, seconded by Mr. Wood, a cordial vote of thanks was passed to the General Secretary, Mr. T. Makemson, for his work during the past year.

Mr. Makemson acknowledged the vote of thanks, and remarked that his work was very much facilitated by the great assistance he received from everybody. He liked the work very much, and was able to extract from it not only a great deal of interest, but at times some amusement, often from unexpected quarters. He recognised that everybody was reasonably sympathetic; they appreciated everything he did and any mistakes that he made—and he feared he did make mistakes at times—were regarded very leniently.

Subscribing Firms.

Mr. Sutcliffe raised the question of the position of subscribing firms, and said he would be able to induce several firms to join but for the fact that they had no vote or voice in the control of the Institute. There were instances in which prominent members of subscribing firms would be valuable additions to the Council, but through the rules concerning such firms they were ineligible.

A Delegate suggested that it was not in order to bring this matter forward now, but that a communication should be sent to the General Secretary so that he might bring it before the Council.

The President expressed the view that Mr. Sutcliffe was in order in raising the point he had. He understood the complaint was that the men representing subscribing firms were not eligible to be officers of the Institute because they were not individual members of the Institute. He asked if Mr. Sutcliffe would take his assurance that the Council would go into the matter and discuss the position and try to put it on a proper footing.

Mr. Sutcliffe expressed his satisfaction with that assurance.

The President added that the matter would probably have to be dealt with at a meeting of the Council. Representatives of subscribing firms could not take office unless they were individual members of the Institute. That was quite clear, and that was the point that had to be cleared up. It was impossible for it to be dealt with that evening, but he quite realised that it was a matter that should be considered and cleared up. The position wanted defining more clearly than it was at present.

Mr. W. Jolley gave notice of motion that representatives of subscribing firms be allowed voting power.

The **President** suggested that that should be sent to the General Secretary.

Mr. Cook suggested that subscribing firms should nominate their representatives at the time of subscribing.

Mr. J. Longden said he had intended to raise this matter on behalf of the Scottish Branch because in canvassing recently for subscribing firms he had been told that the firm would not subscribe because it had no voting power, whereas if it paid the subscription of its foundry manager he would have a vote.

The matter was left for the Council to consider and decide upon a course of action.

The meeting then closed.

TUESDAY, JUNE 11.

The Guildhall Ceremony.

The Congress opened on Tuesday morning, June 11, in the Grand Council Chamber of the Guildhall of the City of London, when the members and delegates were welcomed by the Right Hon. the Lord Mayor (Sir Kynaston Studd, O.B.E.).

The Lord Mayor entered the Council Chamber and was preceded by the sword and mace bearers, who placed their emblems of authority upon the table as the Lord Mayor took his seat.

The **President** (Mr. Wesley Lambert, A.K.C., F.C.S.), said:—My Lord Mayor, ladies and gentlemen: As President of the Institute of British Foundrymen I have the honour to open the proceedings of the Third Triennial Congress of Foundrymen, and to ask the Right Honourable the Lord Mayor to address to us a welcome.

The **Lord Mayor**:—Mr. President, ladies and gentlemen: It gives me much pleasure to meet you here to-day and to offer you a cordial welcome to the City of London in this historic Chamber. This, I understand, is the third occasion on which the foundrymen of the world have been brought together to study the scientific problems bearing on their complex industry, which is the basis of every manufacturing activity.

The first was held in Paris in 1923, and the second in Detroit in 1926; whilst at the present time Britain has the honour of staging what we hope and expect will gather together under one roof the leaders of thought in your industry from all parts of the world. Concurrently with the Congress there is being held an exhibition of foundry plant at the Agricultural Hall. I would specially draw your attention to the fact that the Government Departments, the great national research laboratories and the modern Universities have combined to stage an important exhibit showing the application of research to the foundry industry.

Before this Congress the American delegation has participated in a pre-Convention tour, during which the members have had the opportunity of visiting our great industrial centres and some of the recognised beauty spots of Great Britain. It will have been demonstrated during that tour how British conditions vary from American and Continental, as industries in this country have to cater for complex requirements coming from all quarters of the world, rather than the meeting of a standardised demand emanating from the world's largest domestic market. It is hoped that this Congress will be a profitable and pleasurable one to all overseas delegates and guests.

I end, as I began, by expressing the great pleasure that it gives me to meet you here, and to wish you every success in your undertaking.

Vote of Thanks to the Lord Mayor.

The PRESIDENT: I rise with very great pleasure to propose a very hearty vote of thanks to the Lord Mayor for his address of welcome. It is indeed an honour of which I am sure we are all conscious to have with us this morning the Lord Mayor of this great city. (Hear, hear.) The foundry industry in London, perhaps, has not the call upon the good offices of the Lord Mayor as has the foundry industry in some of the provincial cities upon the good offices of the chief citizens of those cities. Nevertheless, we regard the presence of the Lord Mayor of London as a very great honour, and I formally move a hearty vote of thanks to him.

Mr. S. H. Russell (immediate Past-President): On behalf of the members of the Institute of British Foundrymen and the delegates from overseas, I have pleasure in seconding this vote of thanks to you, my Lord Mayor, firstly for having opened this international Congress, and secondly for having placed at our disposal this beautiful and historic building. It is to us Britons a great honour to be able to welcome our foreign friends and visitors to this beautiful building, and we are much indebted to the Lord Mayor and the Corporation of London for the facilities they have placed at our disposal. We represent what might be called the basic side of a basic industry; we supply the raw materials for the engineering industry, and without our work that industry could not exist. We are very proud of the craft, and the craftsmanship which is still displayed in our trade, and we very much appreciate the honour you have done us in opening our proceedings.

The vote of thanks was accorded with acclamation.

The Lord Mayor, responding, said: I have welcomed you, and you have thanked me for having done what I have been delighted to do, so that we are mutually pleased with one another. I take this opportunity again to say that I wish you every success in your work.

Presentation of Gold Medal to Professor T. Turner.

The Lord Mayor: I am asked to present a medal to Professor Thomas Turner, who for many years was Professor of Metallurgy in the University of Birmingham. On his retirement, two years ago, a presentation was made to him on behalf of the Institute of British Foundrymen and the British Cast Iron Research Association. This gold medal I am presenting to him as a permanent souvenir of the presentation, and I feel honoured in presenting it to him.

The medal was presented amid prolonged applause.

Professor T. Turner: I desire to thank you, My Lord Mayor, for your kindness in presenting this medal, and to express my gratitude to all my old friends in the foundry industry who have in this way signified their approval of work that I have been able to do. It does not fall to the lot of many people to look back over 45 years or so, and, after a useful and happy life, to find that their work has been so recognised, and I thank you for that recognition.

May I also take this opportunity of thanking my American friends for their goodness in presenting to me, through my son, at Detroit nearly three years ago their Siemens Medal, and for having provided me with a replica, which I received during the last few days, and which I can keep upon my desk. I have many friends in the foundry industry in America. Many of you will remember Mr. W. J. Keep, with whom I had the very closest association, and who was so eminent in your country in connection with researches in cast iron. It is a great pleasure to meet the American delegates here to-day; I am proud that for more than 25 years I have been an honorary member, and for many years the only foreign member, of their great Institution.

Presentation of the Oliver Stubbs Medal to the President.

The Lord Mayor: I have now to make another presentation, which I am sure will give you all much pleasure. The Oliver Stubbs Medal is awarded annually to the member of the Institute who has contributed the most meritorious services during the year, and for the year 1928-29 it is awarded to your President, Mr. Wesley Lambert. As you know, he is a distinguished specialist in non-ferrous metallurgy, and by his work in the Institute he has contributed materially to the advancement of non-ferrous foundry practice. I have much pleasure in presenting this medal to you, Mr. President; may you live long to derive pleasure from it.

The medal was presented amid applause.

The President: I should like to thank the Lord Mayor for having presented this medal to me. At the annual meeting yesterday I knew of the award, and returned thanks on that occasion; I can only renew those thanks now, and again express my thanks to the Lord Mayor for having so kindly and so graciously presented the medal to me.

(At this stage the Lord Mayor withdrew, and on reaching the doorway of the Council Chamber he turned to give the gathering a parting salute.)

Greetings from Overseas Delegates.

The accredited delegates from other countries then addressed the Congress, and conveyed the greetings of foundrymen in their respective countries.

The United States and Canada.

Mr. S. T. Johnston (President, American Foundrymen's Association) said that the delegates from the United States of America and from Canada were happy to be present at the Congress, and were also very pleased to see their good friend, Mr. Wesley Lambert, installed as President of the Institute of British Foundrymen. He had been wonderfully gracious, kind and helpful to them during the last two weeks, which they had spent in this country, and they would never forget that. Mr. Johnston conveyed the greetings of the American Foundrymen's Association, on whose behalf he wished success to the Congress and hoped that it would have a lasting impression upon the foundry industry.

Germany.

Dr. Siegfried G. Werner (President, German Foundry Owners' Association) conveyed the greetings of German foundrymen, and their earnest hope that the Congress and exhibition would be very successful and of great international value. He felt sure that those who attended would leave London with the feeling that they had attended one of the biggest and finest conventions ever held.

France.

M. E. V. Ronceray (Vice-President, French Foundry Association) said that the French delegation visited London on this occasion with very great pleasure, just as they had received with very great pleasure the foundrymen from many countries on the occasion of the first international exhibition and congress, which was held in Paris in 1922. He wished the present Congress and exhibition every success, as it deserved, and success to the foundry industry.

Belgium.

M. Marcel Remy (President, Belgian Foundry Association), who addressed the gathering in the French language, expressed the pleasure of the Belgian delegation in being able to attend the Congress and exhibition, and conveyed their greetings.

Italy.

Signor Carlo Vanzetti (Italy) evoked laughter when he apologised for being unable to speak English as well as he would like to, then offered to speak in either French or Italian, and finally decided to use the French language. He expressed the friendly sentiments of Italian foundrymen, and the pleasure it afforded them to attend, and wished the Congress and exhibition, and the industry, the greatest success.

Holland.

Mr. Stoffel, on behalf of the Dutch Foundry Association, to which he referred as being the smallest association represented at the Congress, expressed gratitude for the reception accorded the delegates. The foundry industry in Holland, he said, was "not so bad," but was small in comparison with the industry in Great Britain. The delegates from Holland would no doubt learn a good deal as the result of their visit, and he expressed thanks in advance for the information and help they would receive.

Poland.

M. Buzek was the leader of the Polish delegation, and on his behalf M. A. Poklewski-Koziell (Commercial and Financial Counsellor to the Polish Legation) returned thanks. It was a great privilege, he said, to tender to the Congress the best wishes of the Polish Iron Founders' Association and the Polish metal industries. This was the first occasion on which the Polish foundrymen had had the privilege of participating in this great work, and they appreciated the value of being able to come to this country, whose work was held in such esteem all over the world, and had taught so much that was useful. They had come to learn and to endeavour with the greatest goodwill to create that feeling of co-operation and mutual understanding which was indispensable to the success of this great work. They wished the Congress every success.

Spain.

Senor Mas Baga, of the Spanish delegates, speaking in French, also expressed thanks and good wishes.

Luxemburg.

M. Brasseur, on behalf of the delegates from Luxemburg, expressed their thanks for the welcome extended to them, and wished the Congress success.

Czecho-Slovakia.

M. **Bacher**, speaking in his native tongue, returned thanks on behalf of the Czecho-Slovakian delegation.

Denmark.

M. **Hess** (Denmark) said he did not attend as a delegate of the Danish foundry industry—which he regretted was very small—but was present as a foundryman and business man on his own behalf. Nevertheless, he was indebted for the opportunity of saying that the Danish foundry industry was grateful to England, from which country it had learned much. He hoped the Congress and exhibition would result in the forging of still another link between the two countries, and that Denmark would receive help in the future from England as it had in the past. The English standard had always been the standard at which the Danish foundrymen had aimed.

PRESIDENTIAL ADDRESS.

Mr. S. H. Russell (Past-President) called upon Mr. Lambert to deliver his Presidential Address. Incidentally, in a reference to the award of the Oliver Stubbs Medal for 1928-29 to Mr. Lambert, he said he had been asked by the Awards Committee of the Institute to state that they considered the selection of Mr. Lambert as the recipient to be a very happy one, in that this was the first time the medal had been awarded to a representative of the non-ferrous section of the industry. Also he emphasised that the Awards Committee were not in any way influenced by the fact that Mr. Lambert was shortly to undertake the duties of President, and that the award was made entirely on merits.

The **President** then delivered his address:—

Mr. Russell, Ladies and Gentlemen: Recognising as I do that this is a red-letter day in the history of the foundry industry as a whole, and even more particularly so in the comparatively short history of the Institute of British Foundrymen, the prospect of having to frame a Presidential Address for this occasion was somewhat over-aweing. Not only is this occasion memorable as being the most important International Foundry Congress ever held in Great Britain, but there is also the fact that the Congress is being held in the Capital City of the British Empire, and one is conscious, therefore, that a Presidential Address of a high standard is expected—a standard which, with such very limited literary ability as I possess, cannot possibly be attained by me. I must, therefore, ask your kind indulgence in listening to the few notes which I have woven together as a Presidential Address.

The progress in the foundry industry during the last two or three decades is of such an outstanding character that to attempt to condense a description of even but a few of its principal features into the compass generally associated with a Presidential Address is to attempt the almost impossible. Full justice to a description of the wonderful progress apparent to the student of the foundry industry could scarcely be written up adequately even in tomes of encyclopædic bulk.

First and foremost place in this great progressive march is given, perhaps rightly, to the work of building design and construction, covering the buildings which comprise the modern foundry; readily accessible, substantially built, spacious, centrally heated, well-lighted and ventilated shops with approved sanitary offices, the buildings including, in many instances, both chemical and mechanical-testing laboratories.

Gradually disappearing are many of the old-time, ill-placed, low-pitched, tumble-down, leaky, dust-begrimed, dark, ill-ventilated, insanitary sheds which in the past did duty as foundries.

The Cinderella of the engineering industry has indeed been translated from the noisome kitchen to the spacious hall.

Importance of Transport.

Similar progress is to be seen on all sides in the various departments of the foundry in relation both to the planning of the lay-out and the nature of the plant established therein, and to the accessibility to the stock and transport yards. Quick-moving lifting machinery, including the most modern types of electrically-driven overhead travelling cranes, hoists, elevators, transporters and conveyors, operate in such manner as almost to rival the wizardry of the magician. Well-built bins of reinforced concrete for sand and stock purposes, elaborate, but highly efficient, sand-conditioning machinery, shake-out platforms, well-designed heating and drying-stoves, portable mould-drying apparatus, core-making and moulding machines for each class of repetition work, are all nowadays to be found as part of the mechanical equipment of the modern foundry. Of these several components of the foundry equipment, the progress in lifting and transporting machinery, sand-conditioning and reclaiming machinery, and moulding machines, stands out conspicuously. Much might be said of both transporting devices and sand-conditioning plant, the latter of itself comprising grinding, mixing, screening, magnetting and aerating machinery. Hydraulic and pneumatically-operated moulding machines, large and small, roll-over, turn-over, jolt, jarr and squeeze, are now available to meet almost every requirement of repetition moulding. The introducing of machines whereby sand in ample volume is mechanically projected with the requisite speed and force not only to fill a moulding-box but also to consolidate the contents in the fashion of a mould—as exemplified by the various types of sand-slinger moulding machines found to-day in many foundries—is as truly indicative of the revolutionary progress in foundry equipment as are the well-known systems of producing castings from permanent moulds, which systems may be regarded as the present day high-water mark in foundry production in certain specialised foundries.

Revolutionising the Cleaning of Castings.

Nor have the fettling and cleaning shops been overlooked. Sand and shot-blasting plant, designed not only to be highly efficient, but having the welfare of the operator as a first consideration, power-driven saws of the circular, band and hack variety, sprue-cutting machines, flame-cutting apparatus, surface disc-grinding machines, tumbling-boxes, pneumatic anti-shock chipping hammers, emery and other wheels with hygienic dust-exhausting contrivances, and pickling baths, all are to be found in this section of the modern foundry.

Turning to the melting side, one finds, maybe, almost cheek by jowl with a modernised form—complete with charger, spark arrester and receiver—of that old and revered servant, the cupola, both converters and big-capacity gas or oil-fired open-hearth, reverberatory furnaces, constructed in conformity with the latest and best determined principles of furnace construction; these giant furnaces giving the impression that they are parents safeguarding the battery of gas or oil-fired tilting furnaces which do duty in supplying smaller melts of metal. The electric-melting furnace is no longer a novelty, but has already effected its introduction into the general foundry, and with the still further cheapening of electric power its debut will doubtless soon become only a memory. The wizardry which converted a pumpkin into a fairy coach for Cinderella is indeed but little removed from the magic of the foundry equipment engineer of to-day.

As regards the progress made in the moulder's art, it is obvious to anyone who has had the opportunity of studying this side of the foundry that only one conclusion can be arrived at, namely, that the journeyman moulder has lost nothing of the old-time art. but has indeed so progressed in that art that he is to-day making high-duty complicated castings, with intricate-cored parts, which the old-time craftsman would have considered to be almost outside the bounds of possibility.

Metamorphosis of Metal Utilisation.

Of the progress within the last twenty or thirty years in respect to metals and alloys for foundry use, first place must undoubtedly be given to the aluminium casting alloys. The wonderful development of the aluminium-casting industry is so stupendous as to seem almost incredible. When one is reminded that only as recently as the year 1889 a cast block of aluminium was regarded as an object of such novel interest as to be considered worthy of inclusion as a special exhibit at the Paris Exposition of that year, whereas to-day the output of aluminium castings from a single foundry runs into many hundreds of tons per annum, one can perhaps pardon the use of the word "stupendous" when speaking of the rapid development of this branch of the foundry industry. Who, a few years ago, could have imagined omnibus wheels, pistons for big Diesel-engines, crank-cases for giant aeroplane-engines, huge pressure-vats and such like high-duty parts being specified as castings of light aluminium alloys!

In these applications it is safe to affirm that in the not very far distant future even lighter alloys, mainly composed of magnesium, will become a serious rival for the engineer's favours. Already by the use of these light alloys a saving in weight of 80 per cent. has been effected in the construction of certain parts without any diminution in strength or stability.

Special alloy-steels, high-duty irons, non-magnetic ferrous alloys, high-tenacity cupreous alloys, acid-resisting irons and bronzes, and high-temperature resistant metals are only some of the bright new stars to be found in a brilliant firmament reflecting the progress on the metallurgical side of the foundry industry. Cast-irons, with properties heretofore rarely specified, are being fabricated daily. Alloy steels of such distinctive character as would have been regarded a few years ago as day-dream ideals, are to-day specified without provoking comment. Malleable iron castings of super-excellent quality are fabricated on a routine basis. High-duty cast bronzes of 35 to 45 tons tensile strength are nowadays represented by single castings weighing upwards of 30 tons apiece. The chemical and superheat-plant engineers bear enthusiastic testimony to the splendid progress which has been attained in the fabrication of special irons and non-ferrous alloys to meet their particular requirements.

Centrifugal castings, permanent mould castings, large and small—both gravity and pressure die-cast—are to-day finding a ready market and are in increasing demand. Use has already been made of the word " wizardry," but, at the risk of being accused of repetition, this word alone surely best describes one's impression of the output of a modern centrifugal pipe-casting plant.

Progress in Refractory Materials.

With regard to refractories, one must be pardoned for an all too brief reference to the excellence of such material as is now available for foundry purposes, an excellence resulting largely from the unstinted, unostentatious research work instituted by the manufacturers of such material. The furnace brick of all shapes and sizes, the graphite pot, the refractory earths, the mould facings, etc., each and all show their measure of progressive excellence.

The extended use of oil-sand cores has rendered possible the mass production of intricately-cored castings, which at one time would have taxed the skill of even the most painstaking craftsman. The extended application of oil-sand cores is certainly one of the most outstanding applications contributing to the great progress in the foundry output.

Scientific Aids.

The laboratory side of the modern foundry industry must not be overlooked. The introduction of specially-constructed apparatus and the employment of standardised reagents has assisted the speeding-up of chemical analysis, and has tended towards more accurate and concordant results between one laboratory and another.

Optical instruments for the examination of metals and foundry commodities are in constant use, and even the X-rays have been harnessed for the examination of castings, including those of considerable thickness of section. Pyrometers are now employed generally, and their use is recognised as essential in the non-ferrous foundry; temperature control must be credited with much of the improvement in the uniform quality of the foundry product.

Truly the realities of the modern foundry are more astounding than the phantoms of the most imaginative of the old-time foundry workers, but what is more to the point is that every improvement in the foundry buildings and equipment has a tendency to uplift the workers who are perforce benefited by the improved conditions under which they are working. In this connection there are other progressive features, although non-technical,. of which mention should be made, and which have for their object the welfare of the employees and the cultivation of that social well-being and intercourse so desirable between master and man.

Welfare and Development in the Industry.

Well-lighted, centrally-heated canteens for the workpeople, at which wholesome food can be obtained at nominal prices and in which an air of good-fellowship exists, are to be found attached to the more up-to-date factories, and in some instances spacious reading-rooms, well supplied with technical and other literature, are available for the use of employees.

First-aid and ambulance stations are to be found attached to many works, and competent certified attendants are available to cleanse and dress minor injuries, to deal with "gassed" or "shock" cases, and to render first-aid in the case of more serious accidents in the workshops. Sports clubs have also been instituted, many works possessing their own sports grounds for cricket, football, tennis, bowls, etc., and in addition inter-departmental clubs have been formed for swimming, rowing, cycling, running, country rambles, and other outdoor sports. Indoor sports for the winter evenings are also catered for, billiards, skittles, boxing and card-playing being favourite pastimes. There can be no question whatever that the technical progress and the better social conditions prevailing in each section of industry must tend towards beneficial development for the good of the community, and serve to encourage that delight in the task of the individual without which no material progress worthy of the name can be assured.

Who can foresee the immense possibilities of the future of the foundry industry? When one is reminded that so comparatively recently as the reign of Queen Elizabeth only seven or eight metals were known, of which only four, namely, iron, copper, tin and zinc, were in use for the compounding of constructional—as distinct from ornamental—alloys, whereas to-day, as a result of intensive scientific research, sixty-one metals are now available, and that, year by year, one or more of the previously rarely-used metals is being harnessed to the service of mankind in the form of alloys for industrial uses, the immense possibilities of the utilisation in the foundry of these later-discovered metals affords subject-matter for very fascinating conjecture.

It may be seen, by the use of a simple formula, that if a complete series of binary—two-metal—alloys of all the known metals were compounded in merely one uniform proportion, such as 50 : 50, the number of alloys resulting would be 1,830; if ternary—three-metal—alloys were made also in one definite proportion only, the number of different alloys would total 35,990. To go but one step farther, if a complete series of quartenary—four-metal—alloys, in one uniform proportion, such as 25 per cent. of each of the four metals constituting any one alloy, were attempted, 521,855 separate alloys would have to be produced before each of the known metals was thus proportionately employed in its own group in this series of alloys.

One may inquire: Whence has come the scientific knowledge and the wonderful mechanical and technical skill and the increased regard for the welfare of his fellow-men which have rendered possible the magic of this remarkable progress during the last two or three decades? One need not look much farther afield than around this International gathering of foundry experts —proprietors, managers, supervisors, equipment designers, scientifically-trained metallurgists, and researchers.

International Co-operation.

Science, art, industry and craftsmanship know no nationality. It would be invidious, therefore, to name any nation as deserving of the major share of the credit of having provided the means which have made possible the progress which has been so inadequately outlined in this Address. There are names in this connection that one would dearly like to mention; giants of their calling—names that are on the tongue of every earnest foundry worker, names of many of those present on this occasion and of their forebears, and also of silent men not so well known may be owing to the innate modesty of their nature, names which nevertheless equally deserve to be placed upon the roll of honour. And what a roll —British, American, French, German, Belgian, Russian, Italian, Swedish, Polish, Dutch, Spanish, Swiss, Portuguese, Czech, Japanese— all have generously contributed their quota towards improving the condition, the efficiency, and the output of the foundry industry.

It would ill-behove me were I to neglect such an occasion as this for expressing on behalf of the British foundry industry as a whole, and more intimately on behalf of the Institute of British Foundrymen, the indebtedness which the British foundrymen owe to those nations just mentioned for the splendid efforts of the foundry workers, foundry engineers, and research metallurgists belonging to those respective countries— efforts which have so materially assisted in raising the status of the foundry industry nearer to an equality with the civil, mechanical and electrical engineering industries throughout the world.

I trust that this Address, presented by a very humble student of the industry, will at least have the effect of bringing even closer together those Institutes and organised bodies representing the foundry industry of the world, and that by mutual association and close co-operation, and the free interchange of knowledge and ideas —which interchange forms the primary object of such an International Congress as is now being held—still further progress may be attained. until the industry shall be raised to that high status that its science and craftsmanship so fully merits.

To the Members of the Institute of British Foundrymen, to whom, as President, I can speak openly, let us see that we keep the flag flying high. It is up to us, together with our confreres of the Foundry Equipment and Supply Association, to see that we continue to contribute our quota to the continued progress of the industry we have so much at heart. To those representatives of the overseas organisations I offer every good wish in their future endeavours towards the further progress of this great basic industry, and trust that they will convey to all their fellow-members the appreciation of the Institute of British Foundrymen for the great efforts of their countrymen which have so materially contributed towards the progress I have attempted to review.

A Vote of Thanks to the President.

Mr. F. P. Wilson (Senior Vice-President) proposed a vote of thanks to the President for the admirable, dignified and interesting address he had delivered. In it the President had reviewed progress in the foundry trade in such a way as to interest all present, whether they were scientists, practical foundry workers, suppliers of foundry requisites, or connected in any way with the industry. He hoped that, if there were delegates present who were unable to understand the English language sufficiently closely to be able to follow every word, they would be able to have it translated in order that they might reap full advantage from it.

Mr. V. C. Faulkner (Past-President), who seconded, said that this was the third Presidential Address that Mr. Lambert had prepared, but the one he had delivered was undoubtedly the best he could produce, and the best the Institute could produce. It was a great privilege and honour to be able to second the expression of sincere appreciation for his description of what the modern foundry industry is and what it would be.

The vote of thanks was carried with acclamation.

The **President** responded. Commenting on Mr. Faulkner's remarks, he said it was quite true that he had written two addresses before writing the one he had delivered. The reason was that, after careful consideration, he had come to the conclusion that, inasmuch as this Congress was of an international character, it behoved him to write of something that would interest all present rather than to discuss any domestic or internal matters which might concern, perhaps, only the British foundrymen. It was for that reason he had decided to review foundry progress as he had seen it during the last three or four decades.

The Junior Vice-President.

It was announced by the President that Mr. A. Harley, of Coventry, had been elected Junior Vice-President of the Institute.

Mr. Harley expressed his deep appreciation of his election. He had never appreciated fully before, he said, how impressive such a Congress as this could be. When so many delegates from overseas had responded to the invitation to address the Congress he had felt that such Congresses must play a very great part in maintaining the brotherhood of nations, which was so much desired.

Test Bar Committee's Report.

Mr. John Shaw presented a report of the work of the Test Bar Committee of the Institute for the past year.

(The discussion on the Report was deferred until a later stage of the proceedings.)

The following Paper was then read and discussed:—

"Some Inter-relationships in Grey Iron Metallurgy," by J. W. Bolton (American Exchange Paper).

Works Visits.

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

Messrs. Fraser & Chalmers' Engineering Works, Erith; Messrs. Dewrance & Company, Great Dover Street, S.E.1; The United Glass Bottle Manufacturers, Limited, Charlton.

At the conclusion of each visit the thanks of the Institute was expressed to the various firms for permission to visit their works and for their hospitality.

Later in the afternoon a Reception was held at the City of London Guildhall, by kind invitation of Sir John Dewrance, G.B.E.

Delegates and their ladies were received by Sir John Dewrance and by the President of the Institute, Mr. Wesley Lambert, and Mrs. Lambert.

WEDNESDAY, JUNE 12.

The Conference was resumed at the Institution of Mechanical Engineers, Storey's Gate, Westminster.

Session A was held in the Meeting Hall and was opened by the President at 9.30 a.m.

Greetings were read from the following:—

The President of the French Foundry Technical Association; the President of the National Light Castings Association; Mr. W. G. Hollinworth, ex-General Secretary; Mr. F. W. Finch, Honorary Treasurer.

It was resolved that these gentlemen be thanked for their greetings, and that replies be forwarded.

The President then vacated the chair, which was taken by Mr. F. P. Wilson, Senior Vice-President. The following Papers were read and discussed :—

"Influence of Graphitisation of Cast Iron," by Professor Diepschlag. Presented on behalf of the German Foundry Associations.

"The Elimination of Sulphur from the Alloys of Iron," by K. Gierdziejewski. Presented on behalf of the Polish Foundrymen.

"The Influence of Chromium in Cast Iron," by J. W. Donaldson, D.Sc. (Associate Member).

"The Influence of Manganese in Cast Iron," by A. L. Norbury, D.Sc. (Member).

"The Practical Application of Nickel in Cast Iron," by A. B. Everest, B.Sc., Ph.D. (Associate Member).

Session B (Non-Ferrous).—The Non-ferrous Session was held in the Council Chamber simultaneously with session in the Meeting Hall, and was presided over by the President. The following Papers were read and discussed :—

"Practical Points from the Metallurgy of Cast Bronzes," by H. C. Dews (Member).

"Die Castings," by A. H. Mundey (Member).

"Crystalline Grains in Castings," by Prof. A. Glazunov, presented on behalf of the Czecho-Slovakian Foundrymen's Association.

The Conference adjourned at 12.30 p.m., and during the afternoon parties of members and delegates visited the following works :—

Messrs. Kryn & Lahy (1928), Limited, Letchworth; Messrs. J. & E. Hall, Limited, Dartforth; Messrs. Lake & Elliot, Limited, Braintree.

Banquet.

The annual banquet of the Institute of British Foundrymen was held at the Hotel Cecil, London, on Wednesday, June 12, Mr. Wesley Lambert presiding over a company of some 450 members of the Institute, overseas delegates and ladies.

Research an International Bond.

After the loyal toasts had duly been honoured, Sir John Dewrance, G.B.E., proposed "The

Institute of British Foundrymen and its President," and said that having regard to the very successful international conference that had been organised by the Institute, everybody present would be delighted in joining in in this toast. He himself was a practical founder. When he left college he went first into the foundry, where he studied with great care and eventually became sufficiently skilled to produce a casting which was exhibited in the Royal Academy. He believed the artist had an idea that it was his effort in connection with the casting that influenced the Committee more than the work that he (Sir John) had done, but he thought he himself could say that if the casting had been faulty it would have been remarked upon. (Laughter.) That was in 1880, and since that time he had started a research department in his own firm, which he believed was the first ever established by an engineering firm in Great Britain. As the years had gone on it was common knowledge that research had grown gradually and steadily. He hardly cared to speak of science in the presence of so many eminent scientists, but he would like to say that during his long experience it had gradually been manifested that science has had a great influence and that it would ultimately unite the great civilisations of the world. (Applause.) The great institutions which organised international congresses, such as the International Foundry Congress, were doing that which was of the greatest possible assistance to the civilisation of the world, and he was delighted to be present at a gathering of so many representatives of overseas countries who had come long distances to attend this Congress. He hoped they had enjoyed themselves and that they would go back to their own countries feeling they had received a hearty welcome in Great Britain: certainly Great Britain would be delighted that they should have that feeling. There had sometimes been an impression that Great Britain in the past had been greedy of the surface of the earth, but the real desire of Great Britain had always been to civilise the world, and all those other countries which assisted were doing the same good work as the Britishers. (Loud applause.) It had always been the greatest pleasure of the Britishers to welcome their international friends and so to encourage the general harmony of the whole world. He was convinced that the International Foundry Conference had assisted to that end, and we in this country looked forward to the occasion when the overseas visitors would again be welcomed in this country. He coupled with the toast the name of the President of the Institute of British Foundrymen, Mr. Wesley Lambert.

The PRESIDENT, replying to the toast, said he had a pleasing and easy task, inasmuch as the few words he had to say were of the nature of a thanksgiving address, and moreover, in the words of a popular song, "I Know I am in Jolly Good Company," and that he was also fortunate in being well looked after. The toast master had given him the lead as to how to commence; a certain lady had promised to signal to him if he kept on for too long; one silent member who he noticed had seated himself at the far side of the hall was going to rise from his seat if he did not make himself heard; and an American friend with whom he had kept close comradeship during the past fortnight was going to put his hand up should he so far forget himself as to speak with an American accent.

Growth of Bell Founding.

On behalf of the Institute of British Foundrymen, he thanked Sir John for proposing the toast of "The Institute" and for the very kind things he had said, and he thanked them all for the hearty manner in which the toast had been accepted. They were deeply grateful to Sir John for his continued interest in the Institute in particular and in the foundry industry in general. It was most encouraging and gratifying when a gentleman who had attained the position in science and industry that Sir John had attained to find him associating himself with the Reception Committee for the present International Convention of Foundrymen. On the last occasion of a banquet in London connected with one of the annual conferences, Lord Melchett honoured them with his presence as the principal guest. In his speech on that occasion there were two things among others that Lord Melchett said which he personally noted, and to which he should like to make brief reference. Lord Melchett said that he was glad that the Institute of British Foundrymen appreciated the importance of close contact internationally. Were Lord Melchett able to be with them that evening he would have gathered that they were still continuing the policy of close contact internationally. The other thing to which Lord Melchett referred was the founding of bells. Lord Melchett wondered whether, with all the aid of modern science, we were nowadays able to equal the bell mixtures of some of the old bell founders. It might interest all of them to know that since the Great War one bell foundry alone—and that within ten or twelve miles of Lord Melchett's London office and which foundry he personally visited—had produced no less than 2,640 church and tower bells, varying in finished weight from 18¼ tons to a few pounds each; the total weight of bells approximating 1,000 tons. Of these bells quite a considerable proportion were cast for overseas customers, and experts of all countries concerned were agreed that for sweetness and perfection of tone, and as examples of the bell founders' art, these bells had never been equalled in the history of bell founding.

He was proud to occupy the chair that evening, proud not only personally, but because the fact of his occupying the chair as President of the Institute of British Foundrymen exemplified the democratic constitution of the Institute. The presidential chair of the Institute of British Foundrymen was not a perquisite of the foundry proprietor, but was open to anyone who like himself was only an employee. He was proud because he honestly regarded the Institute as being one of the most important, if not the most important, technical Institution in Great Britain. He was proud also because the Institute was flourishing and was progressing along the right lines, and that this was recognised was, he thought, apparent to all who look around at the gathering, including as it did so many distinguished people of this country and from overseas.

He did not propose to bore anyone with a recital of the history and the aims and objects of the Institute, neither did he propose to analyse the membership figures, nor to give the titles of the technical papers read before the various branches or submitted at the present Convention, but it would ill behove him were he not to take this public opportunity of thanking all those gentlemen who had presented papers. Incidentally, nearly 150 technical papers had been submitted during the past session, and as a member of the Literary Committee he could bear testimony to the value of those papers. Also a word of praise must be given to the Cast Iron Test-Bar Committee, which had done such good work during the last two years, and to the Educational Committee for the good work which was being done in reference to the better training of foundry workers of the younger generation.

It would be unfair of him to poach his colleagues preserve, but as one of the Reception Committee he must express delight at the presence of so many overseas delegates and of the ladies at the banquet. They hoped that the foreign delegates would not leave this country without having recognised that the foundry industry in Great Britain was much more alive than perhaps they were led to think, and that the ladies would bear testimony that London was not always fog-bound.

Acknowledgment of Help.

Before concluding, the President said he had a further pleasing duty, namely, to acknowledge the services of all those ladies and gentlemen who had so generously given their best services on the various Committees associated with the organisation of the present international Conference. A great deal of work was involved, and all had worked right loyally. Then he wished to renew the expression of thanks to the Lord Mayor for his kindness in loaning for the use of the Institute the City Council Chamber and the other departments of the Guildhall, and for his welcome, and to the President of the Institution of Mechanical Engineers for like kindnesses. To Sir John Dewrance and to Sir Hugo Hurst; to Messrs. Bridges, senior and junior—organisers of the Foundry Exhibition at the Royal Agricultural Hall—and to the Conference Committee of the Foundry Trade Equipment and Supply Association for their kindness and generosity in acting as hosts at several of the London functions, and to all the patrons who had assisted financially. To Dr. Rosenhain, F.R.S., and Mr. J. G. Pearce, M.Sc., who had been mainly instrumental in getting together the technical and educational exhibits at the Exhibition at the Royal Agricultural Hall. To the officers of all the various branches for their splendid and successful efforts in entertaining the overseas delegates, and ladies who were able to take the pre-convention tour through Great Britain. To the Lord Mayor, Mayors, Sheriffs, Presidents of the Chambers of Commerce, and other gentlemen and their ladies for the kind receptions given and the hospitality accorded, and the Master Cutler and Mistress Cutler for like favours. To all those proprietors, directors and managers of works, factories and foundries throughout the kingdom for kindly throwing open their establishments for works visits both for gentlemen and ladies and for their generous hospitality on those occasions, and to those members of the staff at the respective works for their kindness in acting as guides and instructors.

He desired to mention one more name, which he was sure would be received with acclamation

—Mr. H. G. Sommerfield the Hon. Secretary of the London Convention Committee. He remembered having read that people entering a church had sometimes mistaken the acolyte for the high-priest. Mr. Sommerfield is indeed the high-priest and he was but the acolyte. Mr. Sommerfield had done yeoman work, and to his efforts, coupled with those of Mr. Makemson, the General Secretary, the success of the function and of the Convention as a whole were mainly due.

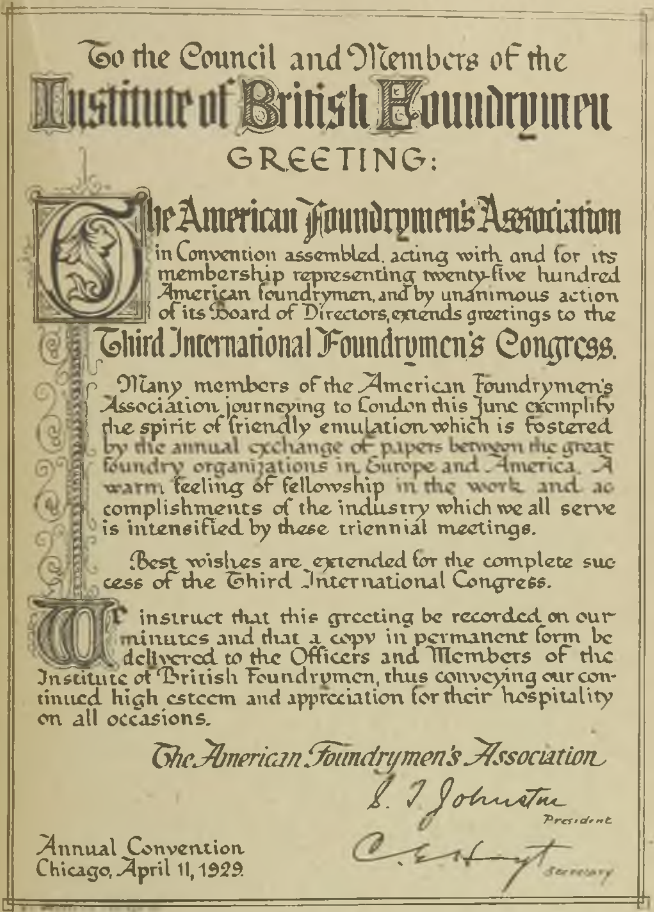
On behalf of the Council and members of the Institute of British Foundrymen he thanked Sir John Dewrance for his kindness in proposing the toast of the "Institute of British Foundrymen," and all present for the hearty manner in which they had accepted it, and he thanked them personally for the forbearance with which they had listened to his response.

United States of Europe.

Mr. S. H. Russell (Past-President, Institution of British Foundrymen), proposing "Our Guests," extended a hearty welcome to them all, and especially those who had travelled many thousands of miles to attend the Congress and visit the Exhibition. Speaking specially to the American delegates, he suggested that during the tour of our industrial centres and also the visits that had been paid to some of the historic spots in this country, they might have been impressed with the fact that this country is not so vast as their own, where there were 42 States, each without a tariff wall between them, and all working under one Government. On the other hand, in Europe there were 28 nations, nearly everyone speaking a different language, each being a sovereign nation, and all having a high tariff wall between them. He believed that, excluding Russia, the area of Europe was very much smaller than the area of the United States, but the prophets foretold that the substitution of one control for the independent sovereign control of the various European nations was entirely within the range of human possibility. At the same time the difficulties were enormous. There was in the first place the difficulty of language, and there was, of course, the intense national spirit that had grown up inside the various nations. However, the prophets told us that the writing was on the wall, and that there is a movement towards grouping the world in a relatively few units instead of into a large number of individual nations. This Conference afforded also the opportunity of giving expression to the belief in this country in the principle of the free exchange and interchange of knowledge in the foundry craft. The old days of secrecy and secret methods had almost entirely disappeared, and he knew that those sentiments were also held by all the overseas delegates. (Hear, hear.) The toast was coupled with the names of Mr. S. T. Johnston (President of the American Foundrymen's Association) and Sir Joseph Petavel, F.R.S. (Director of the National Physical Laboratory).

The Democratic A.F.A.

Mr. S. T. Johnston, who made the first reply, expressed appreciation on behalf of all the overseas delegates of the splendid hospitality they had received during their visit to this country, and speaking specially of the American Foundrymen's Association, said that organisation had 2,500 members. A man was not too old to join that body because there were some white haired men who were members, some of whom had been members for many years and others who had recently joined. Nor could a man be too young to join because there were some apprentices in the Association and many of the younger workers. Again, a man could not be too learned to join because some of the most distinguished men of science were members of the A.F.A., and, on the other side, a man need not consider himself too ignorant to join because the membership included some foundrymen who did not



To the Council and Members of the
Institute of British Foundrymen
GREETING:

The American Foundrymen's Association in Convention assembled, acting with and for its membership representing twenty-five hundred American foundrymen, and by unanimous action of its Board of Directors, extends greetings to the
Third International Foundrymen's Congress.

Many members of the American Foundrymen's Association journeying to London this June exemplify the spirit of friendly emulation which is fostered by the annual exchange of papers between the great foundry organizations in Europe and America. A warm feeling of fellowship in the work and accomplishments of the industry which we all serve is intensified by these triennial meetings.

Best wishes are extended for the complete success of the Third International Congress.

We instruct that this greeting be recorded on our minutes and that a copy in permanent form be delivered to the Officers and Members of the Institute of British Foundrymen, thus conveying our continued high esteem and appreciation for their hospitality on all occasions.

The American Foundrymen's Association

S. T. Johnston
President

C. E. Hoyt
Secretary

Annual Convention
Chicago, April 11, 1929.

Address presented by The American Foundrymen's Association.

know much more than the rough and tumble of the foundry. Nor need anybody be too humble to join because the membership included many in the humble walks of life connected with the foundry trade, and, finally, a man need not be too proud to join the organisation because there were already on the books many men of high position, both on the technical and commercial sides, and who were giving valuable assistance in the work of the Association. After once more referring in highly appreciative terms of the good time all the delegates had had during their stay in this country, and mentioning particularly the visit to the provinces, Mr. Johnston read a printed resolution from the American Foundrymen's Association, which was passed before the American delegates left for their tour of this country, and presented it to the President of the Institute of British Foundrymen in the form of an illuminated address (see page 49).

The Antiquity of the Foundry Industry.

Sir Joseph Petavel, in the course of his reply to the toast, said it had occurred to him that the foundry was not only the most fundamental art in connection with our present civilisation, but also possibly the earliest art which indicated the dawn of civilisation. As man passed from the savage to the first sign of civilisation the first development was the foundry. For the first time he began to produce metals, and for the first time his degree of cultivation of intelligence was measured by the success of his art of founding. They had all heard of the magnificent work now coming from Egypt in gold and silver dating 4,000 years ago, and it revealed a considerable knowledge at that time of metallurgy. He understood that the gold alloy was chosen because it was particularly easily worked and was malleable, and that was one reason why such beautiful work was possible in those days. With the development of civilisation the art of the foundryman became the basis of the art of the engineer. In the earlier days the mechanical engineer could not exist because he had no metals, but when metals came to the fore, when the foundryman began to produce the metals, then mechanical engineering began to transform the world. In the earlier days the foundry was the seat of mystery, and he understood that even down to comparatively recent days there still remained secret mixtures which were added to metals and which alone caused the excellence of the product. In more recent times, however, metallurgy had produced not merely the few metals which the ancients used, but literally dozens of new metals which, combined in various proportions and treated in different ways, formed the basis of the present advance of mechanical engineering. All that had changed the foundry from a place of secrets and mystery to a laboratory of science, and at the present time scientific work was as essential as practical experience. Sir John Dewrance had spoken of the manner in which he had led in the application of research to engineering, and it was the function of the National Physical Laboratory to help industry with knowledge and advice. Mr. Russell had suggested that the time for secrets had passed and that the time for the unity of the world had come. That was a thing to look forward to, but that development was very large, and it would tax even the Institute of British Foundrymen and the American Foundrymen's Association severely to find a melting pot of sufficient size to fuse the European nations together. It was to be hoped that in the future that state of things would be brought about, but for the present he was led to believe that even the American Association found that melting pot a little difficult to manage at the present time with complete success. (Loud laughter.) Finally, Sir Joseph expressed the deep appreciation of the guests, and the ladies, for a delightful evening.

A splendid musical programme was provided during the evening.

THURSDAY, JUNE 13.

The Conference resumed at 9.30 at the Institution of Mechanical Engineers.

Session A was held in the Meeting Hall, and was presided over by the President. The following Papers were read and discussed:—

"Methods of Testing Cast Iron," by MM. Le Thomas and Bois. Presented on behalf of the French Foundry Technical Association.

"The Influence of the Size of Section on the Strength of Grey Cast Iron," by J. G. Pearce, M.Sc. (Member).

"The Critical Examination of Steel Castings," by C. F. Gillott, B.Met.

Session B was held in the Council Chamber and was presided over by Mr. F. P. Wilson, Senior Vice-President. The following Papers were read and discussed:—

"The Vocational Training of Foundry Workers, Foremen and Engineers in Belgium." Presented by the Belgian Foundrymen's Association.

"The Problem of Foundry Moulding Sand," by H. van Aarst. Presented on behalf of the Dutch Foundry Technical Association.

"Coal-dust as applied to Moulding Sands," by B. Hird (Member).

"The Applications of Pulverised Fuel," by H. W. Holland and E. Lowndes.

At the conclusion of the Thursday morning session in the Meeting Hall the President formally thanked the Corporation of the City of London for allowing the Guildhall to be used for the opening of the Congress, the Institution of Mechanical Engineers for placing their building at the disposal of the Conference, the readers of Papers, subscribers to the Congress funds, and all who had assisted in any way in connection with the Congress.

The President's motion was supported enthusiastically.

Luncheon to Overseas Delegates.

At the conclusion of the Conference Session on Thursday the leaders of the overseas delegations were entertained to luncheon at the International Foundry Exhibition, Royal Agricultural Hall, by the President and Council of the Foundry Trades' Equipment and Supplies Association, in conjunction with the Exhibition organisers, Messrs. F. W. Bridges & Sons, Limited.

Mr. H. Winterton, President of the Foundry Trades' Equipment and Supplies Association, presided.

Mr. Wesley Lambert, President of the Institution, proposed the toast of "Our Guests," which was responded to by Mr. Fred Erb, Vice-President of the American Foundrymen's Association, Dr. Ing. S. G. Werner, President of the German Foundry Owners' Association, and Mr. E. V. Ronceray, Vice-President of the Association Technique de Fonderie de France.

Mr. F. P. Wilson, Senior Vice-President of the Institute, proposed the toast of "The Chairman."

Mr. Winterton responded, and expressed the pleasure of his Association and of the Exhibition organisers, of the opportunity of entertaining so many distinguished overseas visitors.

Mr. K. W. Bridges also responded.

During the afternoon members and delegates paid an official visit to the International Foundry Exhibition, and later were entertained by Messrs. F. W. Bridges & Sons, Limited, Mr. H. Winterton again presiding.

On Thursday evening, June 13, nearly 500 delegates and ladies accepted the joint invitation of the London Branch of the Institute of British Foundrymen and the Foundry Trades' Equipment and Supplies Association to a Dance and Cabaret at the New Burlington Galleries. The guests were received by Mr. W. B. Lake, President of the London Branch of the Institute of British Foundrymen, and Mrs. Lake, and by Mr. H. Winterton, President of the Foundry Trades Equipment and Supplies Association, and Mrs. Winterton. A cabaret entertainment was provided by "The Marshmallow Girls" under the direction of Mr. Gordon Marsh, and other artistes included Miss Olive Tyson and Miss Mollie Seymour. The orchestra was under the direction of Mr. Ernest Rutterford. A very enjoyable evening was concluded at midnight by the singing of "Auld Lang Syne."

The next day, Friday, June 14, was the last day of the official Conference arrangements and was devoted to a whole day excursion through the county of Kent to Canterbury. Nearly 200 delegates and ladies, including a large number of overseas visitors, took part. A halt for luncheon was made on the outward journey at the "Tudor House," Bearsted; the party then proceeded to Canterbury, where they were conducted around the Cathedral. On the return journey tea was provided at the "Tudor House" and the party then returned to London.

A very interesting informal ceremony took place in the lounge of the Hotel Cecil upon the return from the excursion to Canterbury, when Mrs. S. T. Johnston, wife of the President of the American Foundrymen's Association, presented a shawl to Mrs. Wesley Lambert, wife of the President of the Institute of British Foundrymen. The presentation was made on behalf of the ladies of the American party as a memento of the tour of Great Britain, on which they were accompanied by Mr. and Mrs. Lambert, and also of their visit to the London Congress.

TOUR OF OVERSEAS DELEGATES

To the International Foundrymen's Congress.

A party of American delegates and ladies, which included Mr. S. T. Johnston, President of the American Foundrymen's Association, arrived in London for the International Foundry Congress on Monday, May 20, and were welcomed by representatives of the Institute.

On Thursday, May 23, the American delegates and ladies, together with officers of the Institute and other guests, were entertained to dinner at the Holborn Restaurant by Sir Hugo Hirst, Bart. Mr. W. B. Lake, J.P., President of the London Branch, presided, and Sir Hugo Hirst proposed the toast of "Our Overseas Guests." The toast was responded to by Mr. S. T. Johnston and Mr. H. Cole-Estep. The chairman proposed the toast of "Our Host," which was responded to by Sir Hugo Hirst.

During their stay in London the American visitors took part in an excursion to Windsor, and also sight-seeing tours of London.

On Monday, May 27, a party of 60 overseas delegates and ladies, including representatives of the United States, Germany, Poland, Czecho-Slovakia and Italy, commenced a two-weeks' tour of Great Britain. The party, which was accompanied by Mr. Wesley Lambert, President-elect of the Institute, and Mrs. Lambert, first journeyed to Birmingham, calling at Leamington and Stratford-on-Avon.

The visitors were entertained to luncheon by the Lord Mayor of Birmingham, who welcomed the visitors and who was thanked by Mr. S. W. Utley, President of the Detroit Chamber of Commerce. Works in Birmingham and Coventry were visited, and the ladies of the party visited various places of interest.

In the evening the members were received by the Mayor of Coventry, and were afterwards entertained to dinner by the Birmingham and Coventry members of the Institute.

Proceeding to Derby on May 29, a full programme of works' visits was undertaken, and a luncheon was given by the firms whose works were visited during the day. Later in the day the visitors were entertained to a complimentary banquet at Matlock Bath by the East Midlands Branch. Mr. H. Pemberton, Branch-President, presided, and proposed the toast of "Our Guests," which was responded to by Mr. S. T. Johnston and by Mr. Fred Erb, Vice-President of the American Foundrymen's Association. Mr. E. J. Fox, managing director of the Stanton Ironworks Company, proposed the health of the secretary of the Branch, and Mr. H. Bunting responded.

On the following day the Stanton Ironworks were visited. The members were entertained to luncheon, and the ladies took part in an excursion through the Peak district. Later in the day the party proceeded to Manchester.

Friday, May 31, was spent in visiting works in Manchester. The ladies visited places of historic and general interest, and in the evening the Lancashire Branch of the Institute entertained the visitors to a banquet at the Midland Hotel.

The Lord Mayor of Manchester responded to the toast of "The City and Trade of Manchester," which was proposed by Mr. A. F. Hageboeck, director of the A.F.A.

The toast of "Our Guests" was proposed by Mr. T. Makemson, general secretary of the Institute, and responded to by Mr. F. Erb, Vice-President of the A.F.A., and Mr. B. Dango, of Germany.

Mr. Daniel Adamson, President of the Institution of Mechanical Engineers, proposed the toast of the Lord Mayor, which was responded to by the chairman, Mr. E. Longden.

On the following day the tour was continued by motor coach to the English Lake District, and on Sunday, June 2, the party proceeded to Glasgow.

On Monday, June 3, the visitors were the guests of the Scottish Branch of the Institute. A special steamer was placed at their disposal, and the day was spent in a cruise on the River Clyde. A reception was held on the steamer by Sir Archibald McInnes Shaw, and a complimentary luncheon was given in the saloon. On returning to Glasgow, the Lord Provost and the President of the Glasgow Chamber of Commerce held a reception in the City Chambers.

On the following day the motor-coach tour was continued through the Scottish Highlands, and the evening was spent in Edinburgh.

After an inspection of the city of Edinburgh, on the morning of June 5, as the guests of the Scottish Branch of the Institute, the visitors proceeded to Newcastle.

On Thursday, June 6, a number of works in the Newcastle district were visited, and a complimentary luncheon was given by the Newcastle Branch of the Institute, previous to which the party were given a civic reception by the Lord Mayor. In the afternoon the North-East Coast Exhibition was visited. On the following day the motor tour was continued by way of Ripon and Harrogate to Sheffield. The members were received by Mr. J. T. Goodwin, President of the Sheffield Branch, and Past-President of the Institute. In the evening they were received by the Master and Mistress Cutler, and were entertained to a dance at the Cutlers' Hall.

On June 8, the last day of the tour, a reception was held at Sheffield University by the Lord Mayor of Sheffield, and the members then visited various works. At the luncheon which followed the guests included leaders of the civic and industrial life of the city, and visits were paid to places of interest in the afternoon.

Later in the day the party returned to London by train in readiness for the opening of the International Foundrymen's Congress.

The thanks of the Institute are due to all the Branches, Branch officers and members for the arrangements which were made: to all who subscribed to the entertainment fund; to the Lord

Mayors and Mayors of the various cities; to the directors and managers of the various works visited; and to all who assisted in connection with the tour.

THE INTERNATIONAL FOUNDRY EXHIBITION.

The International Foundry Exhibition, which was held in the Royal Agricultural Hall from June 5 to 15, was attended by an exceptionally large number of visitors, including many overseas visitors who were present in London for the International Congress.

The Exhibition, which was organised by Messrs. F. W. Bridges & Sons, Limited, in conjunction with the Foundry Trades' Equipment and Supplies Association, was one of the largest Foundry Exhibitions held in this country.

An important feature was the large and complete technical exhibit, which was organised by the various Research Associations and Universities in conjunction with a Committee of which Mr. Wesley Lambert was chairman and Mr. F. K. Neath, secretary. The exhibit showed modern developments in melting practice, moulding sands, casting processes and special alloys, and research and laboratory methods.

An Educational Exhibit of considerable importance was also arranged with the cooperation of various British and foreign colleges where training in foundry practice is given.

PAPERS PRESENTED AT THE INTERNATIONAL FOUNDRYMEN'S CONGRESS, LONDON.

SOME INTER-RELATIONSHIPS IN GREY-IRON METALLURGY.

By J. W. Bolton, M.Sc. (American Exchange Paper).

Discussing relationship between strength and composition, J. G. Pearce[1] said: "If these (researches) can be shown to correlate (tests, working properties, and operating conditions) even for a single set of melting conditions, a great step forward in foundry control becomes possible." The present state of knowledge of grey cast iron as an engineering material generally is recognised as chaotic. A great deal of valuable quantitative research has been carried out. In the absence of intensive effort toward exacting correlation of this material, most of the present-day conclusions are but qualitative. This condition is understood by all grey iron metallurgists. Technical societies in America are devoting much time to study of the problems involved. This work undoubtedly will bring about major changes in specifications and methods of testing. With more accurate knowledge of the engineering properties of various grades of iron, the character and quality of product will become more nearly standardised. The engineer will make greater use of grey iron castings to the degree that he is informed of its desirable properties. Scientific foundrymen hold no brief for this or that engineering material. The best material is that which fully satisfies engineering requirements in the most economic manner. For this purpose it may be bronze, for that steel, and for the other, grey iron. However, foundrymen must seek accurate

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[1] Proceedings of The Iron and Steel Institute. 1928.

knowledge, that they may select without prejudice—for this alone spells real progress. With no intent of particular selection, attention is directed to the value of Papers of the type lately contributed by J. G. Partridge.[2]

This Paper deals with schemes of correlation which the writer feels may be in sympathy with the present trend of engineering thought in this matter—particularly so in Great Britain and in America. He feels that the hope so eloquently expressed by Mr. Pearce is capable of materialisation—that, in fact, great advances in foundry metallurgy rapidly approach realisation. The spirit of co-operation manifest in these International Congresses augurs that the moment of this realisation is not far distant. With the consideration and appreciation of additions to the knowledge made possible by investigators in all great industrial countries, it seems most proper and fitting to call attention to the brilliant advances, to the thoroughgoing work, of the able workers of Great Britain. From the very inception of the iron and steel industry, a very large portion of its phenomenal progress has been due to the efforts —individual and collective—of these men.

Two Important Problems before Foundrymen.

Two problems before the foundryman to-day are: (1) Study of the influence of manufacturing practice on given grades of cast iron; and (2) Relationship of test results to engineering properties of the casting. A more detailed set of questions was proposed in a recent editorial in THE FOUNDRY TRADE JOURNAL as follows: " Ever since Mr. John Shaw presented his Paper to the summer meetings of the American Foundrymen's Association, the situation of theoretical consideration of cast iron has become more complicated. Arising from the discussions, the following questions have been posed: (1) Are experiments carried out on small quantities of synthetic mixtures of pure materials really helpful? (2) Are conclusions drawn from diagrams

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[2] The Magnetic and Electrical Properties of Cast Iron—Carnegie Scholarship Memoirs, 1928.

based on the summation of silicon and carbon contents of great value? (3) Is the control of the matrix of more importance than the control of the graphite formation? (4) Is the condition

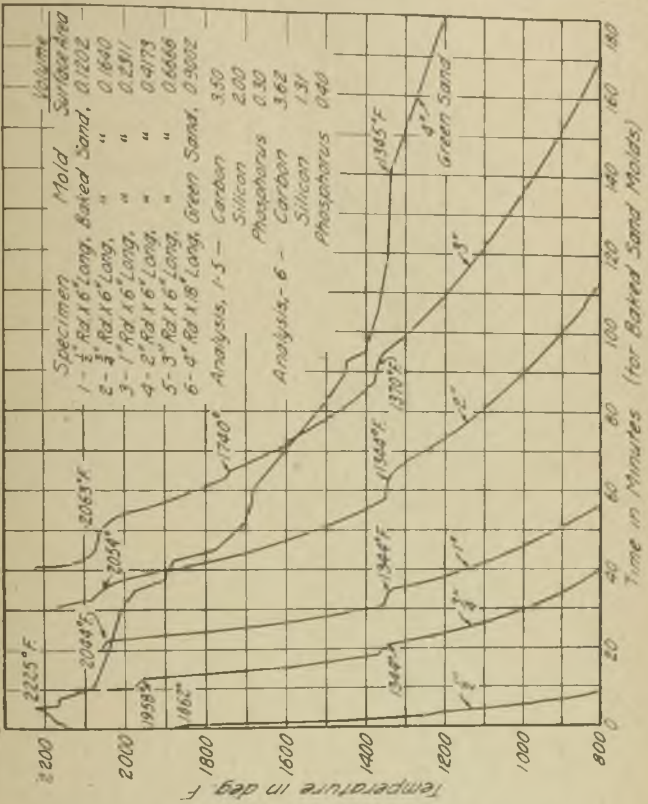

FIG. 1.—COOLING VELOCITY, COOLING CURVES.

of the graphite dependent on the nature of the carbides resulting from composition or thermal history? (5) Can the recently discovered critical manganese percentage be definitely stated on

TABLE I.—*Classification of Cast Irons according to Silicon and Carbon Content.*

Group No.	Carbon %.	Silicon %.	C + 0.30 Si.	C + Si.
1	Above 3.50	Above 2.50	4.25 up	6.00 up
2	,, ,,	2.26—2.50	4.21 up	5.88 up A
3	,, ,,	2.01—2.25	4.14 up A	5·63 up C
4	,, ,,	1.76—2.00	4.06 up B	5.38 up E
5	,, ,,	1.51—1.75	3.99 up C	5·13 up G
6	,, ,,	1.26—1.50	3.91 up D	4.88 up I
7	,, ,,	1.01—1.25	3.83 up E	4.63 up K
8	,, ,,	0.76—1.00	3.76 up F	4.88 up M
9	3.26—3.50	Above 2.50	4.13 up A	5.88 up A
10	,, ,,	2.26—2.50	4.09 B	5.76 B
11	,, ,,	2.01—2.25	4.02 C	5.51 D
12	,, ,,	1.76—2.00	3.94 D	5.26 F
13	,, ,,	1.51—1.75	3.87 E	5.01 H
14	,, ,,	1.26—1.50	3.79 F	4.76 J
15	,, ,,	1.01—1.25	3.71 G	4.51 L
16	,, ,,	0.76—1.00	3.64 H	4.26 N
17	3.01—3.25	Above 2.50	3.88 up D	5.63 up C
18	,, ,,	2.26—2.50	3.84 E	5.51 D
19	,, ,,	2.01—2.25	3.77 F	5.26 F
20	,, ,,	1.76—2.00	3.69 G	5.01 H
21	,, ,,	1.51—1.75	3.62 H	4.76 J
22	,, ,,	1.26—1.50	3.54 I	4.51 L

21	,, ,,					
22	,, ,,	1.26—1.50	3.54	I	4.51	L
23	,, ,,	1.01—1.25	3.46	J	4.26	N
24	,, ,,	0.76—1.00	3.39	K	4.01	O
25	2.76—3.00	Above 2.50	3.63 up	H	5.38	E
26	,, ,,	2.26—2.50	3.59	H	5.26	F
27	,, ,,	2.01—2.25	3.52	I	5.01	H
28	,, ,,	1.76—2.00	3.44	J	4.76	J
29	,, ,,	1.51—1.75	3.37	K	4.51	L
30	,, ,,	1.26—1.50	3.29	L	4.26	N
31	,, ,,	1.01—1.25	3.21	M	4.01	O
32	,, ,,	0.76—1.00	3.14	N	3.76	P
33	2.51—2.75	Above 2.50	3.38 up	K	5.13	G
34	,, ,,	2.26—2.50	3.34	K	5.01	H
35	,, ,,	2.01—2.25	3.27	L	4.76	J
36	,, ,,	1.76—2.00	3.19	M	4.51	L
37	,, ,,	1.51—1.75	3.12	N	4.26	N
38	,, ,,	1.26—1.50	3.04		4.01	O
39	,, ,,	1.01—1.25	2.96		3.76	P
40	,, ,,	0.76—1.00	2.89		3.51	

NOTES :—Manganese in most foundry irons runs between 0.45 and 0.80, within which range no subclassification seems necessary. Phosphorus subdivisions might be 0.0—0.15, 0.16—0.30, 0.31—0.50, 0.51—0.70, 0.71—1.00; this element influences the stiffness of the metal, and also is a factor in its fluidity and hardness. At the present time, no logical subdivisions on sulphur content have occurred to the writer; perhaps the sulphur/manganese ratio will furnish a basis for further classification. Nickel and chromium have powerful influences on cast iron, and irons containing them exhibit somewhat different characteristics from " straight " silicon-carbon irons.

TABLE II.—*Computed Cooling Rates and Moduli.*

	Size of bar.	Length cast.	Length between supports.	Cross section area.	Surface area sq. in.	Volume cub. in.	$\frac{\text{Volume}}{\text{Surface area.}}$	Relative mod. rup.	Log. mod. rupture.
1	¼×12×12						0.1200		
2	0.500 d.	21	18	0.196	33.4	4.12	0 1234	366.640	2.56425
3	0.800 d.	15	12	0.503	38.7	7.55	0.1951	59.672	1.77577
4	0.875 d.	21	18	0.601	58.9	12.6	0.2139	68.414	1.83514
5	½×12×12	—	—	—	—	—	0.2308	—	—
6	1.00 d.	15	12	0.785	48.7	11.8	0.2423	30.552	1.48504
7	1.00 d.	21	18	0.785	67.5	16.5	0.2444	45.831	1.66116
8	1×1	27	24	1.00	110.0	27.0	0.2455	36.0	1.55630
9	1.20 d.	21	18	1.131	81.4	23.8	0.2924	26.523	1.42362
10	1.25 d.	15	12	1.227	61.4	18.4	0.2997	15.666	1.19496
11	1.30 d.	21	18	1.327	88.4	27.9	0.3156	20.860	1.31931
12	2×1	27	24	2.00	166.0	54.0	0.3253	18.0	1.25527
13	1×2	27	24	2.00	166.0	54.0	0.3253	9.0	0.95424

14	1.40 d.	21	18	1.639	95.4	32.3	0.3386	16.702	1.22277
15	1.50 d.	15	12	1.767	74.2	26.5	0.3571	9.052	0.95674
16	1.50 d.	21	18	1.767	102.5	37.1	0.3620	13.579	1.13287
17	1.5×1.5	27	24	2.25	166.5	60.75	0.3650	10.67	1.02816
18	1×12×12	—	—	—	—	—	0.4286	—	—
19	2.00 d.	15	12	3.142	100.5	47.1	0.4686	3.819	0.58195
20	2.00 d.	21	18	3.142	138.2	66.0	0.4776	5.7288	0.75806
21	2×2	27	24	4.00	224.0	108.0	0.4820	4.500	0.65321
22	2.20 d.	21	18	3.801	152.7	79.8	0.5226	4.3042	0.63389
23	2.50 d.	21	18	4.909	174.8	103.1	0.5898	2.9332	0.46734
24	2.5×2.5	27	24	6.25	282.5	168.75	0.5980	2.303	0.36229
25	3.00 d.	15	12	7.069	155.5	106.0	0.6817	1.1316	0.05369
26	3.00 d.	21	18	7.069	212.1	148.4	0.6996	1.697	0.22968
27	3×3	27	24	9.00	342.0	243.0	0.7110	1.333	0.12483
28	2×24×24	—	—	—	—	—	0.8571	—	—
29	4.00 d.	15	12	12.57	213.6	188.6	0.8830	0.477	9.67852-10
30	3×24×24	—	—	—	—	—	1.20	—	—
31	6.00 d.	15	12	28.27	339.3	424.1	1.250	0.141	9.14922-10
32	4×24×24	—	—	—	—	—	1.440	—	—
33	8.00 d.	15	12	50.27	477.5	754.1	1.579	0.0596	8.77525-10

theoretical grounds? (6) Can the low-carbon high-silicon development be related to one of the existing theories? (7) Can the super-heating theory be definitely substantiated? (8) Is the gas content of cast iron to be taken as a serious factor? (9) Is ingotism of paramount importance? (10) Are internal stresses receiving their quota of consideration in discussing some phenomena? (11) Can free graphite exist in normal cupola-melted iron? It is obvious that further Papers are needed which will clarify our ideas."

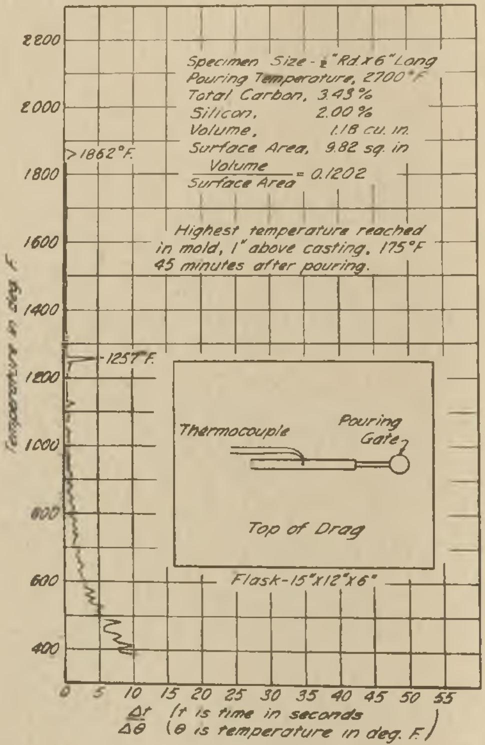

FIG. 2A.

Four Factors influence Mechanical and Physical Properties of Grey Cast Iron.

The properties, mechanical and physical, of any grey iron casting depend upon the following factors: (1) Chemical composition of metal, initial, incidental and final; (2) structural, mechanical and chemical make-up of charge (all materials); (3) melting process, conditions—chemical, thermal and mechanical, and (4) thermal, chemical and mechanical history, furnace spout to finished casting.

The iron-carbon-silicon series of alloys known as grey iron contain pearlite, ferrite, and as cast formed graphite. Within this general structural make-up, alloys of widely divergent properties can be obtained. To attempt systematic study, it is necessary at first to classify or group these alloys. The simplest primary classification is according to chemical analysis of final alloy. Such a system of classification is outlined in Table I, based on percentages of total carbon and of silicon. Some 40 groups are listed. (It is obvious that some of these alloys are not grey irons unless cooled slower than at an ordinary cooling rate.) In addition certain sub-groupings are necessary according to presence of phosphorus, manganese, sulphur, various metals, metalloids, gases, etc. However, in usual foundry practice, the carbon-silicon groupings are most important.

Although the second factor—make-up of charge—undoubtedly is important, it seems impossible at the present time to attempt more than a qualitative classification. The degree of graphitisation of charged materials has some effect on the possibility of degree of solution of graphite during the melting process—hence on the presence of graphite nuclei in the molten metal. This, of course, influences the degree of graphitisation of the final casting. Thus the amounts of sand-cast pig, chilled pig, steel, scrap, etc., should be noted in all research work. Furthermore, the size of the pieces charged, their general grain-size, etc., should be indicated. Much careful research is needed to demonstrate whether or not the so-called inherent properties of the raw materials always persist unaltered through the melting process and influence the final product.[3]

Third, the cupola or furnace operation has much to do with the quality of metal melted therein. For example, it is known that superheating during the melting process at first tends to delay the progress of graphitisation on cooling. At still higher temperatures the effect of this phenomenon may be altered or changed. Iron badly oxidised in cupola-melting does not compare favourably with that obtained from a good hot working cupola with normal blast. Crucible-melted irons generally are not comparable with those obtained from the cupolas—a fact that has vitiated the exact practical significance of work of many investigators. Therefore, in any work on comparison or correlation, the exact type of furnace and its operating characteristics should be stated clearly.

Thermal and mechanical history of the metal from furnace spout to cooled casting is the fourth factor. The degree of graphitisation depends to a great degree on the cooling velocity from the liquidus to a temperature probably somewhat below the eutectoid point. The writer regards cooling velocity and composition the most important factors influencing the final properties of the metal. Cooling velocity is a curvilinear function, not easy to express in a simple manner, as shown in Fig. 1. It depends on many factors. Among these are:—(1) Initial temperature (which may or may not coincide with pouring temperature); (2) final temperature (*i.e.*, room temperature); (3) specific heat of the alloy, at all points along the curve; (4) volume of metal to be cooled; (5) metal-surface area, for dissipation of heat; (6) cooling gradients within metal and mould; (7) conductivity of mould material; (8) speed of pouring; (9) energy release apparent in thermal arrests (see Figs. 2A to 2E); and (10) mechanical factors.

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[3] E. Piwowarsky, Trans. A.F.A., 1926, p. 914-981.

Relationship of Volume to Surface Area a Significant Factor.

It is apparent that with carefully-regulated foundry practice many of these factors are nearly constant, or at least susceptible to a reasonable degree of control. The most significant factor is the relationship of volume to surface area—expressing the well-known foundry fact that cooling rate is proportional to section size. In Table 11 is shown a list of various simple

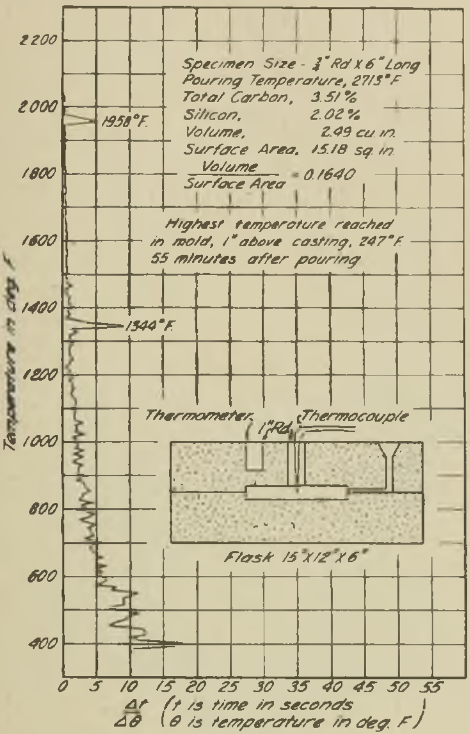

FIG. 2B.

shapes arranged in the order of their volume/surface area relationship.

In Fig. 3 there is experimental proof of the validity of this ratio for bars cast under carefully controlled and reproducible conditions. In this we have used the average rate of cooling from the solidification arrest (about 1,121 deg. C.) to the pearlitic inversion (about 732 deg. C.). (That there is some graphitisation below 732 deg. C. is well known.) It is interesting to contemplate the net effect to time-temperature (or

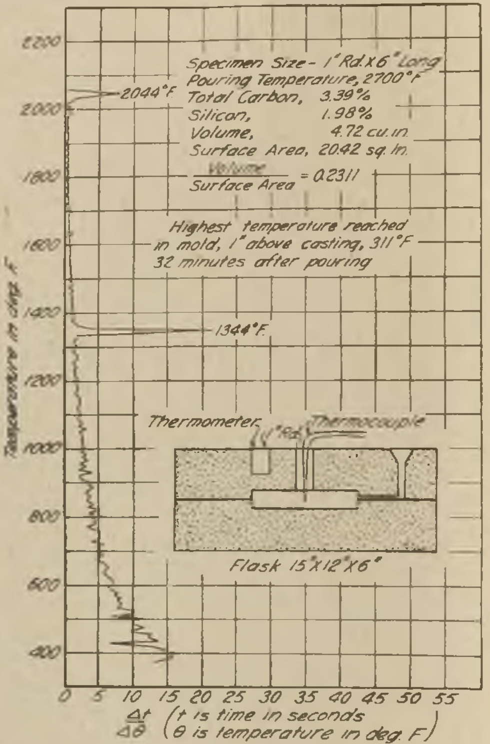

FIG. 2c.

cooling curves) *versus* temperature-graphitisation rates on the net rate of graphitisation under casting conditions.

The factors involved and their controllability follow:—(1) Initial temperature depends to some

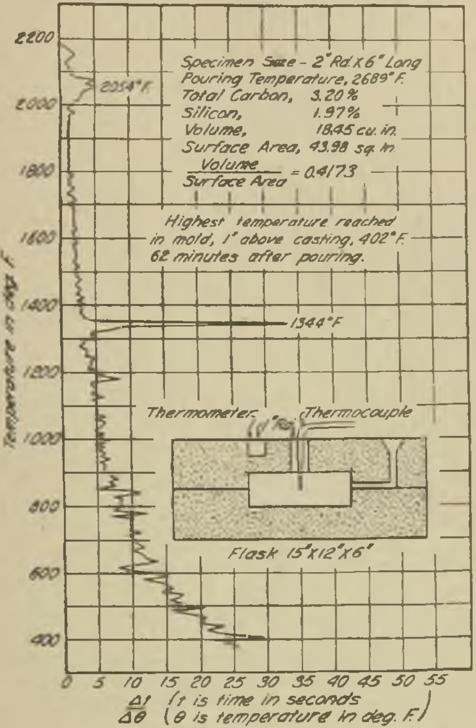

FIG. 2D.

degree on the process employed and on the method of operation of the process; (2) pouring temperature is controllable; (3) final temperature may be assumed as constant; (4) specific heats of various types of iron do not vary much; (5) magnitude of cooling gradients within the metal itself are as yet little understood. That they are very important is evident from the variations in grain size, etc., found on examination of the cross section of some castings—notably

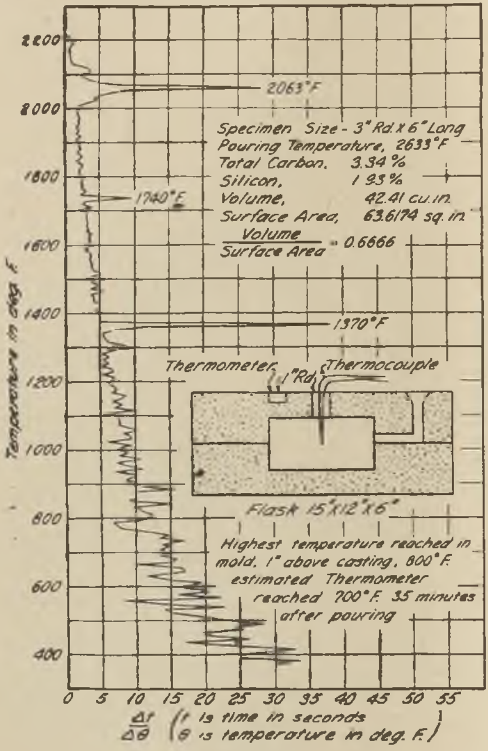

Fig. 2e.

heavy sections with high-carbon irons. This effect is manifest in mechanical properties;[4] (6) conductivity of mould material, of course, varies somewhat. (See Fig. 3.) This is controllable for research purposes; (7) speed of

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[4] See Arthur Smith—"Foundry Trade Journal," Feb. 2, 1928, p. 79, Fig. 2; also J. W. Bolton—Trans. A.F.A., 1928, Vol. 36, p. 499, Fig. 8.

pouring depends on gating and workmanship—both relatively controllable, but rarely defined in experimental work; (8) mechanical factors often are overlooked, as, for example, were the

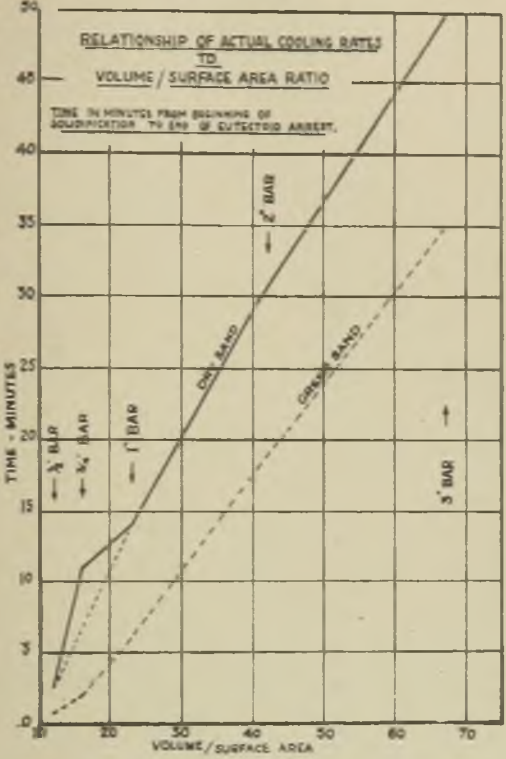


FIG. 3.—RELATION OF $\frac{v}{a}$ TO ACTUAL COOLING RATE.

bars sand-cast, were they tumbled, what sort of risers were used, etc.?

In any work of classifying irons according to mechanical test, the method of testing should be defined clearly and completely. In much research work neither analysis nor size of sections is mentioned.

Influence of Manufacturing Practice.

It, then, is possible to solve the first problem

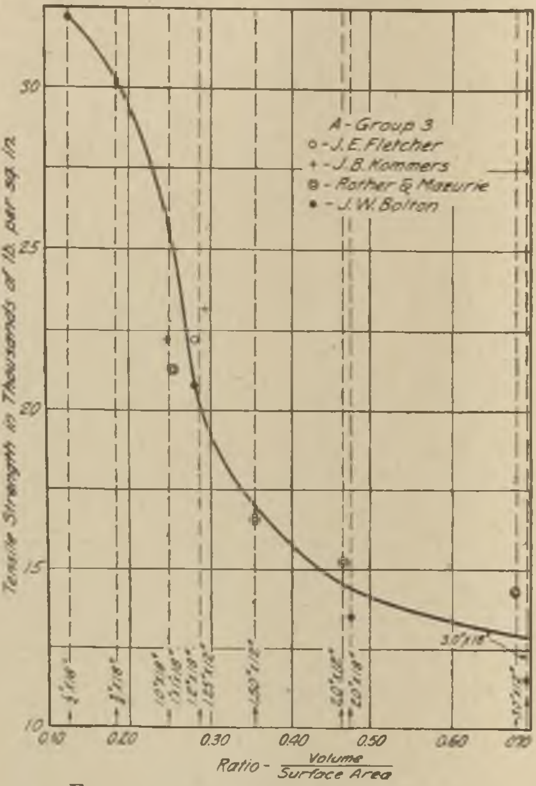


Fig. 4.—Study of Grade of Iron.

(study of the influence of manufacturing practice on given grades of cast iron) as follows:—

(A) Arrange a classification of irons according to composition: and (B) make an intensive study of each grade. In this study it is necessary to give consideration to the influence of the four factors indicated in a previous paragraph. Although there are vast gaps in the data necessary, methods of statistical research can be applied to very good advantage on existent data. A list of several interesting compilations of data is attached (Table III). A partial study of one grade of iron is shown in Fig. 4 and notes. The writer has compiled data covering many of the groups, and regrets that space is not available for inclusion of this voluminous, yet interesting, substantiation of the practicability of the scheme of study. These indicate that Mr. Pearce's hope is quite possible of practical realisation. While the very complexity of the problem denies exact mathematical prediction of each and every property, it is unquestionable that most of these will some day be charted to a degree of accuracy compatible with usual engineering practice. An exact analogy can be drawn to the art and science of the manufacture and testing of steel, wherein reasonably accurate engineering data can be found in many handbooks.

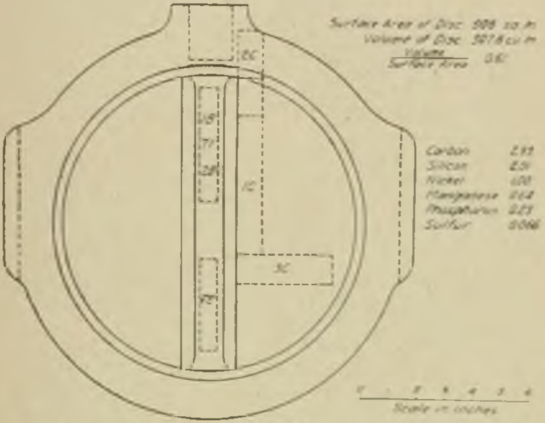


Fig. 5a.

Relationship of Test Results.

The second problem is relationship of test results to the properties of castings. Two viewpoints predominate—that of many British and Americans, who believe that test results can be correlated so that properties of castings may be predicted therefrom with reasonable accuracy, and that of the French and other Continental investigators, who hold that tests must be made on the castings themselves. It is logical to expect that if a ladle of the same grade of iron is divided into two parts and each part subjected to exactly the same treatment, the two resultant materials will be the same. Very few Papers have been published in which definite attempts have been made to make test-piece and casting each comply with the four factors listed previously.

That it can be done, may be demonstrated by one example and summaries of other tests—all very much condensed. The possibility of such correlation is so well recognised in America that leading specification-making bodies are proposing inclusion of such directions in specifications so that test and operating conditions may be as nearly as possible correlated.

Example 1.—The casting of design shown in Figs. 5A to 5E was probed thoroughly. It was found that the volume/surface area relationship of this casting (overall) was 0.61, corresponding approximately with test bar 2.4 in. by 18 in. However, the casting is not uniform in section, and allowance should be made for this fact. This was a scrap casting, due to blowholes in portions indicated. The analysis shows carbon 2.93 and silicon 2.01 per cent. neither corresponding to group 27 or 28 of Table I. A detailed list of the test accompanies the diagram.

Tensile ..	T1	35,507	lbs.	T2	39,265	All these tests from casting.
Shear ..	1B	41,875	,,	1C	45,946	
,, ..	2B	44,652	,,	2C	45,650	
				3C	46,418	

Brinell, edge, average 203
,, rib, ,, 195

Tensile T2 is slightly higher than T1, the latter being in the heavier portion of the rib. Shears 1B and 2B are close to T1, their average 43,263 lbs. per sq. in. transferred to tensile in shear-tensile chart.[5]

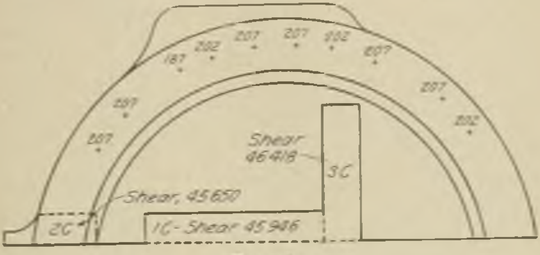


FIG. 5B.

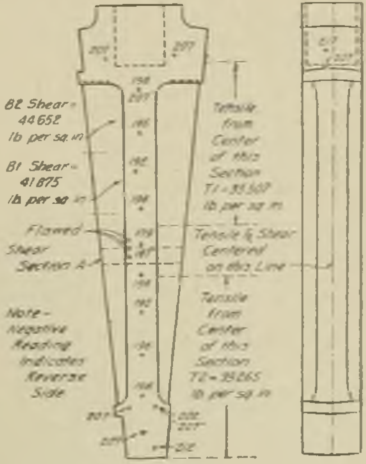


FIG. 5C.

The average of shear strengths 1, 2 and 3C, 46,005 lbs. per sq. in., corresponds to a tensile of about 38,000 lbs. per sq. in. (Fig. 6). This is comparable to 39,265 lbs. per sq. in. of T2.

---

[5] J. W. Bolton—Trans. A.F.A., 1928, p. 495, Fig. 4.

taking T1 and T2 average value (37,368 lbs. per sq. in.) as representative of the casting, whose relative cooling-rate approximates that of a 2.4-in. bar, we take the value 37,800 per sq. in. from the writer's data. This is a good check

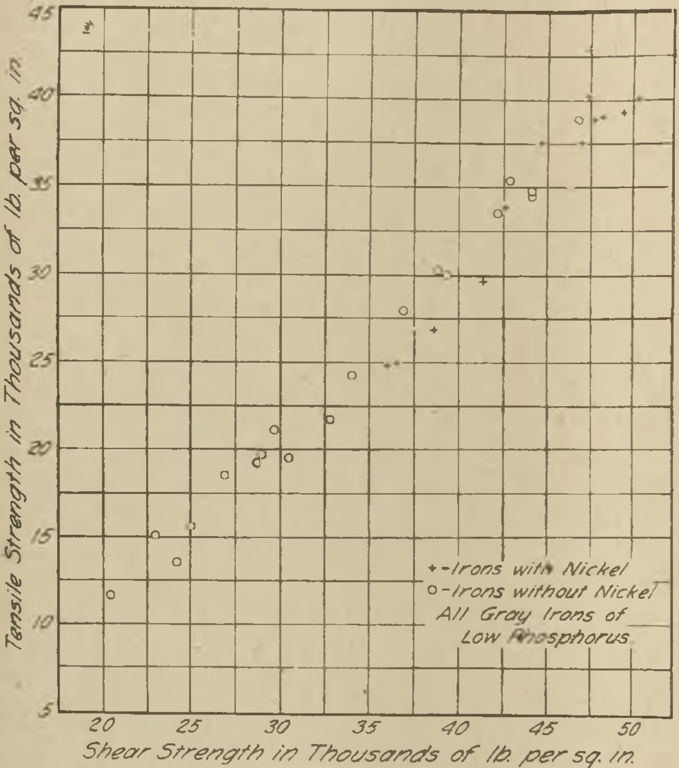


FIG. 6.—SHEAR-TENSILE RELATIONSHIPS.

when one considers that the tensiles T1 and T2 were taken from a section subject to some shrinkage. The Brinell numbers (195-203) when compared show that these compare with the tensile within the limitations of the Brinell correlation.

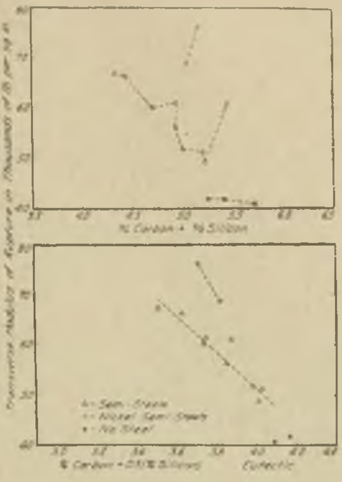

Transverse Modulus of Rupture in Thousands of lb per sq in
80
70
60
50
40
3.5
4.0
4.5
5.0
5.5
6.0
6.5
% Carbon + % Silicon
80
70
60
50
40
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
△ - Semi-Steels
○ - Nickel Semi-Steels
● - No Steel
% Carbon + 0.3(% Silicon)
Eutectic

FIG. 7A.

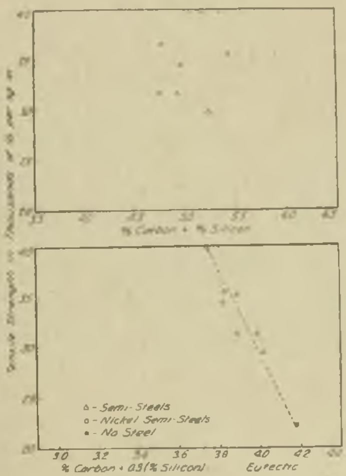

Tensile Strength in Thousands of lb per sq in
40
35
30
25
20
3.5
4.0
4.5
5.0
5.5
6.0
6.5
% Carbon + % Silicon
40
35
30
25
20
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
△ - Semi-Steels
○ - Nickel Semi-Steels
● - No Steel
% Carbon + 0.3(% Silicon)
Eutectic

FIG. 7B.

TABLE III.—*Compilati*

Reference serial.	Total carbon.	Silicon.	Combined carbon.	Manganese.	Sulphur.	Phosphorus.	Dia. cast.	Transverse load.	Deflection.	Span.
1	3.52	2.17	0.73	0.60	0.08	0.32	0.50	199	0.73	18
2	3.59	2.14	—	" Cra	ne Pat	tern "	⅓ in.	dia. —	—	—
3	—	Max.	tests	½-in.	bars	—	—	203	—	—
4	3.52	2.17	—	0.60	0.08	0.32	0.75	566	0.49	18
5	—	Max.	tests	¾-in.	bars	—	—	600	—	—
6	3.52	2.17	—	0.60	0.08	0.32	1.00	1,191	0.275	18
7	—	Max.	test	1.0-in.	bar	—	—	1,275	—	—
8	3.52	2.10	—	0.60	0.10	0.34	1.06	1,917	—	12
10	3.54	2.20	0.56	0.64	0.07	0.27	1.20	1,922	0.276	18
11	3.52	2.14	0.48	0.49	0.12	0.63	1.20	—	—	18
12	3.68	2.17	0.55	0.54	0.08	0.65	1.25	3,450	0.123	12
13	3.68	2.17	0.55	0.54	0.08	0.55	1.25	—	—	12
14	3.52	2.10	—	0.60	0.10	0.34	1.03	2,450	—	12
15	3.52	2.10	—	0.60	0.10	0.34	1.55	7,725	—	12
16	3.52	2.10	—	0.60	0.10	0.34	1.57	5,975	—	12
17	3.53	2.09	0.58	0.52	0.05	0.84	2×1	2,085	0.34	24
18	3.52	2.17	0.29	0.60	0.08	0.32	2.00	7,170	0.165	18
19	3.52	2.10	—	0.60	0.10	0.34	2.06	12,267	—	12
20	3.52	2.10	—	0.60	0.10	0.34	2.03	15,667	—	12
21	3.52	2.10	—	0.60	0.10	0.34	2.55	27,450	—	12
22	3.52	2.10	—	0.60	0.10	0.34	2.55	21,450	—	12
23	3.52	2.17	0.29	0.60	0.08	0.32	3.00	18,173	0.118	18
24	3.52	2.10	—	0.60	0.10	0.34	3.08	35,517	—	12
25	3.52	2.10	—	0.60	0.10	0.34	3.05	45,067	—	12

J. E. Fletcher—" F.T.J.," July 21, 1927—11. J. B. Kommers—Proc. A.S.T.M., 1928—12. 13.
J. W. Bolt

Data on Cast Irons.

mod. rupture	Tensile.	Tensile dia. pulled.	Shear.	Dia. sheared.	Brinell 3,000 kg.	Rockwell B.	Per cent. steel.	No. bars averaged.	Sp. gravity.
3,000	32,317	0.375	41,550	0.358	—	96	6	5	7.181
—	32,500	0.500	—	—	—	—	6	1	—
—	33,760	0.375	—	—	—	—	6	—	—
,830	30,243	0.505	38,800	0.505	180	90	6	6	7.112
—	30,534	0.505	—	—	—	—	6	—	—
,290	22,205	0.505	32,850	0.505	162	88	6	4	7.116
—	22,725	0.505	—	—	—	—	—	—	—
,900	21,250	0.875	—	—	—	—	0	3	—
,900	22,125	0.686	—	—	154	85	6	12	7.094
1,500	22,450	?	—	—	—	—	—	2	—
,000	23,200	0.33	—	—	172	87	0	5	—
—	24,900	0.60	—	—	—	—	0	5	—
,400	square	—	—	—	—	—	0	3	—
,200	square	—	—	—	—	—	0	3	—
,600	16,500	0.875	—	—	—	—	0	3	—
,500	—	—	rectang	le —	—	—	0	6	—
1,075	13,485	0.800	24,325	0.505	112	—	6	3	7.087
1,000	15,330	0.875	—	—	—	—	0	3	—
,700	square	—	—	—	—	—	0	3	—
1,650	square	—	—	—	—	—	0	3	—
,950	15,130	0.875	—	—	—	—	0	3	—
,840	11,561	0.800	20,500	0.505	94	—	6	3	6.972
1,100	14,270	0.875	—	—	—	—	0	3	—
1,600	square	—	—	—	—	—	0	3	—

—12. Talbot—17. W. Rother and V. Mazurie—Trans. A.F.A., 1926—8, 14, 15, 19–22, 24, 25.
W. B., 18, 23.

Following this same method of checking the actual strengths of castings with calculated strengths, we cite below six typical examples:—

Example 1 (above).—Actual tensile strength, 37,368; calculated tensile, 37,800.

FIG. 7C.

Example 2.—125-lb. casting of uniform section. Actual shear, 31,345 lbs. per sq. in.; average, calculated, 31,525.

Example 3.—730-lb. casting, complicated shape, uniform section. Actual tensile strength, 28,433 lbs. per sq. in.; average, calculated tensile, 22,500. (*Note.*—Very small choke-gate was used, samples cut from far side.)

Example 4. — 700-lb. casting, sections 1 to 1½ in.; actual tensile, 28,843 lbs. per. sq. in., average, calculated tensile, 25,030.

Example 5.—325-lb. casting. Actual tensile, 27,055 lbs. per sq. in.; average, calculated tensile, 26,000.

Example 6.—300-lb. casting. Actual tensile, 22,250 lbs. per sq. in.; calculated tensile, 21,250.

All these examples were made on commercial castings, of reasonable complicated design, all but Example No. 1 were cored castings, and variations in section were those encountered in sound engineering practice. Although the results above obtained represent direct tests we have made, it is conceivable that greater variations may be found in practice. However, it is believed that greater variations usually will be explicable on comparison of the factors influencing the bars and castings under consideration.

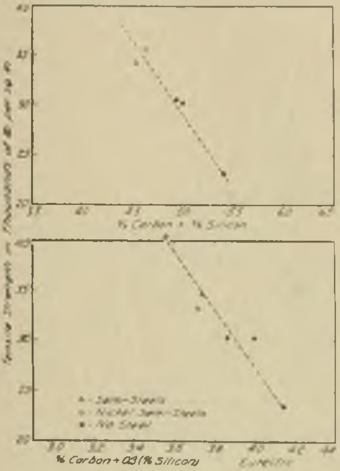


Fig. 7d.

Calculated data were obtained from test bars which, excepting Example No. 1, were *not* cast on the same day as the castings, but were from the same cupola and quite close to the same analysis. As in Example No. 1, tests using stress-strain diagrams, Brinell and shear were made. Some of the calculated data were interpolated from curves. From consideration of all these tests, the following opinions are justified.

Reasonable correlation of tests to the properties of the castings themselves must be established or cast-iron research is futile. It is the casting that the engineer designs, the manufacturer sells and the customer buys. These men care little about the "quality of the iron in the ladle." They are concerned only with what they get, namely, the casting. However, it is possible to tell a great deal about the quality of the metal in the casting, as is evident from the following considerations:—

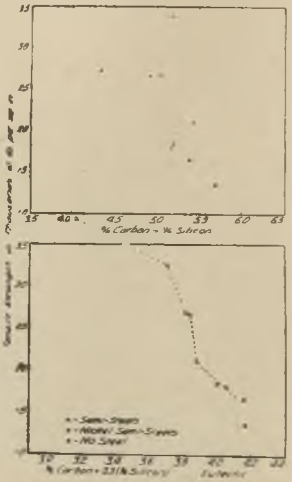
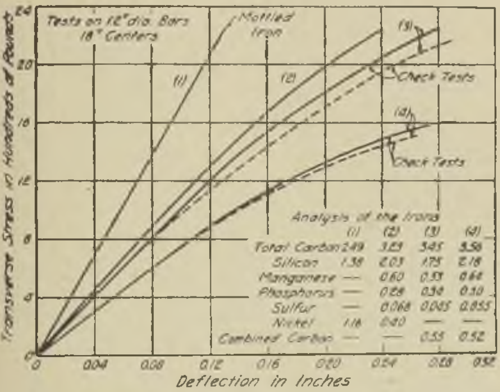


FIG. 7E.

(a) Many working properties of steel and other metals are predicted regularly from tests. Granting the limitations of the tests and the difficulty of their exact interpretation, which, by the way, applies to all materials, no one would deny that great progress has been made by use of tests. In a general way tests are used every day to determine properties of commercial metals.

(b) If in two or more cases exactly the same grade of material is accorded the same or equivalent treatment, the altered materials will still be the same, one to another.

(*c*) Test-bars are castings of certain specified shape and dimensions. If castings and test-bars all of the same analysis and cooling rate are poured at the same time from the same material, one would expect to find similar metal in each. The problems encountered are:—(1) to make test-bars whose cooling rates are like those of the castings, and (2) to use common sense in making allowance for peculiarities in design and foundry practice—particularly those which may promote shrinkage or other defects and those which call for slow or fast pouring of castings.



Analysis of the Irons

	(1)	(2)	(3)	(4)
Total Carbon	2.49	3.23	3.45	3.56
Silicon	1.38	2.03	1.75	2.18
Manganese	—	0.60	0.53	0.64
Phosphorus	—	0.28	0.34	0.30
Sulfur	—	0.068	0.085	0.055
Nickel	1.16	0.40	—	—
Combined Carbon	—	—	0.55	0.52

FIG. 8.—COMPARISON OF STRESS-STRAIN CURVES OF VARIOUS IRONS.

(*d*) These points are borne out because the foundryman of wide experience can take an analysis and a result on one of the so-called arbitration test-bars and many times predict quite closely what the iron in the casting will be like.

It then is possible to solve the second problem —relationship of test results to the properties of the casting. What is needed is co-operation in accumulation and interpretation of sufficient data. Careful study must be made of test methods. In the correlation shown in the examples above, the general agreement becomes more remarkable when it is considered that (*a*) the metal flow in the castings may be slower than in the bar; (*b*) that the machined tensile bar is in case of the castings closer to the cooling surfaces than in the tensile bars—thus neglecting the well-known and demonstrated differences due to cooling gradients of unlike sections of similar volume/surface area relationship. This is most apparent in larger sections.

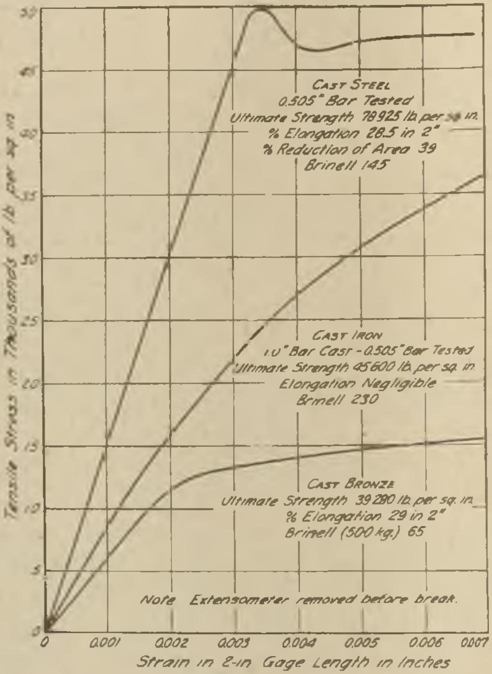


Fig. 9.—Stress-Strain Diagrams of Various Metals.

The usual commercial impracticability of the French scheme of trepanning a small shear sample from actual castings appears a barrier to the widespread use of this method. In America, attempts to get similar tests into specifications for steel castings have been opposed. There may be some merit in the idea of cast-on bars for certain types of casting. The work of the late George K. Elliott, Willard Rother, and the writer demonstrate certain objectionable features in the original Frémont test. This test, as proposed, was hardly precise enough for use in commercial specifications. The machine did not seem sufficiently rigid and the method of preparation of the test-bar by a hollow drill is open to criticism. Accurately-machined bars are an absolute necessity, and a rigid and accurate machine is needed. The test-piece proposed was too small to be representative of the general properties of the iron. On the other hand, the basic idea of the French engineers is very good. With proper modification, the shear test is quite useful in research work.

It perhaps is possible to indicate the American view point on several of the eleven questions asked by THE FOUNDRY TRADE JOURNAL.

Transactions of various American associations contain many discussions criticising attempts made to draw practical conclusions from crucible-melted metals. However, it is well recognised that general metallurgical understanding is enhanced by such work, and that it is of decided ultimate value.

No silicon-carbon summation results can be used as a short cut to complete knowledge of the expected properties of the metal. However, they are useful if applied with discretion. Some interesting relationships are implied in Figs. 7A to 7E, which show silicon-carbon summations v.s. strength, and in Figs. 8, 9, 10 and 11. The same applies to attempts at correlation of Brinell values to tensile and transverse strength —useful within limits, but no panacea.

The present trend of thought seems to be that control of amount and form of graphite is more important than control of matrix alone. A 2.70 per cent. carbon iron of 0.60 per cent. combined carbon possesses different properties from a 3.70 per cent. carbon iron with 0.60 per cent. combined carbon. However, neither factor can be ignored. The condition of the graphite undoubtedly is dependent on the nature of the carbide resulting from influences of both composition and thermal history.

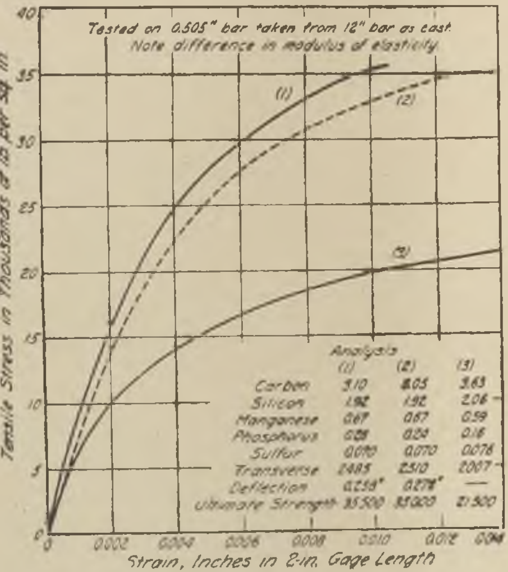


FIG. 10.—TENSILE STRESS STRAIN OF VARIOUS GRADES OF CAST IRON.

The work of the United States Bureau of Standards sheds a great deal of light on the lack of seriousness of the gas problem.[6] The importance of this factor seems to have been

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[6] Jordan, Eckman & Jominy—The Oxygen Content of Coke and Charcoal Cast Iron. Trans. A.F.A. Vol. 33, pp. 431-441, 1925.

exaggerated unduly in former years.[7] We refer to dissolved gases, not to blowhole and incipient shrinkage.

Ingotism is very important, yet more recognised through inference than by direct reference. Macroscopic methods deserve more attention.

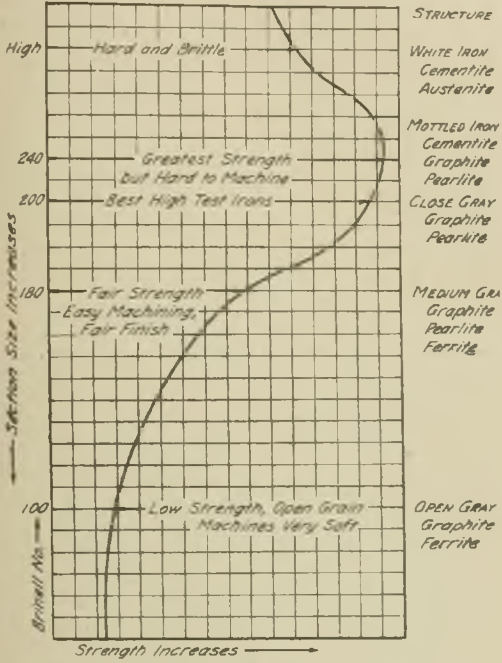

FIG. 11.—QUALITATIVE DIAGRAM OF SECTION TENSILE RELATIONSHIPS.

Internal stresses are being recognised in the heat-treating practices followed by many American firms.[8]

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[7] J. W. Bolton—"The Foundry," Aug. 15, 1924, pp. 628-634.
[8] O. W. Potter—Trans., A.F.A., Vol. 33, pp. 294-346, 1925.

In presentation of this Paper, the writer has attempted to have it in sympathy with the present trend of American engineering and metallurgical thought. As one daily concerned in phases of practical operation in iron, steel and non-ferrous foundries, practical rather than academic motives possibly are more apparent. On the other hand, it would be unfair to claim that all of the ideas herein advanced represent the unanimous opinion over here. In one matter the writer can voice a unanimous sentiment. The American Foundrymen's Association, those whom it represents, have the greatest respect and cordiality for their fellow-workers across the sea. As the years go by they confidently hope and expect this feeling of good fellowship to continue and to expand to mutual advantage.

SUPPLEMENTARY DATA TO FIG. 4.

Coefficient of Expansion (average 70–1,000 deg. F.) :—

½-in. test bar	13.27	× 10^6 per deg. C.
¾-in. test bar	13.25	,, ,, ,, ,,
1-in. turned to ¾-in. ..	12.49	,, ,, ,, ,,
2-in. ,, ,, ..	13.39	,, ,, ,, ,,
3-in. ,, ,, ..	13.27	,, ,, ,, ,,

Growth (6 reversals, over 100 hours' test) :—

¾-in. bar from 1.20 bar grows 8^{-8} in. per inch per hour at 750 deg. F.

¾-in. bar from 1.20 bar grows 0.589 per cent. in 100 hours at 1,000 deg. F.

125 times as fast at 750 deg. F.

Rockwell Uniformity—See Trans. A.F.A. 1928 (J. W. Bolton, p. 469–512) :—

B 46 (centre)
39
38
58
59
67
66
65
59
60
69
69 (edge)

Drop Test—

Anvil 5 in. between supports. Hammer 20.*

Size.	Started at	Broke at	Times struck.
In.	In.-lbs.		
½	20	40	2
¾	40	70	4
1	50	120	8
2	200	1,100	30

* NOTE.—The 2-in. bar was struck 28 times, advancing by 20-lb. increments to 740 in.-lbs., then raised to 1,000 and broke at 1,100 in.-lbs.

Fatigue Limit :—

J. B. Kommers found the fatigue limit 11,800 lbs. on R. R. Moore machines.

Impact Value :—

J. B. Kommers, using a Russel impact machine, 12-in. span, found an impact value of 16.5 lbs. per cub. in., energy of rupture.

Discussion of Tensile Test Results from test bars from ordinary cupola practice.

In general, there is a very good agreement between all results, except that of Prof. Kommers on the ASTM arbitration bar. In case of the 1.0-in. size, Rother & Mazurie stated that they used a 0.875 tensile bar. No mention is made of special centring devices, and it would seem hard to get a 0.875 bar with threaded ends out of a 1.0-in. test-piece. Bolton used a 0.505 bar, which is fairly small. On the 1.20 and 1.25-in. bars, Bolton used a 0.686 bar, while Fletcher probably had a 0.800-in. bar, which should be slightly stronger, not quite so great a portion of the weaker centre. On both 2-in. and 3-in. bars Bolton used a smaller test-piece than Rother, which would explain a difference, as experienced in heavy sections. As shown by the writer ("Iron Age," Jan. 3, 1924) pouring temperature has more influence on the large bars. Along this line the following tests were made from a 2-in. bar.

Dia. tested	Tensile.
1.38	14,021
0.800	13,485
0.505	12,875

Differences in moulding practice have much to do with the soundness of metal. In bronze, same pattern and pouring temperature, change to a smaller flask with larger gate made 3,000 lbs. average difference in tensile strength.

DISCUSSION.

The Paper was introduced by Mr. D. M. Avey, who expressed regret that the author was unable to be present at the Congress.

Future of American Research Forecast.

Mr. R. S. MacPherran (U.S.A.) said the day would come when there would be a correlation of bulk with the surface of castings. The American Foundrymen's Association was working on this matter, and a report of the Committee dealing with it would be presented in due course.

Mr. R. F. Harrington (U.S.A.), referring to the trepanning of specimens and the attempt to correlate the results of tests on bars taken from the castings and on cast specimens, said it was becoming more fully realised that it was necessary to use larger test specimens than had been used hitherto, in order that the results obtained might be more strictly comparable. He anticipated that the American Foundrymen's Association would be able to shed some more light on that particular subject. He was glad that Mr. Bolton had emphasised above all the fact that they had to sell castings, and not test-bars, and that they were concerned to turn out proper castings by the adoption of sound foundry methods.

Mr. J. T. Mackenzie (U.S.A.) said that the work of the American Foundrymen's Association Committee on grey cast iron was concerned with the examination of the properties of the iron in the molten state, with the idea of determining the properties which made for the production of sound castings or otherwise. They had just completed some work of considerable magnitude on the determination of the temperatures, and had shown up the faults of the optical pyrometer in that regard. Following that, they were engaged upon a study of the shrinkage of cast iron in the freezing range; if they were successful in developing a test for that, it would be extended to the contraction from the freezing point to room temperature, which would include shrinkage as we now know it. He could not emphasise too strongly that the soundness of the casting had more to do with the quality of the cast iron than with the tensile strength of the test-bar.

Professor T. Turner (late Professor of Metallurgy at the University of Birmingham, and Past-President of the Institute of Metals) acknowledged that the results put forward in the Paper represented a very considerable amount of practical work, and combined with it an attempt at scientific correlation. In earlier investigations of subjects of this kind we had been content to say that a thing was good or bad, or very good or very bad, and we had had no quantitative values. We did not become scientific until we could express many of the properties in figures; at the same time, if we did use figures, we must be very careful that those figures were correct, because there was nothing more misleading than a wrong figure. We had recognised for many years the importance of the rate of cooling of a casting; the attempt to correlate bulk with surface—which, of course, determined the rate of cooling—was very interesting, and one felt that Mr. Bolton had made a considerable advance in that direction. Commenting on Mr. Bolton's reference to the value of crucible-cast synthetic mixtures, he said that every scientific man recognised that those could not correspond accurately with what obtained in practice, in view of the many variables that entered into the problem in practice, but the great advantage of the study of the synthetic mixtures was that we were able to eliminate a number of the variables and to study one thing at a time. Having learned one thing among a number, we could gradually find the wider truths.

Graphite should be Scientifically Classified.

Referring to the question of graphite, he said the author had stated that the control of the amount and form of graphite was more important than the control of the matrix alone. In connection with the amount and form of graphite, however, we had no quantitative value. The form of graphite was sometimes very fine indeed, like that of soot; some of it was in the form of curved flakes, and some was in the form of flat flakes. Those were simple kinds of graphite, but there were also intermediate qualities, each of which corresponded to entirely different physical properties in the material, and when describing graphite we should endeavour to state to which class it belonged, or whether it was a mixture of more than one class. Ledebur, who was a pioneer in this work, had pointed out the importance of the finely-divided graphite. But what did we mean by "finely-divided graphite"? Some of it was very small, and could be seen only with the aid of a microscope of very high power, whilst some was in the form of flakes almost as large as one's finger-nail; there were other sizes between these two extremes, and we ought to have some method of classification. Some years ago he had classified graphite by extracting it, purifying and drying it, and passing it through sieves, and recording that so much went through a sieve of one size and so much went through another size. That was a slow and cumbersome process, and we ought to be able to classify graphite microscopically, and to say, for instance, that some of it was larger than 0.05 in., and that size we might consider to be large. There were various grades above that, however. Some graphite was smaller than $\frac{1}{200}$ of an inch (0.005). We might classify in terms of millimetres. Graphite larger than 1 mm. we might call coarse in an ordinary casting, and we might classify down to sizes as small as 0.01 mm. Whatever the classification adopted, however, we ought to have some method, not merely of classifying graphite as being coarse or fine or intermediate, but of stating that the bulk of it was of a certain definite size; then we should be able to compare the results obtained by one investigator with those obtained by another.

When Gas in Metal is Dangerous.

With regard to gas, he was glad that the author did not regard it as serious, comparatively speaking. The effect of gas was serious if that gas happened to come off during the process of solidification so as to give rise to blow-holes or spongy masses, which would deteriorate the casting, but otherwise the casting seemed not to be effected, whether the metal was melted in an atmosphere containing one gas or another. It was somewhat analogous to aerated water. When aerated water was enclosed in a corked bottle, it looked like ordinary water, but when the cork was removed there was considerable effervescence. During the cooling of a metal containing a gas in solution the gas came off, and it was for the founders themselves to ensure that that gas came off quietly and did not cause bubbles; so long as it did not come off in bubbles he did not think they need worry about gas.

The French View-Point.

M. E. V. Ronceray (France) expressed the view that the Paper was a condemnation of the use of test-pieces cast separately from the actual castings. He was glad to note that the author attached great importance to the soundness of castings, because at the Foundry High School in France the students were taught that the factors which were of the greatest importance were (1) soundness, (2) tensile strength or internal strain, (3) strength of material, and (4) cost. It would be noted that strength was placed third in order of importance, and that soundness was placed first. The problem of internal strain was very important, because very often strains existed where they were not expected, especially in cast iron, and there were no scientific means of finding out what stresses existed in castings. A casting might be sound, and it might also be made of strong material, but even so it might be worth nothing. In a Paper by the President of the Académie des Sciences, it seemed to be proved that these troubles could be overcome by certain heat treatment. If that were proved by prolonged experiment, we should have made a great step forward. With regard to the Fremont test, it seemed to be the view of many people that this was a shear test. The French Foundry Technical Association had taken the trouble to print an issue of its "Bulletin," in which was concentrated all the Papers that had been published with regard to this question, and if those Papers were read carefully it would be appreciated that the shear test was only one part of the Frémont test. The ideal test was a bending test on a small sample taken from the casting. Mr. Bolton had commended the ball test, not as a final test, but as a test of heterogeneity of the castings. There was a tendency, however, to try to link all the tests together, but it was well known that there was no definite connection between the ball test and the tensile test, for instance. It appeared also that difficulty had been experienced in taking small samples from castings, but those who would take the trouble to read the Paper by MM. Le Thomas and Bois on cast-iron testing methods, which Paper was to be presented to the Congress, would find that there was absolutely no difficulty in that respect. The proof of that was that the process described in that Paper had been adopted by the French Navy a few weeks ago, after a three-years' test.

Melting Conditions of Paramount Importance.

Mr. J. G. Pearce (British Cast Iron Research Association) said that the author had placed all foundrymen in his debt by collecting together the factors which influence the properties of the capricious conglomerate called grey iron, as he had done in this and his A.F.A. Paper at Philadelphia in 1928. It was particularly useful to have the author's results on a clearly-defined set of experiments, because work on a haphazard collection of tests did not make for scientific conclusions any more than stringing together a collection of letters made words or of words, understandable English. Everything lay in the selection of the tests and the arrangement of the results.

He said he could confirm without hesitation the importance of the melting conditions, by which he meant those conditions of charge-constitution and furnace-running which affected the structure, and hence the properties of the metal other than the chemical composition itself. Referring to the problem of volume—surface-area ratio—he said he had carried out some work on the mechanical properties of cylindrical bars, and had tried to relate the strength of bars of different thicknesses to the diameter* and equations to the curves could be readily worked out. They would, however, differ for each iron. The cylindrical bar was a very simple casting, and if one excluded the ends of the cylinder, which were comparatively unimportant, the ratio of volume/area was proportional to the diameter. The ratio would work in simple cases, but in the more complicated cases he was not so optimistic. If one cast a flat plate, it would have a certain volume/area ratio. If one cast it as a double plate, *i.e.*, with one-half turned over on to the other half, sandwich fashion, the ratio would remain the same, but obviously the two halves of the plate would affect each other in cooling, and the structure of the metal would be different. Thus, the test results would be altered very seriously, and he could not see how Mr. Bolton accounted for the influence of adjacent masses in a casting. This applied to all cored castings. He (Mr. Pearce) was proposing to proceed from a consideration of simple castings, such as cylindrical bars, to slightly more complicated castings, such as liners and piston pots, and not immediately to the more complicated cored castings such as Mr. Bolton had considered. These considerations made him less optimistic than the author with regard to the use of the volume/area ratio. Mr. Fletcher had used its reciprocal

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* See "Influence of Size of Section on Strength of Grey Cast Iron" by J. G. Pearce, Proceedings, I.B.F., Vol. XXII.

in 1918,* and Keep used it as far back as 1895.† No very striking developments, however, had originated from it. Again, he (Mr. Pearce) had used the transverse test, which could be applied at or very near to the cast size of the metal, and he had tried to relate that to the tensile, compression and other tests. Mr. Bolton was compelled to machine his tensile and shear bars to a comparatively small section, below the main sizes of the test-pieces. This, of course, affected the strength. He would also be limited in the section of the bar he could actually test. Transverse tests up to 5 in. thick presented no difficulty, but tensile and shear tests at this diameter did so. It would help if Mr. Bolton would give details of the shear test he used. Presumably his "calculated" tensile results were based on bars cast the next day, having a cooling ratio as close as possible to the casting which he was actually examining.

In conclusion, he said that British foundrymen would very warmly reciprocate the sentiments expressed in the concluding paragraph and look forward to an increased interchange of information in future.

Mr. W. Jolley, in a tribute to Mr. Bolton, and in thanking him for having given in his Paper a tremendous amount of information which would be of great value to foundrymen, said that the differences between the results obtained in the laboratory and in the foundry were sometimes very wide, and Papers such as this, which assisted foundrymen in the correlation of their test results so that the properties of their castings might be predicted, were of extreme value.

Raw Materials have their Significance.

Mr. J. E. Fletcher (Consultant, British Cast Iron Research Association), after paying a tribute to the American foundrymen for their wonderful work on correlation, said that the Research Association had been trying to correlate

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* Journal, Iron and Steel Institute, 1918, No. 2.

† Transactions of the American Society of Mechanical Engineers 1895, Vol. 16.

as far as it could the various properties of cast iron as influenced by cooling rate and composition. There was one phase of this subject, however, which was often left out of consideration, namely, the effect of variable conditions during the making of the foundrymen's raw material, pig-iron, in the blast furnace, which influenced in such a serious fashion the ordinary casting. Most practical foundrymen were only too conscious of the fact that irons of the same analysis, when used in a cupola, often gave different results. This matter had been touched upon by one of our American friends this year, and some valuable work had been done in this connection. He was one of those who believed that the conditions at the beginning of things had a great deal to do with the results obtained at the end, and he suggested that the Institute should try to obtain from the blast-furnace people a good deal more information than they had hitherto vouchsafed to the foundrymen. He was very glad that Mr. Bolton had given particulars of an actual casting at the end of his Paper, because, after all, it was the final casting that mattered. Also, he was glad that it was a fairly thick casting, because in the case of a thin casting the cooling ratio was fairly easy to apply.

Chemical Composition and Mechanical Properties may be Unrelated.

Mr. John Shaw said the Paper was founded upon two clear ideas: First, to classify irons into various grades of composition, and secondly, to correlate the physical properties of these grades when melted and cast under known conditions. For the purpose of the latter he had sub-divided the factors influencing mechanical and physical properties of grey cast iron under four headings, (1) chemical composition; (2) structural, mechanical and chemical make-up of charge; (3) the melting process; and (4) the thermal and mechanical history from furnace spout to finished casting. This was a very large order. If, to the specified grades in Table I, there were added the four types of phosphorus content, one arrived at a figure of 200 composi-

TABLE IV.—*Effect of Cupola Conditions and Steel Additions on Physical Properties.*

Tensile. Tons/sq. in.	Shear. Tons/sq. in.	T.C.	Si.	T.C.+Si.	$T.C.+\frac{Si}{3}$	Shear Ten.	C.C.	Mn.	S.	P.
9.8	16.8	3.44	1.56	5.00	3.91	1.71	0.59	0.68	0.11	0.64
10.0	16.2	3.46	1.60	5.06	3.94	1.62	0.56	0.65	0.114	0.48
10.9	18.2	3.41	1.93	5.34	3.99	1.67	0.51	0.76	0.103	0.58
13.4	20.0	3.43	1.49	4.92	3.88	1.49	0.63	0.71	0.113	0.64
13.5	19.9	3.44	2.03	5.47	4.05	1.47	0.49	0.72	0.089	0.86
14.9	20.4	3.43	1.98	5.41	4.02	1.37	0.53	0.74	0.110	0.61
17.6	24.5	3.35	1.49	4.84	3.80	1.39	0.60	0.76	0.12	0.51
18.1	27.0	3.36	1.47	4.83	3.80	1.49	0.56	1.20	0.103	0.58
18.8	18.6	3.40	1.91	5.06	4.00	1.00	0.58	0.72	0.116	0.76

tions, and many still believed that full knowledge would not be obtained until some such scheme was tried out. The importance of the first three headings of the sub-division was not fully recognised. Some very illuminating work had been carried out recently by Mr. Jolley and his staff, and it was to be hoped that Mr. Jolley could be persuaded, in the near future, to present a Paper showing the various structures and the methods of obtaining them.

Table IV contains three examples, from the bottom, middle and top of a table containing 53 examples.

The chemical composition was practically the same, yet the tensile results varied nearly 100 per cent. The bars were all of the dimensions 14 in. by 1 in. by 1 in., so that the surface area and volume was the same. These results were obtained by varying cupola practice, and altering charges and casting temperature. Other factors might affect the physical properties, but these experiments had thrown much light on some of the reasons why chemical analysis did not always fall into line with physical tests. The expression of the relationship of volume to surface area in definite terms was a new idea, and would bear testing out. One did not realise at first glance that if one had, say, a block of iron 4 in. by 4 in. by 10 in., and transformed this into a plate 16 in. by 10 in. by 1 in., the surface area was increased from 192 sq. in. to 372 sq. in., while the volume remained the same. This would give a different factor for each, that might relate each to its proper bar structure. There were objections to this, however. In a large and complicated casting there might be widely varying sections, and to calculate surface area and volume of such a casting was not a simple matter; the figure obtained would be an average, and, after all, one would use an average composition for such a casting, probably erring on the hard side for the thin portion, to allow for the annealing effect of the heavier section.

Referring to the test-results relationship, he said he would not care to accept the tensile result of a bar of the same composition as the casting, if that bar had not been cast out of the same ladle of metal; neither would a shear result converted into a tensile be acceptable. Whilst it might be granted that under the very closely controlled conditions specified by Mr. Bolton, approximations in both cases were possible, and their use for works information and research of great value, these approximations would not be acceptable to the buyer of the casting. It must be remembered that in many cases the inspector or buyer had only the one or two simple tests to rely on to give him some idea of the physical properties of the material. Finally, Mr. Shaw said that those who had read this Paper, together with the one presented on the same subject a year ago, could not but be grateful to Mr. Bolton for the great amount of work he had done and for the valuable information he had imparted.

Vote of Thanks.

The President (Mr. Wesley Lambert), proposing a vote of thanks to Mr. Bolton, said that he would be gratified by the discussion it had evoked. The President agreed with the view that, apart from the tensile strength or any other mechanical-strength figures relating to a casting, the most desirable thing was to have a sound casting, free from internal stresses. The buyer wanted a casting which he knew to be sound and free from internal stress, but it was also necessary to know the strength, to enable the designer to design his parts; therefore, any attempt to correlate the information obtainable by any means was of value. He proposed, formally, a hearty vote of thanks to Mr. Bolton for his Paper and to Mr. Avey for having presented it.

Mr. J. G. Pearce, who seconded, said he looked forward to the opportunity of studying the Paper, together with the discussion upon it, when published.

The vote of thanks was carried with acclamation.

THE INFLUENCE OF GRAPHITISATION OF CAST IRON.

By Professor E. Diepschlag.

[GERMAN EXCHANGE PAPER.]

At an International Foundry Congress held in Paris in 1927, M. André Levi[1] made a remarkable statement as to the transmission of properties in cast iron. Proceeding from the well-known fact that two different samples of cast iron of the same chemical composition often have very different mechanical properties, he established that, in addition to the chemical analysis of a metallic material, some other characteristic factors must be derived to predict it exactly, and in the case of cast metals the previous thermal history must especially be taken into consideration. By this, the rate of heating of the material, the degree and time of superheating and the rate of cooling is understood. The chemical composition and the previous thermal history are, in many cases of metal alloys, two independent values, and for a given chemical composition the mechanical properties may be predicted when the earlier thermal history is known.

However, in grey cast-iron materials, these two determining characteristics are not independent of each other, as it is nearly impossible to modify the speed of cooling, for example, without at the same time changing the chemical composition. The carbon present in a cast iron is determined by chemical analysis to exist partly as graphite and partly as combined carbon, and the proportion of these two parts is modified in relation to the thermal conditions. In the case of cast iron of a given chemical com-

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[1] André Levi, "L'hédérité des fontes, La fonderie moderne," 1927, page 399. Extracted FOUNDRY TRADE JOURNAL, page 42, vol. xxxvii.

position, the mechanical properties are not exclusively determined by the previous thermal history; therefore, a new value must be considered—peculiar to cast iron—which is recognised by Levi as a transmissary property. This third value is caused by the influence of the thermal history on the chemical composition and the chemical reaction of the alloy under the influence of heat.

An Explanation of Inherent Properties.

For the separation of crystals from a saturated salt solution, it seems possible, in reference to the size of the separating crystals, to produce a forced crystallisation. Thus, if the first crystals appearing or actually present are very small, the later separating crystals will be small also, and *vice versa.* Therefore, if a cast iron having coarse-grained graphite crystals is melted and then cooled down, the remelted sample will have similar coarse-grained graphite deposits, unless, through a high superheating, the nuclei are totally destroyed. In most of the common remelting processes the superheating temperature and time is insufficient to destroy the nuclei completely. Consequently, a remelted cast iron is associated with coarse-grained graphite if the original material was so constituted. On the contrary, when remelting cast iron having fine-grained lamellæ, they are again found in the alloy after remelting. Thus, the structure of a pig-iron or scrap used for remelting purposes is largely reproduced in the final product, and in this sense the term "transmission of properties" may be used.

If one tries to reconcile the chemical composition of an alloy and its mechanical properties generally, there is only a qualitative relationship between the amounts of the constituents and these properties. In the case of cast iron, however, the influence of graphite heavily predominates all other constituents. It is true the development of the matrix to perfect the mechanical properties has attracted much attention during the last few years, and the steps taken to obtain a ferritic or pearlitic matrix have been very fully outlined. But, in this connection, it was recognised that all improvements of the matrix are masked by the existence of more or less large quantities of graphite being distributed throughout the mass in diverse orientations.

Overcoming Inherency.

P. Bardenheuer and K. L. Zeyen[2] established from their experiments that an annealed chilled cast sample had better mechanical properties, even though it had a ferritic matrix, than a sand-cast sample having a pearlitic matrix. They postulate from this that the structure of the metallic constituents is only of minor importance in relation to the mechanical properties of grey cast iron, and that, in the main, the form and the distribution of the graphite is decisive. Thus, with regard to the quantity, the form and the distribution of the graphite, only after the most favourable conditions are created, the question of the formation of the matrix becomes important.

So if, on the one side, the relationship between the mechanical properties and the chemical composition really refers to the ratio between these and the quantity and form of the graphite, and, on the other hand, as postulated, a transmission of the structure of the pig and scrap iron taking place in normal remelting methods, founders must study these metallurgical questions, not merely as to the final product, but with similar assiduity to the quality and properties of the metallic raw materials employed. The most important raw material in this case is the pig-iron. This must not only be evaluated according to its chemical composition, but rather with reference to the type and quantity of the graphite content. The graphite is mainly responsible for the tensile strength, and these properties are modified by remelting—only slightly, never completely.

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[2] P. Bardenheuer and K. L. Zeyen, "Stahl und Eisen," 8 (1928), page 515.

How Blast-Furnace Conditions affect Final Product.

During smelting in the blast furnace, after the reduction of the iron ores, the metal mainly dissolves the carbon in the zone of highest temperature, that is, in the furnace hearth. It may be supposed that in the neighbourhood of the tuyeres the iron is nearly saturated with carbon. During the dropping of the iron to the bottom of the furnace a re-separation of the carbon begins whilst the pig-iron is still in the furnace. Old blast furnaces making foundry pig-iron often show, after blowing out, a quantity of graphite on the hearth lining. In other cases it is possible that, by the reduction of silicates or MnO and FeO in the slag, the carbon dissolved in the iron is partly eliminated in the hearth, and, as these new constituents are added to the iron, a saturation with carbon does not take place in the furnace. However, this saturation point possibly may be decreased during further cooling after the pig-iron is tapped. During tapping, the iron precipitates its graphite, which in consequence of its low specific gravity and size of the crystals, comes up to the surface. Recent investigations, carried out by A. Michel[3] at some German blast-furnace plants, have resulted in pig-iron to-day being produced at these plants in all cases in the hyper-eutectic condition. That means that the separation of graphite is controlled to take place in the liquid charge. The separation of graphite takes place in these qualities of iron along the liquidus line of the iron-carbon diagram, and should theoretically terminate there if the alloy is of the eutectic composition. However, under-cooling the charge causes a removal from this point, and probably in pig-iron there is no eutectic point at all, because it is not the true binary iron-carbon system. At elevated temperatures the charge is thinly liquid, and the separated graphite rises to the surface; at lower temperatures the rising of the graphite is retarded, only a part of it reaching the surface; the other part remains

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[5] A. Michel, "Stahl und Eisen," 47 (1927), page 696.

in the charge until solidification, and so this graphite becomes a constituent of the alloy. These graphite crystals have their origin in the liquid charge, and so they increase without hindrance. They are visible in the structure as well-defined entities existing in roughly straight lines. In all alloys with a solidification interval there takes place first the separation of mixed crystals in hypo-eutectic alloys and of cementite in hyper-eutectic alloys, and, finally, with the complete solidification the separation of the eutectic mixture. The quantity of each constituent is definitely determined by the position of the alloy in the solidification diagram. At the same time, when the eutectic mixture is separated, in most of these alloys a certain part of graphite is formed, so that in the solid solution of the alloys the carbon exists partly as graphite. The quantity of graphite as against the quantity of combined carbon cannot be definitely determined in advance. Apart from experience, several influences do regulate these quantities of graphite.

Influence of Remelting.

Finally, in the solid solution, the quantity of graphite can rise, because the solubility of the carbon decreases with lowering temperature, and the carbon is separated partly as carbide and partly as graphite. Again, the relative quantities of graphite and cementite cannot be accurately predetermined, as it is varied by several influences. During the cooling down of the pig-iron from the liquid state to low temperatures, graphite is separated at different ranges of temperature. Thus, if the pig-iron is hyper-eutectic, there will be large graphite aggregations, most of which come up to the surface, but a small part is enclosed in the solidifying mass; there will be thin graphite during the passing from the solidification interval to the solid solution from the eutectic mixture, and, finally, fine graphite as the carbon is progressively separated out of the solid solution. Here it should be noticed that the separation of graphite out of the liquid mass only takes place if the iron cools down once. If such an iron is remelted, these large graphite aggregations rise to the surface and are not trapped in the mass during the solidification of the charge. If hyper-eutectic grey cast iron is melted in a crucible, kish may be clearly observed covering the surface of the charge. During the cooling down of such a charge, graphite is only separated when the temperature passes the solidus line in the diagram and again in the region of the solid solution.

Graphite and Combined Carbon Content Control.

The relative quantities of graphite and cementite cannot be predetermined exactly by reference to the eutectic and the solid solution lines, being dependent upon several diverse factors. Supposing that in iron-carbon alloys the iron-carbide system and the iron-graphite system are co-existing, this case is one of those where the constituents present are gravitating towards two different equilibra. The positions of both equilibria are known for the binary iron-carbon system. In these cases generally, neither the one equilibrium is attained nor the other, but usually a labile state is existing lying between the two equilibria. Through special influences, the position of this state can be removed to the one or the other side. The strongest influence has proved to be the rate of cooling, in such a manner that, with decreasing rate of cooling, the quantity of graphite increases. Besides this, other influences, such as that of the different normal constituents of grey-iron alloys, have been investigated in detail, so that it is possible to-day to give exact statements in this connection.

Analysis and Mechanical Properties.

Having established the possibility of influencing the degree of graphite separation, at least in a qualitative manner, by regulating the rate of cooling and by adding suitable quantities and kinds of alloying elements, the relation between the analysis of the resultant alloy and its mechanical properties are still indeterminate. All that analysis shows is the weight of the graphite in a unit weight of the iron alloy, but it is not possible to find out by analysis how many lamellæ are contained in a unit volume of the alloy. The alignment of each individual nida; are certain sizes of these nidæ prevailing, and are the graphite nidæ equally distributed throughout the mass. The elucidation of these questions would give a more exact relation between the structure of any grey-iron alloy and its mechanical properties than is determined by the usual chemical analysis. These questions assume wide importance if, according to Levi, the size of the crystals is transmitted after remelting. The relationship between the size of grains of the graphite in a grey-iron alloy and its mechanical properties have been determined by experiment by Bardenheuer,[4] who controlled the size of graphite grains in his samples by modifying the rate of cooling. He cast different test-pieces of normal size with coarse-grained, very coarse-grained and very fine-grained graphite separations. These tests showed that the finest graphite gave the best conditions for the production of the most favourable mechanical properties.

Controlling Graphitic Structure.

After these determinations it appears to be of importance to ascertain under what conditions the graphite is separated in fine or coarse grains and if it is possible to influence the separations arbitrarily. To ascertain these, the process of separating may be again considered. If the charge passes because of the lowering of the temperature from the liquid to the solid solution, the separation of the graphite takes place in the same manner as the crystallisation of any other liquid mass having constituents in solution. In a homogeneous charge existing in the liquid state, primarily during the cooling down.

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[4] Bardenheuer, "Stahl und Eisen," 7 (1927), page 857.

nuclei appear in the region of increasing speed of crystallisation growing into crystals. The size of these crystals depends upon the speed of growth, the period, the existence of neighbouring crystals of the same or a foreign kind, and the conditions of concentration of the liquid. Crystals of the same kind unite if their neighbouring position is favourable. If in hypereutectic alloys graphite separations are already present, they are the starting points of further crystallisation. If in eutectic alloys, within a small interval of temperature, the nuclei exist and at the same time the rate of crystallisation is high, crystals grow, the size of which depends upon the number of nuclei, and if its degree of undercooling is low. However, if numerous nuclei appear later, when the rate of crystallisation is slow and the liquid charge is highly undercooled, there will be numerous small crystals. In these relations the influence of the rate of growth of the crystals and the number of the crystals on their size is clearly explained. The influence of time is also perceptible, the longer this period, that is, the passing from the liquid to the solid state, the more the crystals that can grow or unite with neighbouring crystals. The conditions of concentration also influence the amount and the number of the graphite separations, and the growth of the crystals is hampered the greater the quantity of the mixed crystals there is in the solidification interval. Moreover, the time of passing from liquid to solid diminishes with the increasing content of mixed crystals. If the composition of the alloy is not far from the eutectic concentration, then the graphite separations must become fine.

α and β Graphite.

The graphite in the solid solution is the result of the gradual transformation of the austenite into martensite and the consequent decrease of the solubility of carbon. The separation of the carbon from the solid solution gives partly cementite and partly graphite, and generally it spreads out reticularly in the alloy, probably favoured by the expansion of volume which is a characteristic of this transformation, and the graphite separations mainly originate in the nidæ of this network structure. The quality of this graphite differs from that separated primarily as well in its constitution as in its physical properties. W. A. Roth established that graphite in pig-iron is a modification which he calls β-graphite, and the graphite which is separated out from the solid solution differs from this, and is identified by him as α-graphite. Both modifications differ in their ignition temperatures and in their specific gravity.

FIG. 1.

Importance of Nuclei.

In the solidification of pig-iron, the number of mixed crystals and their extent depends upon the number of nuclei, which latter are influenced by certain inherent conditions. The number and size of austenite crystals especially depends upon the rate of cooling of the mass; if it is slow, a number of well-developed crystals will grow, but if it is rapid, however, a greater number of smaller crystals of irregular form grow. The graphite crystals, being separated during the solidification of the remaining liquid mass, will grow (according to Bardenheuer[6]) at every crystal face with about the same rate of crystallisation, assuming them to be separated, until near the solidification point, if liquid is still present. However, with an increased undercooling, remarkable differences in the growth from the single faces of the crystals are observed. The faces, having a greater rate of crystallisation, restrain the others which grow more slowly, the crystals having inferior facets

Fig. 2.

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[6] Bardenheuer, "Stahl und Eisen," 47 (1927), page 861.

because of retarded growth in one or two directions. In the first case, with slow cooling and slight under-cooling, the graphite crystals grow to rounded grains. In the second case, with a serious under-cooling and a higher rate of cooling, graphite crystals grow in the form of thin leaves of varying size. These small leaves surround the surface of the existing austenite crystals and have a twisted form, which in section is worm-like.

Fig. 3.

Situation Summarised.

The form and quantity of the graphite crystals in pig-iron can be differentiated in the following manner:—(1) Graphite in large straight plates (hyper-eutectic graphite) separated whilst the major portion of the mass is liquid; (2) graphite in compact rounded grains separated near the eutectic line if the rate of cooling is slow and the degree of under-cooling is slight; (3) graphite in thin leaves, with spirals corresponding to the surface of the austenite crystals, and separated in condition of under-cooling; (4) graphite in a very fine state and equally disseminated (eutectic graphite) separated if the constitution of the alloy is favourable; and (5) graphite in soft and porous flakes, often adjacent to the cementite, and separated from the solid solution during cooling.

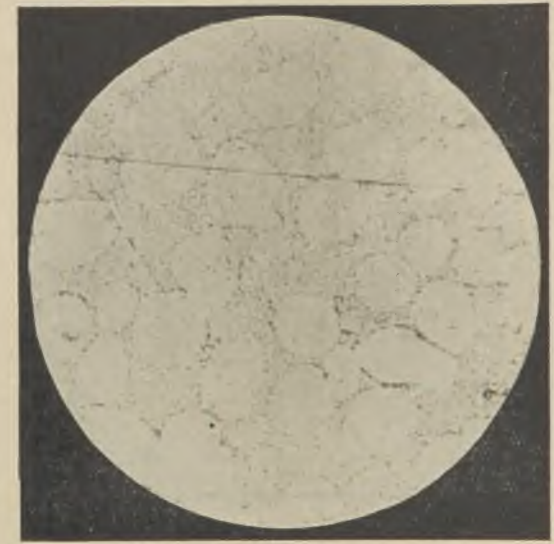

Fig. 4.

Identification of Graphite Types.

These different kinds of graphite may be recognised on the surface of pig-iron microsection. However, they are not usually separated under their "favourable" conditions, and, therefore, all sorts of varieties and transitional states may be found; they are not always seen in their well-defined forms, and sometimes it may be difficult to recognise the kind of graphite, especially as quite often in iron alloys not merely one kind of graphite but several exist. For instance, K. Ishikawa has described two types of graphite in cast iron which he designated as platy graphite and graphite in whirl. The graphite in whirl, he says, is the most desirable kind for cast iron, because it has a moderate strength and its structure is very homogeneous throughout the whole casting. To produce this structure Ishikawa suggested a composition containing about 3.2 per cent C and 1.7 per cent. Si. This kind of graphite is identical with the graphite in thin leaves. M. Hamasumi[6] has studied the question of the origin of the graphite in whirl, with the result that this structure is not always assured even if the indications of

FIG. 5.

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[6] M. Hamasumi, "Sc. Rep. Ser. I," vol. xiii, No. 2. See FOUNDRY TRADE JOURNAL, page 71, *et seq.*, vol. xxxii.

Ishikawa are closely observed. He supposes, therefore, that there are still other influences operating, and he refers to a Paper of K. Honda and T. Murakami[7], who stated that gas, especially carbon monoxide, plays a part in the separation of graphite. One of the results of Hamasumi is that there are two kinds of curly graphite, graphite in whirl and a worm-like[8] graphite. He says the one or the other is separated according to the rate of cooling. It may be seen by this that these authors already saw the possibility of recognising different kinds of graphite.

FIG. 6.

Now it would be very valuable to have a method of determination available by which the different kinds of graphite could be recognised

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[7] K. Honda and T. Murakami, "Sc. Rep.," vol. x, No. 4.
[8] Kikume. Ed. FOUNDRY TRADE JOURNAL.

and quantitatively determined. The analytic method for the determination of graphite only allows the evaluation of the total quantity of graphite contained in the alloy. All experiments to isolate the single crystals of graphite out of the alloy were abortive, and thus it has been impossible to measure the size and quantity of the crystals, or, for example, to derive a basis for the measurement of size, form and number

FIG. 7.

of the crystals prevailing in the alloy. Dr. Franz Roll[9] determined the size and form of the graphite crystals by observing on the surface of a microsection some single lamellæ of graphite by measuring their size and position and after removing a thin layer remeasuring and so on until he ascertained the whole size

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[9] "Die Giesserei," 1928, page 1270.

of the crystal. As a result, he was able to determine by this method the space occupied by the graphite. This method may certainly throw light on this question, but it cannot generally be employed because it is too laborious.

Experimental Evidence.

Therefore, an attempt had to be made to supply an explanation of the graphitic structure from its appearance under the microscope after the manner of Hamasumi. To make an experiment for recognising and determining the different kinds of graphite, it was first tried to make samples containing the graphite in specific well-defined forms, and this was done initially without considering the means which had to be employed.

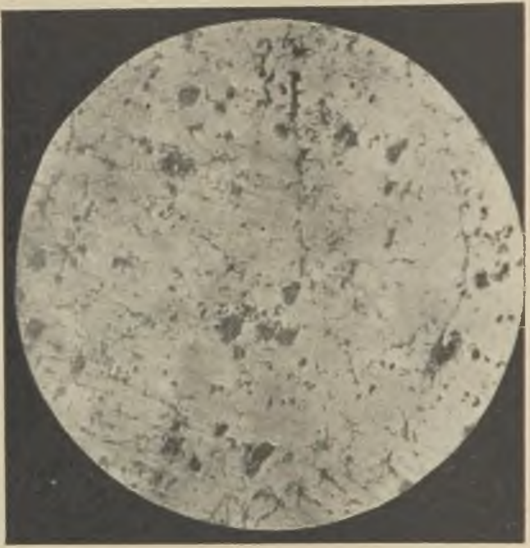

Fig. 8.

Fig. 1[10] is a microsection showing well-defined platy graphite. This graphite interrupts the metallic structure of the alloy in an important manner, and it seems probable that it is separated when the mass, or most of it, is still liquid. This structure is obtained, as the author's experiments have shown, if the iron cools down slowly under an argillaceous slag.

Fig. 9.

The plates of graphite are larger and better defined as the rate of cooling is slow.

Fig. 2 illustrates a sample having the graphite in thin leaves. To obtain this structure a certain relationship between the composition of the alloy and the rate of cooling must be determined. It is not easy to state with existing

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[10] All the microphotographs shown are magnified to 120 diameters and are unetched.

knowledge an exact relation between these two factors.

Fig. 3 shows a microphotograph of an alloy of the same composition as Fig. 2, except that before casting 2 per cent. of copper was added. The graphite is present as thin, crooked leaves, but in addition there are numerous nidæ of graphite.

Fig. 4 shows the graphite in its finest distribution, that is, the graphite eutectic. To obtain this structure, a chemical composition of the alloy confined within certain limits is necessary, but personal experiments have shown that there are other obscure conditions to be taken into account.

Fig. 10.

After having created these standard forms, attention was next directed to the question as to whether the grey qualities of blast-furnace smelted pig-iron show a graphite formation on the surface of a microsection similar to those of the standard forms. A large number of samples from different blast-furnace plants were procured and examined, with the result that the majority did not permit of a rational classification as to whether several kinds of graphite were co-existing. Difficulty was thus presented in deciding which was predominating, or whether the graphite was a transitional product, however, an exact characterisation was deemed to be useless. A certain number of specimens did show a characteristic structure, and a selection of these are included in later illustrations.

FIG. 11.

Interesting Structures from Diverse Sources.

Fig. 5 shows a micro of a sample of a Swedish charcoal pig-iron containing C 4.2, Si 0.64, and

Mn 0.1 per cent. The graphite is in thin, curly leaves. A similar structure is shown in Fig. 6, which is a sample of pig-iron produced in a small blast furnace.

Fig. 7 illustrates a sample of an English pig-iron containing C 3.32, Si 3.28 and Mn 0.58 per cent. Besides graphite in thin leaves, globular graphite is also seen. A similar kind of structure is shown in Fig. 8, a pig-iron with Si 2.64 per cent., from a German plant. A noteworthy microsection showing platy graphite is reproduced in Fig. 9. Fig. 10 shows the structure of an Indian pig-iron with well-defined eutectic graphite.

FIG. 12.

Condition of Graphite and Transverse Strength.

No doubt the mechanical properties of these alloys are definitely dependent upon the type of graphite contained in the structure of the alloy. Platy graphite very largely interrupts the metallic continuity of the alloy, and samples with graphite of this type will have very low strength properties. The strength values increase with an increasing refinement and curliness of the graphite. As an illustration, some examples from practice may be cited. Test-bars, 650 mm. long by 30 mm. dia. (26 in. by 1.2 in.), were cast and tested in the usual manner. The first test-bar contained graphite in platy form, as shown in Fig. 11. This structure was obtained by melting the alloy under an argillaceous slag and cooling it down slowly. The second test-bar contained graphite in the form shown in Fig. 12, that is, in curly striæ. The structure of the third bar is shown in Fig. 13. It was obtained by a still slower cool-

Fig. 13.

ing than previously. The striæ are thinner. The rate of cooling, which must be controlled to obtain these desirable thin striæ of graphite, depends upon the chemical composition, and must be found by experiment. The results of the test are set out in Table I.

The result of all these investigations is that often, in various qualities of grey pig-iron, a certain type of graphite prevails in the structure, and that the kind of graphite separation strongly influences the mechanical properties. If, now, as has been previously stated, a transmission of the properties of the pig-iron to the remelted cast iron can be postulated, full attention must be directed to the kind of graphite in pig-iron as well as in the cast iron itself. Normally, a poor structure in the original pig results in a very slightly improved structure in the cast iron using the normal every-day remelting processes. This explanation conforms with practice, that is, the qualities of grey pig-iron produced in various plants and of the same chemical composition sometimes give, after a remelting, a cast iron of varying qualities. It is the structure, especially the type of graphite in the pig-iron, which is the cause of these differences being not perceptible from the result of chemical analysis. In consequence the evaluation of the quality of pig-iron must include the type of graphite present.

TABLE I.—*Influence of Type of Graphite on Mechanical Strength.*

Test-bar.	Type of graphite.	Deflection in mm.	Transverse strength in kgs. sq./mm.
1	Platy (Fig. 11) ..	17.5	23.5
2	Curly (Fig. 12) ..	12.1	42.0
3	Fine curly (Fig. 13)..	12.3	47.3

Result of Sequestration of Foundries.

When making pig-iron for foundry use, blast-furnace men not only have to ensure that they fulfil the desired chemical composition, but also to endeavour to produce a pig-iron with the most favourable structure for foundry purposes. No doubt, in blast-furnace practice, managers have several means at their disposal to influence the structure of the pig-iron, not only by regulating the speed of cooling of the pig-iron, but by certain measures in the furnace practice itself. As shown above, rate of crystallisation, the number of nuclei and degree of undercooling of the mass play a decisive part in the development of the structure, not only in regard to the graphite itself, but also for all other metallic crystals. No doubt, these influences have no constant value, but are governed by certain laws; for example, speed of cooling, number and kind of constituents, and perhaps others. Honda, as well as Bardenheuer, have stated that gas contained in the liquid charge plays a certain part during the crystallisation. Moreover, it seems evident that the kind and composition of the graphite influences these crystallisation processes. It is a fact, known to blast-furnace men, that pig-iron produced with a slag rich in lime is very coarse grained, whilst those made under a slag rich in silica is fine grained. It seems that an argillaceous slag also influences the structure of the alloy in a sense that platy graphite predominates. As experience shows that the fine curly graphite often occurs in pig-iron alloys produced in charcoal blast furnaces or in small furnaces, it seems probable that still other influences, such as the temperature of the blast, the temperature in the hearth or the period of the working of the charge, are important.

The experience that the quality of the pig-iron is not solely expressed by chemical analysis has long been well known when blast furnaces and foundries were a composite plant. This phase lost its force when, through the growth of industry, the sequestration of blast furnaces and foundries gradually took place. To-day, direct contact between pig-iron manufacture and the quality of cast iron must be re-established.

WRITTEN CONTRIBUTION.

Dr. A. L. Norbury (British Cast Iron Research Association) wrote that he was greatly in sympathy with the author when he stressed the important effect that the size and number of the graphite flakes in the pig-iron used had on the size and number of the graphite flakes in the resulting casting. He had expressed somewhat similar views in a Paper the previous month to the Iron and Steel Institute.*

By suitably varying the melting conditions (in crucible melts) it was possible to produce at will castings containing very coarse graphite flakes or, alternatively, castings containing the fine kind of graphite that the author called eutectic graphite, and to produce both types from a given pig-iron without any material alteration in chemical composition. He did not find, however, that refining the graphite increased the strength in all cases. For instance, in pearlitic castings, refinement of the graphite beyond a certain stage resulted in the production of ferrite in place of pearlite, and this lowered the strength more than the refining of the graphite increased it.

Prof. Diepschlag, in reply to Dr. Norbury's contribution, wrote that, considering the relations between the structure of a section of a grey-iron alloy and its mechanical properties, it must be borne in mind that one sees only the surface of the picture, or a small area of the test-bar. That is only a small part of the whole material, and the conclusion may not be quite true in all cases that the structure seen in the section must necessarily represent the whole specimen. The average results of a certain number of tests only give the correct approximation of these relations.

He thought it quite probable that with a certain degree of distribution and refinement of the graphite—especially graphite in eutectic form—the mechanical properties of the metallic

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* Journal, Iron and Steel Institute, Vol. CXIX, p. 443.

crystalline bodies prevail over those of the graphite, and give the alloy its character. It is very useful that Dr. Norbury has ascertained the limit of the prevailing influence of the graphite, because it is just in this region one would expect to find the grey-iron alloys with both the best mechanical properties and good pouring qualities.

THE INFLUENCE OF CHROMIUM IN CAST IRON.

By J. W. Donaldson. D.Sc., A.I.C. (Associate Member).

Introduction.

In a recent investigation carried out by the author, and presented as the French Exchange Paper on behalf of the Institute of British Foundrymen in 1928,[1] the influences of total carbon, silicon, phosphorus and manganese respectively on the carbon decomposition and volume changes of cast iron were determined. These investigations were continued to determine the influence of various special element-additions, and in the present Paper the influence of chromium on heat-resisting and other properties is considered.

The use of chromium in cast iron was first experimented with by Keep,[2] who added chromium to the extent of 2 per cent., and found that there was a slight increase in strength up to 1 per cent., then a decrease, while the shrinkage was increased when less than 1 per cent. was added. Campion,[3] in a later investigation, found that 1 per cent. of chromium increased the strength and hardness, and also the amount of combined carbon. Hurst[4] states that in an iron containing 1 per cent. of silicon an addition of 0.9 per cent. chromium rendered the fracture quite mottled, and that 4 per cent. added to an iron containing 1.5 per cent. silicon rendered the fracture perfectly white, and that drastic annealing at 900 to 950 deg. C. failed to produce graphite.

Smalley,[5] in his systematic investigations with special element additions to cast iron, added

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[1] J. W. Donaldson, Bull. de l'Assoc. Tech. de Fonderie, 1928, vol. 2, p. 257.

[2] W. J. Keep, "Cast Iron," 1916, p. 212.

[3] A. Campion, "Foundry Trade Journal," 1918, vol. 20, p. 467.

[4] J. E. Hurst, Metallurgy of Cast Iron, p. 139.

[5] O. Smalley, Proc. Inst. of Brit. Found., 1922–23, vol 16 p. 495.

chromium to ordinary grey cast iron and to cylinder iron. The influence of chromium additions of 0.11 and 0.15 per cent. respectively was to increase the strength and hardness slightly, while with the larger addition of 0.78 per cent. to the ordinary iron the tensile strength fell, the transverse strength was affected slightly, and the Brinell hardness increased. A similar addition of chromium to the cylinder iron produced an increased transverse strength and Brinell hardness, but little change in the tensile strength. Experiments by Piwowarsky[6] show that with up

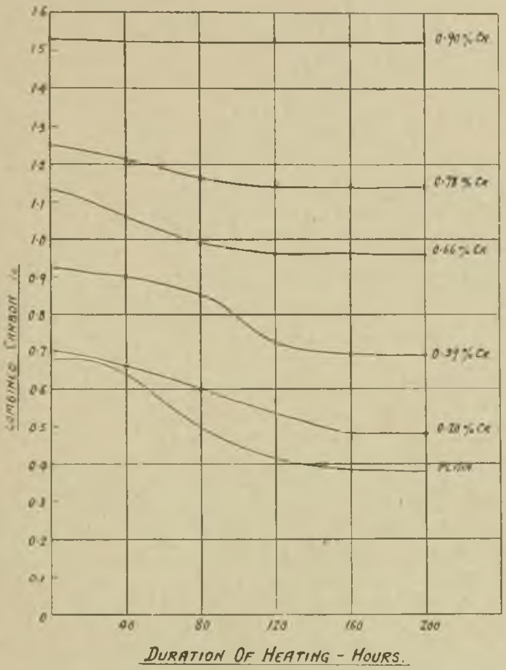

FIG. 1.—HEAT TREATMENT AT 450 DEG. C.

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[6] E. PIWOWARSKY, "Foundry Trade Journal," 1925, vol. 31, pp. 331–34, 345–46.

to 0.5 per cent. of chromium the strength and shock-resisting properties of cast iron are increased to the extent of about 10 per cent., while the hardness increases from 20 to 25 per cent. Hamasumi's[7] investigations show that the addition of 0.4 per cent. of chromium raises the tensile strength of cast iron from 16.5 to 22.8 tons per sq. in. without materially altering the structure, and that cast iron is not rendered brittle by chromium up to this amount.

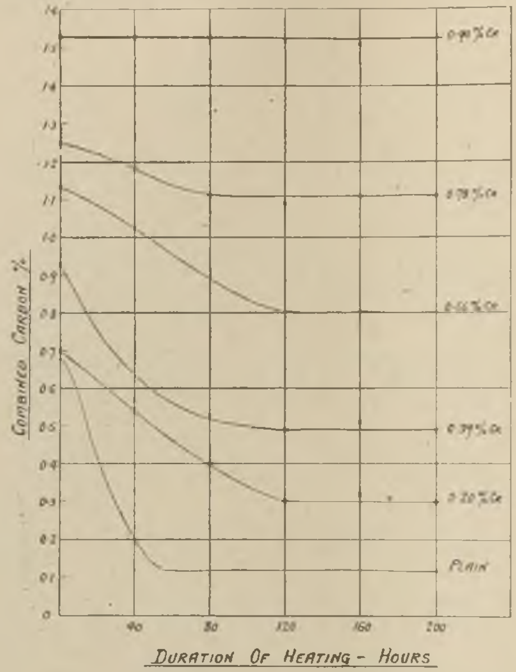

Fig. 2.—Heat Treatment at 550 deg. C.

The results of these investigations establish denitely that 0.5 per cent. of chromium in the

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[7] H. Hamasumi, "Foundry Trade Journal," 1925, vol. 32, p. 71.

presence of 1 to 2 per cent. of silicon increases the tensile and transverse strengths and the hardness of grey cast iron. This increase is brought about by the chromium preventing the formation of graphite and producing a more stable double carbide of iron, and chromium. With the exception of Hurst's work, however, little has been done on the heat-resisting properties of chromium cast irons, and it was with those properties and the thermal and corrosion properties that the following experiments deal.

Table I.—*Analyses and Tests.*

Mark.	P	Cr 1.	Cr 2.	Cr 3.	Cr 4.	Cr 5.
T.C., per cent. ..	3.16	3.19	3.17	3.16	3.24	3.21
C.C., per cent. ..	0.68	0.70	0.93	1.13	1.25	1.53
Gr, per cent. ..	2.48	2.49	2.24	2.03	1.99	1.68
Si, per cent. ..	1.48	1.42	1.40	1.42	1.60	1.48
S, per cent. ..	0.054	0.049	0.040	0.07	0.058	0.041
P, per cent. ..	0.70	0.70	0.69	0.68	0.77	0.66
Mn, per cent. ..	0.97	0.96	0.97	1.00	0.95	0.95
Cr, per cent. ..	Nil	0.20	0.39	0.66	0.78	0.90
M.S., tons per sq. in.	16.6	17.0	18.4	17.8	15.8	13.4
Br. No.	223	235	248	255	262	277

Cast Irons Used.

To an ordinary cast iron containing approximately 3.20 per cent. of carbon, 1.5 per cent. silicon, 0.7 per cent. phosphorus and 1.0 per cent. manganese, chromium was added to obtain a series of irons containing 0.20, 0.39, 0.66, 0.78 and 0.90 per cent. of chromium respectively. The exact composition of these irons and the plain iron, together with their tensile strengths and Brinell hardness, is given in Table I.

As the chromium increased up to 0.39 per cent. the tensile strength increased from 16.6 tons to a maximum of 18.4 tons, decreasing with further chromium additions to 13.4 tons with 0.90 per cent. chromium. The Brinell hardness increased uniformly from 223 in the plain iron to 277 in the 0.9 per cent. chromium iron. The irons containing over 0.4 per cent. chromium have a mottled fracture, and under the microscope showed the presence of free cementite. Difficulty was also experienced in machining those irons.

The irons were all cast in dry-sand moulds into bars 16 in. by $1\frac{1}{8}$ in. dia. The chromium was added in the ladle, as 65 per cent. ferrochrome, and the irons were re-melted in crucibles before casting to render them uniform. They were all cast at approximately the same temperature and under similar conditions.

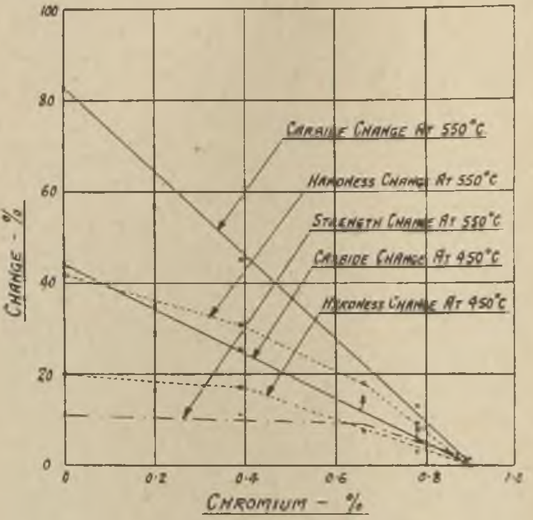

Fig. 3.—Percentage Changes.

Heat-Treatment Changes.

The methods of testing were those adopted in previous tests with plain cast irons. Bars from each of the irons were heated in an electric resistance furnace for 8 hours per day to 450 deg. C., cooled overnight, and re-heated on the following day to the same temperature. At the end of each 5 days' or 40 hours' heating, the total and combined carbon of each iron was

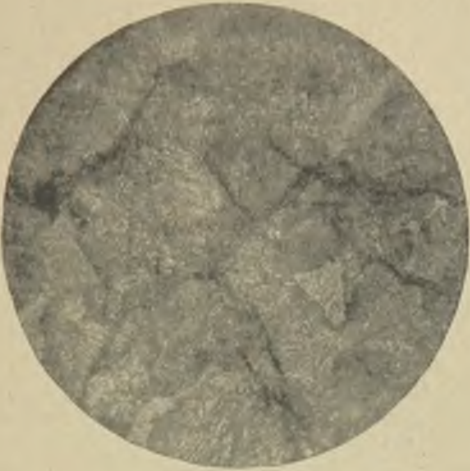

Fig. 4.—P. As Cast. × 540.

Fig. 5.—P. Heat Treated for 200 hrs. at 550 deg. C. × 540.

estimated, the Brinell-hardness determined, and, where material permitted, the tensile strength determined. Similar tests were carried out on bars at 550 deg. C. The results are given in Tables II and III and represented graphically

TABLE II.—*Heat Treatment at* 450 *deg. C.*

Chromium irons.		Duration of heating in hours.					
Cr per cent.	—	0	40	80	120	160	200
Plain ..	T.C. per cent.	3.16	3.17	3.17	3.19	3.13	3.15
	C.C. per cent.	0.68	0.64	0.48	0.43	0.38	0.38
	Tens. M.S...	16.6	16.2	15.7	15.3	15.4	15.5
	Br. No. ..	223	212	197	183	183	179
Cr 1, 0.20 per cent.	T.C. per cent.	3.19	3.18	3.16	3.16	3.13	3.21
	C.C. per cent.	0.70	0.66	0.60	0.57	0.49	0.50
	Tens. M.S...	17.0	16.8	16.4	—	16.0	15.9
	Br. No. ..	235	223	212	197	197	197
Cr 2, 0.39 per cent.	T.C. per cent.	3.17	3.18	3.17	3.18	3.16	3.20
	C.C. per cent.	0.93	0.90	0.85	0.72	0.69	0.69
	Tens. M.S...	18.4	17.9	17.5	17.4	17.2	17.3
	Br. No. ..	248	235	212	207	201	207
Cr 3, 0.66 per cent.	T.C. per cent.	3.16	3.14	3.16	3.14	3.10	3.09
	C.C. per cent.	1.13	1.06	0.99	0.96	0.95	0.96
	Tens. M.S...	17.8	—	—	—	—	—
	Br. No. ..	255	241	235	235	235	235
Cr 4, 0.78 per cent.	T.C. per cent.	3.24	3.30	3.20	3.26	3.28	3.29
	C.C. per cent.	1.25	1.21	1.16	1.15	1.14	1.14
	Tens. M.S...	15.8	—	—	—	—	—
	Br. No. ..	262	255	255	255	255	255
Cr 5, 0.90 per cent.	T.C. per cent.	3.21	3.16	3.24	3.20	3.20	3.21
	C.C. per cent.	1.53	1.51	1.54	1.53	1.52	1.54
	Tens. M.S...	13.4	—	—	—	—	—
	Br. No. ..	277	277	277	227	277	777

in Figs. 1 and 2, while the percentage changes produced by all the irons are given in Table IV and graphically in Fig. 3.

Consideration of Table II and Fig. 1, which deal with the experiments carried out at 450 deg. C., show that as the chromium content increases the stability of the combined carbon under temperature is increased. In the plain iron decomposition takes place to the extent of 44 per cent. and is more or less complete after 160 hours' heating. With the addition of 0.2 per cent. of chromium decomposition is more uniform although the amount is less, 28 per cent., and is complete after 160 hours' heating. The 0.39 per cent. chromium iron shows a 26 per cent. decomposition after 120 hours, while additions of 0.66 and 0.78 per cent. chromium reduce

TABLE III.—*Heat Treatment at 550 deg. C.*

Chromium irons.		Duration of heating in hours.					
Cr per cent.	—	0	40	80	120	160	200
Plain ..	T.C. per cent.	3.16	3.13	3.16	3.15	3.15	3.14
	C.C. per cent.	0.68	0.12	0.11	0.09	0.12	0.12
	Tens. M.S...	16.6	15.8	15.1	14.8	14.6	14.8
	Br. No. ..	223	138	129	129	125	129
Cr 1, 0.20 per cent.	T.C per cent.	3.19	3.13	3.17	3.15	3.17	3.17
	C.C. per cent.	0.70	0.54	0.40	0.30	0.32	0.30
	Tens. M.S...	17.0	16.3	15.8	15.3	15.1	15.1
	Br. No. ..	235	197	171	152	152	152
Cr 2, 0.39 per cent.	T.C. per cent.	3.17	3.16	3.22	3.20	3.15	3.21
	C.C. per cent.	0.93	0.57	0.53	0.49	0.51	0.49
	Tens. M.S...	18.4	17.9	17.4	16.8	16.4	16.4
	Br. No. ..	248	207	174	170	170	170
Cr 3, 0.66 per cent.	T.C. per cent.	3.16	3.17	3.10	3.12	3.15	3.13
	C.C. per cent.	1.13	1.02	0.89	0.79	0.80	0.80
	Tens. M.S...	17.8	—	—	—	—	16.3
	Br. No. ..	255	235	217	212	212	212
Cr 4, 0.78 per cent.	T.C. per cent.	3.24	3.23	3.27	3.21	3.19	3.22
	C.C. per cent.	1.25	1.18	1.11	1.09	1.11	1.11
	Tens. M.S...	15.8	—	—	—	—	15.0
	Br. No. ..	262	255	248	248	248	248
Cr 5, 0.90 per cent.	T.C. per cent.	3.21	3.20	3.20	3.22	3.25	3.20
	C.C. per cent.	1.53	1.53	1.53	1.52	1.51	1.53
	Tens. M.S...	13.4	—	—	—	—	13.2
	Br. No. ..	277	277	277	277	277	277

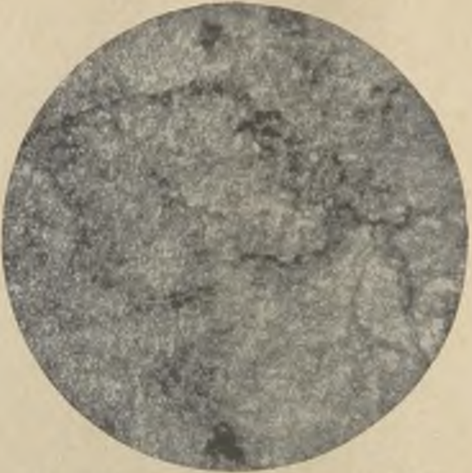

Fig. 6.—Cr. 2. As Cast. × 540.

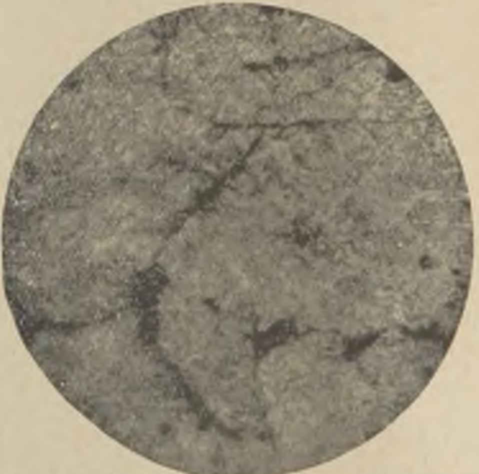

Fig. 7.—Cr. 2. Heat Treated for 200 hrs. at 550 deg. C. × 540.

the amount of decomposition still further to 15 and 9 per cent., equilibrium conditions being attained after 80 and 40 hours' heating respectively. With 0.90 per cent. chromium the combined carbon remains unchanged after 200 hours' heating and the Brinell-hardness decrease, which has diminished from 20 per cent. in the plain iron as the chromium increases, is *nil*.

TABLE IV.—*Percentage Changes at* 450 *deg. and* 550 *deg. C.*

Temperature.	Iron.	Duration of heating in hrs.	C.C. decrease.	Tens. strength decrease.	Brinell hardness decrease.
—	—	—	Per cent.	Per cent.	Per cent.
450 deg. C.	Plain	160	44.1	6.6	19.8
	Cr 1, 0.20 per cent. Cr ..	120	28.6	6.5	16.2
	Cr 2, 0.39 per cent. Cr ..	120	25.8	6.0	16.5
	Cr 3, 0.66 per cent. Cr ..	80	15.1	—	7.8
	Cr 4, 0.78 per cent. Cr ..	40	8.8	—	2.7
	Cr 5, 0.90 per cent. Cr ..	200	Nil	—	Nil
550 deg. C.	Plain	40	82.4	10.9	42.1
	Cr 1, 0.20 per cent. Cr ..	120	57.1	11.2	35.3
	Cr 2, 0.39 per cent. Cr ..	120	47.3	10.9	31.4
	Cr 3, 0.66 per cent. Cr ..	80	29.2	8.4	16.8
	Cr 4, 0.78 per cent. Cr ..	80	11.2	5.1	5.4
	Cr 5, 0.90 per cent. Cr ..	200	Nil	1.5	Nil

Similarly at 550 deg. C., with 0.90 per cent. chromium, there is no change in the combined carbon content and the Brinell-hardness remains the same, the tensile strength diminishing by 1.5 per cent. (Table III and Fig. 2). The other chromium additions of 0.20, 0.39, 0.66 and 0.78 per cent. chromium produce combined carbon decompositions of 57, 47, 29 and 11 per cent. respectively, which is considerably less than the 82 per cent. decomposition in the plain iron. This decrease in the combined carbon content is reflected in the strength and hardness properties, particularly with additions of over 0.4 per cent. chromium. The rate of decomposition is slower in the chromium irons, equilibrium conditions being attained after approximately 100 hours' heating, whereas in the plain iron the decomposition that takes place is complete after 40 hours.

Fig. 8.—Cr. 5. As Cast. × 540.

These results, obtained by chemical and mechanical tests, are confirmed by microscopic examination. Figs. 4 and 5 show the structure of the plain iron as cast and after 200 hours' heat treatment at 550 deg. C. After treatment the pearlite shows considerable decomposition, the graphite is increased in size, and there is oxidation of the iron in the vicinity of the graphite. In the 0.39 per cent. chromium iron, Figs. 6 and 7, cast and heat-treated, the amount of pearlite unaffected is considerably greater; the graphite shows little change with little or no oxidation of iron. The two microphotos of the 0.90 per cent. chromium iron, Fig. 8, as cast, and Fig. 9, heat-treated, show practically no variation in structure.

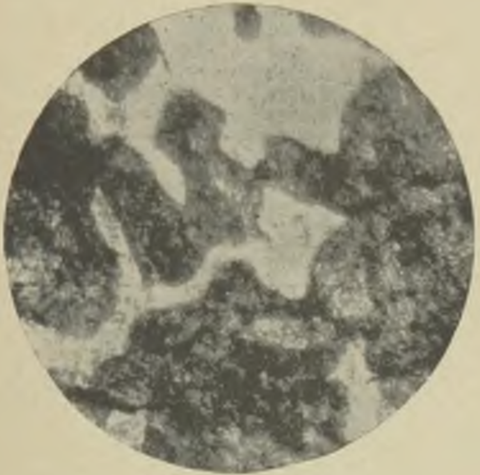

Fig. 9.—Cr. 5. Heat Treated for 200 hrs. at 550 deg. C. × 540.

Summing up generally, it will be noted, Fig. 3, that as the chromium content of grey cast iron is increased, the influence of the chromium is to stabilise the combined carbon, both at 450 and 550 deg. C., complete stability being attained with 0.90 per cent. of chromium. This increased stability of the combined carbon under temperature is no doubt due to the presence, according to the recent work of Westgren,

TABLE V.—*Volume Changes.*

Cr. Per cent.	No. of heatings.	Length. In.	Dia. In.	Vol. Cub. in.	Change. Per cent.
Nil	0	6.0000	1.0000	4.710	—
	5	6.0004	1.0005	4.715	0.11
	10	6.0011	1.0006	4.716	0.13
	15	6.0010	1.0006	4.716	0.13
	20	6.0011	1.0006	4.716	0.13
	25	6.0011	1.0006	4.716	0.13
0.20	0	6.0000	1.0000	4.710	—
	5	5.9999	0.9998	4.708	0.04
	10	5.9997	0.9997	4.707	0.06
	15	5.9990	0.9993	4.703	0.15
	20	5.9988	0.9994	4.703	0.15
	25	5.9988	0.9994	4.703	0.15
0.39	0	6.0000	1.0000	4.710	—
	5	5.9992	0.9998	4.707	0.06
	10	5.9985	0.9997	4.706	0.08
	15	5.9979	0.9992	4.701	0.18
	20	5.9980	0.9989	4.698	0.25
	25	5.9978	0.9988	4.697	0.27
0.66	0	6.0000	1.0000	4.710	—
	5	6.0004	1.0001	4.711	+0.02
	10	6.0000	0.9999	4.709	−0.02
	15	5.9998	0.9997	4.707	0.06
	20	5.9998	0.9997	4.707	0.06
	25	5.9997	0.9997	4.707	0.06
0.78	0	6.0000	1.0000	4.710	—
	5	6.0001	1.0000	4.710	—
	10	6.0000	1.0000	4.710	—
	15	5.9997	0.9997	4.706	0.06
	20	5.9989	0.9993	4.703	0.15
	25	5.9984	0.9992	4.701	0.18
0.90	0	6.0000	1.0000	4.710	—
	5	5.9998	0.9998	4.708	0.04
	10	5.9995	0.9995	4.705	0.10
	15	5.9992	0.9990	4.700	0.21
	20	5.9990	0.9989	4.699	0.23
	25	5.9991	0.9989	4.699	0.23

Phragmen and Negresco,[8] of chromium in the cementite of the pearlite and affects the heat-resisting properties of the irons enabling them to retain both their strength and hardness.

Volume Changes.

The volume changes were carried out on bars accurately machined to 6 in. long by 1 in. dia. These were heated in an electric-resistance furnace to 550 deg. for eight hours per day, cooled over night and reheated the following day. At the end of every 40 hours' heating the bars were measured and the volumes determined. The results are given in Table V and Fig. 10.

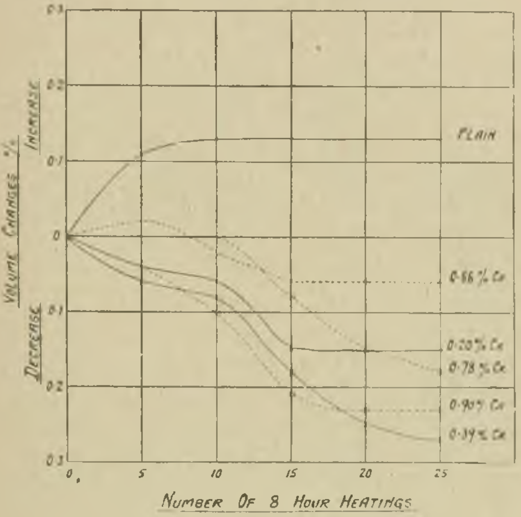

FIG. 10.—VOLUME CHANGES.

Consideration of these results show that while the plain iron has a volume increase, all the irons containing chromium show contraction after prolonged heating. The irons containing

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[8] A. WESTGREN, G. PHRAGMEN, and TR. NEGRESCO, Journ. Iron and Steel Inst., 1928, vol. 1, p. 383.

0.20 and 0.39 per cent. of chromium contract to the extent of 0.15 and 0.27 per cent. respectively. Further addition of chromium to 0.66 per cent. reduces the contraction to 0.06 per cent., while still further additions to 0.78 and 0.90 per cent. increase this reduced contraction to 0.18 and 0.23 per cent. respectively.

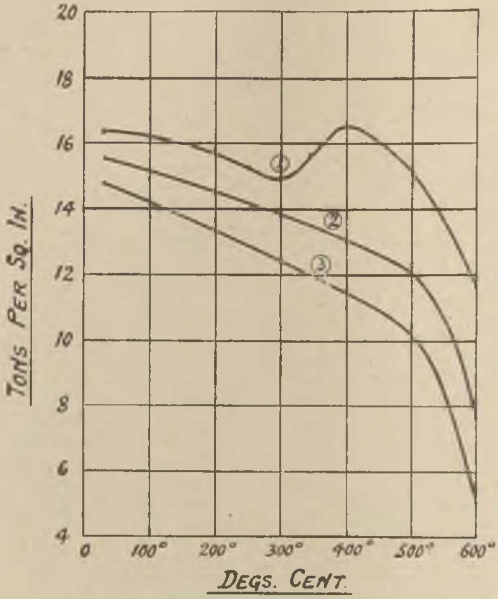

Fig. 11.—Plain Iron.

(1) As Cast.
(2) Heat Treated for 200 hrs. at 450 deg. C.
(3) Heat Treated for 200 hrs. at 550 deg. C.

These results appear to be very erratic and at first, it is difficult to conceive why the increase of chromium from 0.39 to 0.66 per cent. should produce a lower volume contraction.

It is possible that the explanation may be found by considering the general structure of the irons. The two lower-chromium irons are essentially grey cast irons having a structure consisting of pearlite and graphite with a small amount of free ferrite, whereas the structure of the higher-chromium irons consist of pearlite, graphite and free cementite. Experiments have shown that white cast irons containing large proportions of free cementite and no graphite are not affected by volume changes, so that the mottled nature of the three higher-chromium irons may have slowed down the volume contraction-changes due to the chromium.

Considering next the contraction-changes due to the chromium. This phenomenon, as yet, cannot be explained or defined. Andrew and Hyman[9] state as a result of their work on the growth of special cast irons at 900 deg. C., that chromium when added in sufficient quantity (1.5 per cent.) considerably retards and reduces growth but does not prevent it; and the author has found that heating the 0.39 per cent. chromium iron to 800 deg. C. produces a small volume increase. Growth in grey cast iron is produced by decomposition of the combined carbon of the pearlite and increase in the size of the graphite lamellæ and these changes may or may not be followed by oxidation of the iron in the vicinity of the graphite. All the chromium irons are subject to varying degrees of combined carbon decomposition excepting the 0.90 per cent. iron, but microscopic examination shows little or no change in the nature of the graphite and no oxidation. It would, therefore, appear that the contraction change which takes place at temperatures below the critical-range is in some manner due to the chromium and exceed the volume change produced by combined carbon decomposition. What the nature of the change is cannot be determined by ordinary microscopic investigations and is probably molecular.

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[9] J. H. Andrew and H. Hyman, Jour. Iron and Steel Inst., 1924, vol. 1, p. 451.

From the results obtained it would, therefore, appear that two main factors operate in the volume changes of those chromium irons. First there is the contraction phenomenon due to the chromium, as yet not explainable; and second, the change due to the structural nature of the irons. This latter point, the growth of a purely grey cast iron as compared with the growth of a mottled cast iron of a similar composition and the omitting of elements, such as chromium, which may produce complication, requires further

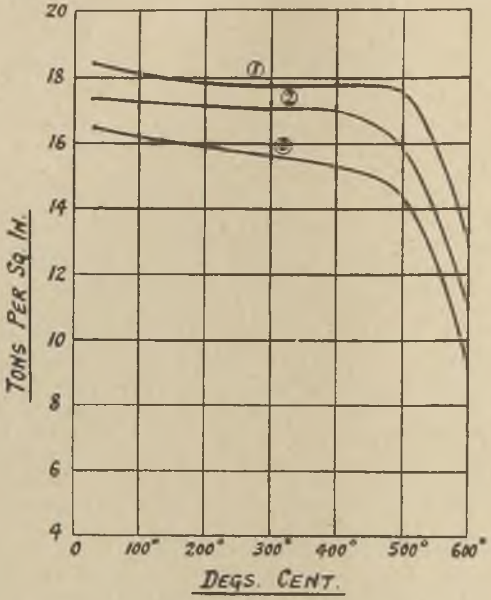

FIG. 12.—CHROMIUM IRON, 0.39 PER CENT. CR.

(1) AS CAST.
(2) HEAT TREATED FOR 200 HRS. AT 450 DEG. C.
(3) HEAT TREATED FOR 200 HRS. AT 550 DEG. C.

investigation, and might also explain the erratic volume changes that are known to occur in irons of a border-line composition.

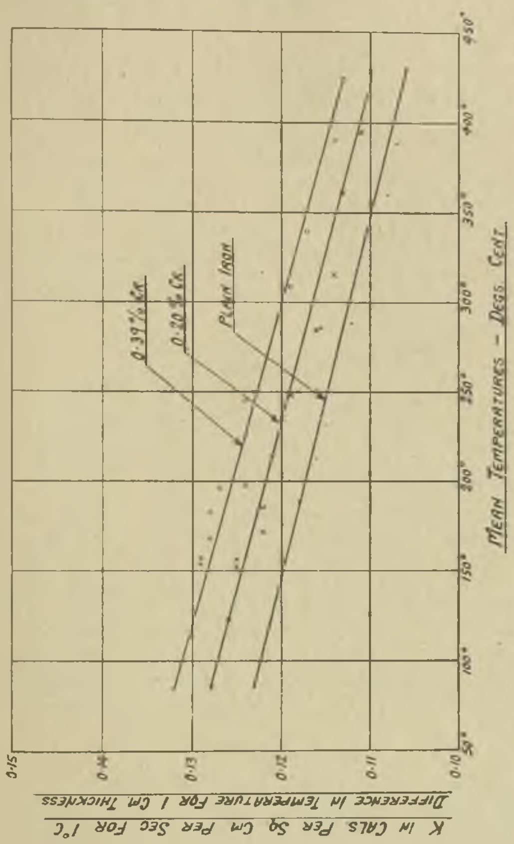

FIG. 13.—THERMAL CONDUCTIVITIES OF PLAIN AND CHROMIUM IRONS. AS CAST.

Elevated Temperature Tests.

The strength of plain and chromium cast irons at elevated temperatures has been dealt with by the author in his Paper on "Special Cast

Irons,"[10] and the curves obtained for the plain iron and the iron containing 0.39 per cent. of chromium are reproduced in Figs. 11 and 12. It will be seen that the effect of this chromium addition is to increase the strength of cast iron at elevated temperatures, both in its " as cast " and heat-treated conditions. The strength is maintained to 500 deg. C., whereas in the iron containing no chromium it falls off at 400 deg. C. The breaking stresses of the two irons, when tested at 400 deg. after 200 hours' heat-treatment at 550 deg. C., are 11.0 and 15.6 tons per sq. in. respectively, and show the beneficial effects of a small chromium addition. It will also be noted that the depression occurring in the " as cast " of the plain iron is practically eliminated by the chromium.

Thermal Conductivity.

In a like manner the thermal conductivity of the plain iron and the two chromium irons containing 0.20 and 0.39 per cent. of chromium have been fully dealt with in a previous Paper on " The Thermal Conductivities of Grey Cast Irons,"[11] and again the curves obtained are reproduced in Fig. 13. These curves show that the thermal conductivity value for the plain iron at 100 deg. C. of 0.122 is increased by the chromium additions to 0.127 and 0.132, and at 400 deg. C. the K values of the two chromium irons are 0.111 and 0.114, as against 0.107 for the plain iron. Chromium, therefore, tends to increase the thermal conductivity of grey cast iron.

Corrosion Tests.

In view of the many advantages which have been gained in steel in reducing corrosion by additions of chromium, it was considered of interest to subject the various chromium irons, together with the plain iron, to a series of corrosion tests, to determine, if possible, if such small

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[10] J. W. Donaldson, Proc. Inst. Brit. Found., 1924–25, vol. 18, p. 89.

[11] J. W. Donaldson, Proc. Inst. Mech. Engineers 1928, No. 4.

additions of chromium had any influence on cast iron.

Test-pieces, 25 mm. long by 20 mm. dia., were machined from each iron, buffed, polished and immersed in the following solutions for 28 days at 60 deg. F. (15 deg. C.). The solutions were N/10 hydrochloric acid, N/10 nitric acid, N/10 acetic acid, tap water, sea water, and N/10 ammonium chloride. At the end of the period the test-pieces were washed, dried in alcohol and the loss in weight determined. Three tests were carried out on each iron in each solution, and from the average weights obtained the loss in weight per 100 sq. cm. determined. The results were given in Table VI and Figs. 14 and 15.

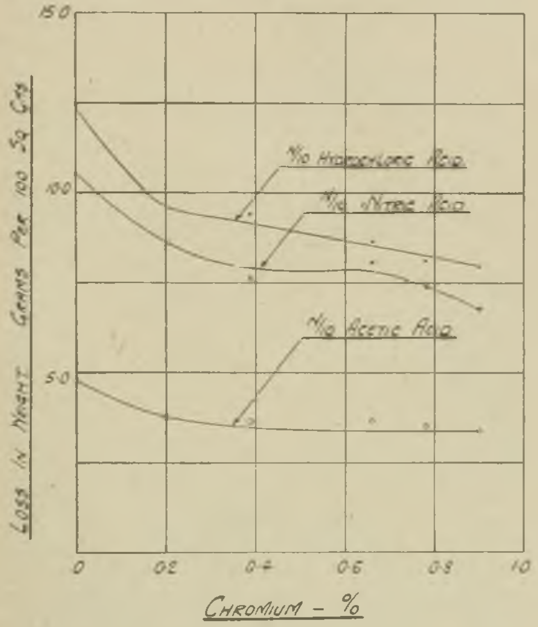

FIG. 14.—CORROSION TESTS.

The general influence of the chromium additions is to effect a slight beneficial effect as regards resistance to corrosion. This influence is most marked in the case of sea water, and least noticeable with tap water, N/10 acetic acid and N/10 ammonium chloride. The influence of chromium in retarding the corrosion in all cases follows the addition of 0.20 per cent. chromium and increases slowly as the chromium content increases.

TABLE VI.—*Corrosion Tests.*

Loss in Weight. Grams per 100 *sq. cms. of Surface Area, after* 28 *days.*

Cast iron.	Corroding media.					
	N/10 HCl	N/10 HNO_3	N/10 HA	Tap water.	Sea water.	N/10 AmCl
Plain ..	12.48	10.51	4.77	0.30	0.78	0.84
0.20 per cent. Cr	9.53	8.62	3.72	0.23	0.42	0.69
0.39 per cent. Cr	9.48	7.68	3.60	0.25	0.32	0.72
0.66 per cent. Cr	8.67	8.06	3.67	0.22	0.35	0.73
0.78 per cent. Cr	8.09	7.31	3.51	0.21	0.31	0.68
0.90 per cent. Cr	7.91	6.75	3.39	0.21	0.29	0.65

These results are somewhat in accordance with the results obtained by Kotzschke and Piwowarsky[12] in their series of experiments on the corrosion of cast iron. These investigators found that chromium exerted a beneficial influence on the resistance of cast iron to acids, when present to the extent of 1 per cent., but with castings subjected to the rusting effect of solutions of salts, chromium is of little advantage. In general it would appear as if chromium would have to be present in considerably larger amounts than 0.90 per cent. to exert any marked influence on the corrosion properties of cast iron.

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[12] P. KOTZSCHKE and E. PIWOWARSKY, Arch. Eisenhüttenwes 1928-29, vol. 2, p. 333.

Summary.

Chromium added to grey cast iron in quantities up to 0.90 per cent. increases the stability of the combined carbon at temperatures up to 550 deg. C. This increase in stability is probably due to the presence of chromium carbide in the cementite of the pearlite, and is reflected in the increased strength both at ordinary and elevated temperatures and in the Brinell hardness. Better heat-resisting irons are, therefore, obtained, but there is difficulty in machining irons with over 0.4 per cent. of chromium.

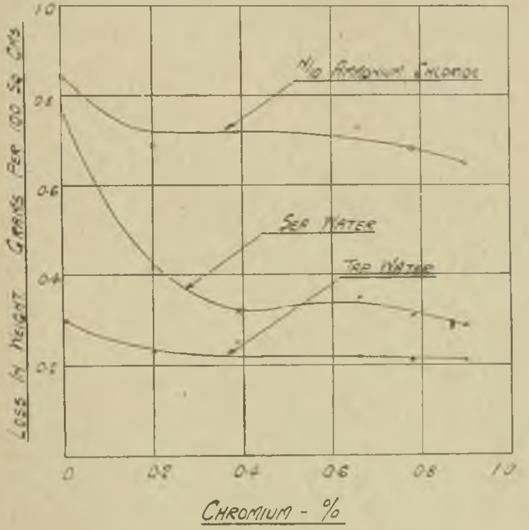


Fig. 15.—Corrosion Tests.

The influence of chromium on volume changes at temperatures below the critical range is erratic, but the general effect is to produce a contraction. The nature of this contraction is difficult to explain or define. With chromium up to 0.4 per cent. the thermal conductivity is increased by about 8 per cent.

Small additions of chromium reduce very slightly the corrosion of grey cast iron. The effect is most noticeable with sea water, and to a lesser extent with strong acids. With weak acid, tap water, and ammonium chloride little advantage is gained.

The author thanks Mr. James Brown, C.B.E., and the other directors of Scotts' Shipbuilding and Engineering Company, Limited, Greenock, for permission to carry out the above investigations.

THE INFLUENCE OF MANGANESE IN CAST IRON.

By A. L. Norbury D.Sc. (Member).

Introduction.

Considerable differences of opinion exist as to the influence of manganese on the chilling properties of cast iron. Some hold the view that manganese decreases the tendency to chill, others that it increases the tendency to chill. For instance, many manufacturers of chilled rolls find that manganese additions decrease the depth of chill, while many manufacturers of grey-iron castings find that manganese increases the tendency to chill. Evidence is available in support of each view. Some published results, for instance, indicate (1) that as the manganese content of a grey iron (containing only traces, *e.g.*, 0.01 per cent. sulphur) is increased from 0.0 per cent. to about 0.3 per cent. manganese it exerts a graphitising action on the cementite. Other results indicate (2) that additions of 1 per cent. and upwards of manganese exert a chilling action.

Experiments have been carried out to check the above apparently conflicting results and have confirmed them. The explanation appears, however, to be that the graphitising action of manganese only occurs in low-manganese irons and is an indirect one due to its capacity for combining with sulphur. The presence of only traces (*e.g.*, 0.01 per cent.) of free sulphur is sufficient to prevent the graphitisation of considerable quantities of cementite and an excess of manganese (above that required to form MnS) is required to neutralise the stabilising action of such sulphur on the cementite. Apart from this indirect action, manganese always exerts a stabilising action on cementite. Evidence bearing firstly on the graphitising action, and secondly on the chilling action of manganese is summarised below.

Graphitising Action of Manganese.

Hague and Turner[1] were apparently the first to draw attention to the graphitising action of small quantities of manganese. They found that increasing the manganese content of a grey iron (T.C. 2.6 per cent., Si 3.0 per cent., P trace, S trace) from 0.03 to 0.5 per cent. caused the following marked differences: (a) the combined-carbon content fell from 1.03 to 0.22 per cent.; (b) an expansion occurred at 687 deg. C. on cooling (without manganese no expansion was obtained at these low temperatures), and (c) the pearlite matrix was largely decomposed into ferrite and graphite.

Coe[2] confirmed the above result, and in a grey iron containing total carbon 2.8 per cent., Si 1.8 per cent., S trace, P trace, found that with manganese 0.03 per cent. there were numerous small crystals of cementite, while with manganese 0.18 per cent. and upwards, the crystals of cementite were absent and a considerable portion of the pearlite had been decomposed into ferrite and graphite.

Data from papers by Coe[3] and Wüst and Meissner[4] showing the effect of small additions of manganese in decreasing the combined-carbon contents of grey irons have been plotted in Fig. 1. It will be seen that increasing the manganese content from 0.03 per cent. to about 0.3 per cent. in these grey irons causes a fall in combined carbon in every case—which is in accordance with the findings of Hague and Turner, and Coe. Further additions of manganese cause a slight increase in the combined-carbon content.

These results have been confirmed by casting similar series of grey-iron bars containing increasing quantities of manganese between 0.0 and 0.5 per cent. In each case as the manganese was increased from 0.0 per cent. to about 0.3 per cent., the combined carbon fell from about 1.3 to below 0.9 per cent. Some analyses showing this are given in Table I.

The graphitising action of manganese, if increased from 0.0 to 0.3 per cent. or over, on the secondary cementite in grey iron is confirmed in a somewhat different manner by means of the data plotted in Figs. 2A and 2B. These figures show the combined-carbon contents of 1.2 in. diameter sand-cast bars of various carbon and silicon contents. The vertical position of each dot in these figures indicates the total-carbon content, while the horizontal position indicates the silicon content, and against each dot is written the combined-carbon content.

TABLE I.—*Effect of small percentages of manganese on combined contents of 1.2 dia. sand-cast grey-iron bars.*

Series A.

No. of test bar	1.	2.	3.
C. C.	1.29	0.91	0.54
Mn	0.02	0.10	0.33

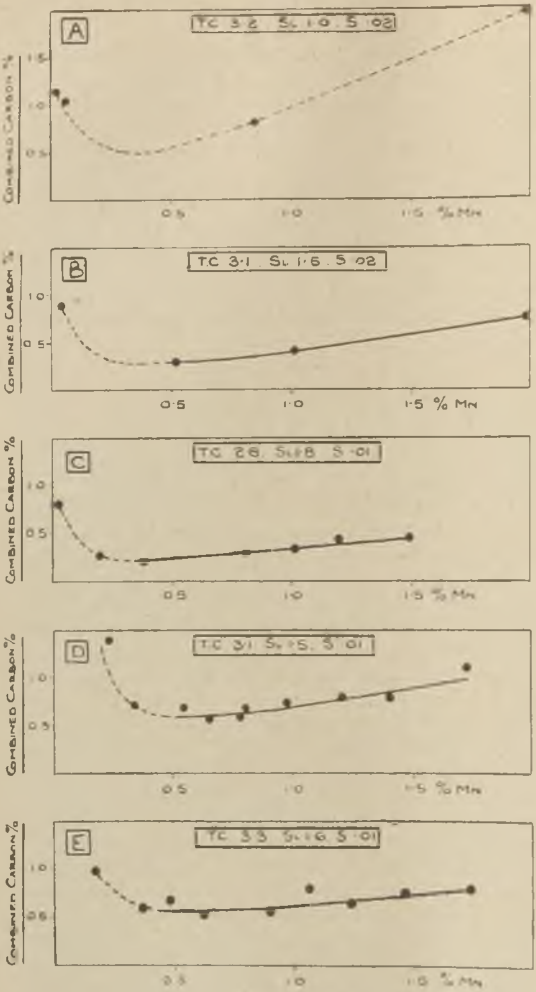
T.C., 3.0 ; Si, 1.9 ; S, 0.03 ; P, 0.03 per cent.

Series B.

No. of test bar ..	4.	5.	6.	7.	8.
C. C.	1.29	1.10	0.99	0.90	0.84
Mn	0.06	0.11	0.20	0.24	0.43

T.C., 2.77 ; Si, 1.53 ; S, 0.03 ; P, 0.03 per cent.

The results in Fig. 2A have been taken from data published by Maurer[5] and *contain* 0.68 *to* 1.23 *per cent. manganese* and 0.04 to 0.13 per cent. S. Those in Fig. 2B *contain manganese below* 0.2 *per cent.* and 0.01 to 0.03 per cent. S and have been taken from a Paper by Wüst and Kettenbach.[6] Compositions to the right of the curved chill lines would be grey. The combined-carbon contents of the grey irons in Fig. 2A (Mn 0.68 to 1.23 per cent.) average about 0.9 per cent. combined carbon; those in Fig. 2B (Mn below 0.2 per cent.) are, however, obviously exceptionally high, averaging about 1.3 per cent. combined carbon. The high combined-carbon contents in Fig 2B are, as before, the result of low-manganese contents (below 0.2 per cent. in this case).



Figs. 1A, 1B, 1C, 1D, 1E.—Effect of Manganese on the Combined-Carbon Contents of Grey Iron Bars. Figs. 1A, 1B, 1C have been Constructed from Data Published by Coe for 2 in. × 1 in. Bars; Figs. 1D and 1E from Data Published by Wüst for 1.2 in. Bars.

Effects of Phosphorus, Nickel and Aluminium.

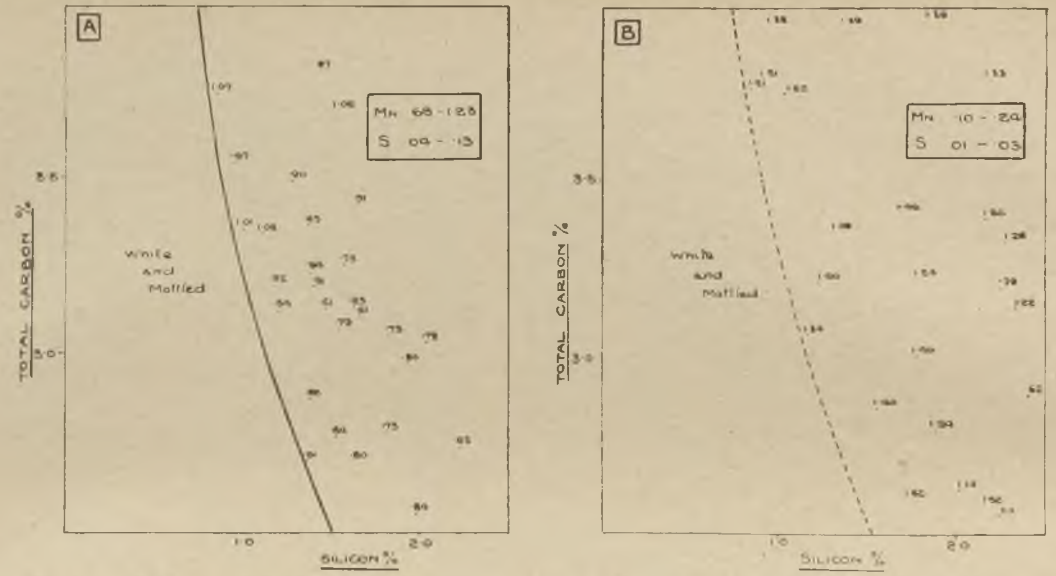
Manganese appears to be the only element commonly alloyed with cast iron which can graphitise the secondary cementite in the above manner. That neither phosphorus, nickel nor aluminium has this action is evident from the following data, viz., Wüst and Stotz's[7] data giving the combined-carbon content of 1.2 in. dia. sand-cast grey-iron bars containing manganese below 0.2 per cent. and sulphur below 0.03 per cent. and various amounts of carbon, silicon and phosphorus show high combined-carbon contents similar to those in Fig 2B (viz., 1.3 per cent.)—which are not decreased or increased by increasing the phosphorus from 0.0 to 2.0 per cent. (A similar conclusion as to phosphorus results from a study of Coe's[8] data.)

Similar high combined-carbon contents in grey irons containing traces of manganese and sulphur and several percentages of nickel are evident in data published by Everest, Turner and Hanson,[9] and in grey irons containing traces of manganese and sulphur and several percentages of aluminium in data published by Everest.[10]

Microscopic Examination of Grey Cast Irons containing Low-Manganese and Traces of Sulphur.

Photomicrographs at 200 dias. of the grey-iron test-bars Nos. 1, 2 and 3 (Table 1) are shown in Figs. 3, 4 and 5 respectively. In these figures, the fall in combined-carbon from 1.29 to 0.54 per cent. is very marked. This fall is due entirely to the manganese content being increased from 0.02 to 0.33 per cent., the sulphur is constant at 0.33 per cent. and the silicon at 1.9 per cent. and the total carbon at 3.0 per cent.

Fig. 3 shows the presence of three or four lakes of white cementite and numerous dark patches which, when magnified to 1,000 dias. as in Fig. 6, are seen to consist of cementite lamellæ much closer together than they are in pearlite. Such patches presumably consist of secondary (or pro-eutectoid or hyper-eutectoid)



FIGS. 2A AND 2B.—COMBINED-CARBON CONTENTS OF 1.2 SAND-CAST BARS OF VARIOUS TOTAL CARBON AND SILICON CONTENTS. FIG. 2A, WITH MN 0.68-1.23, SHOWS NORMAL COMBINED-CARBON CONTENTS, WHILE FIG. 2B, WITH MN 0.10-0.24, SHOWS ABNORMALLY HIGH COMBINED-CARBON CONTENTS, FIG. 2A HAS BEEN CONSTRUCTED FROM DATA PUBLISHED BY MAURER, AND FIG. 2B FROM DATA PUBLISHED BY WÜST AND KETTENBACH.

cementite. (The form of the secondary cementite in Fig. 6 suggests that it has been deposited at a single temperature instead of being deposited from the γ solid-solution continuously as the temperature on cooling fell from the eutectic temperature to the eutectoid temperature. In other words, the γ solid-solution containing about 1.2 per cent. combined-carbon has supercooled until the γ α allotropic-change temperature was reached, and this change caused the cementite to be deposited from solid-solution in a form which may be likened to pearlite with a combined-carbon content of 1.2 per cent. instead of the usual 0.9 per cent. The same thing probably occurred in the cast irons made by Hague and Turner,[1] since these investigators

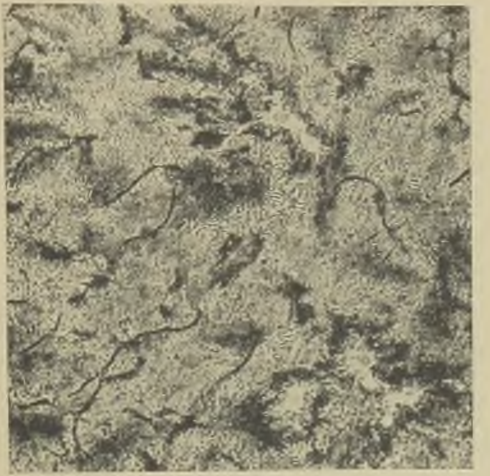


Fig. 3.—× 200. T.C., 3.0; Si, 1.9; S, 0.03; P, 0.03; Combined Carbon, 1.29, and Manganese, 0.02 per cent. White Lakes of Primary Cementite containing Iron Sulphide. Dark Patches of Secondary Cementite.

found only traces of thermal-arrests between the eutectic and eutectoid temperatures.)

The white lakes of cementite in Fig. 3 contain islands of yellow iron sulphide. One of these magnified to 1,000 dias. is shown in Fig. 7. The sulphide was yellow in colour—in fact, similar in colour to a polished and etched specimen of iron sulphide. This indicates that the 0.02 per cent. manganese in this test bar (No. 1) is not combined with the sulphur, but is combined with some other constituent. It also suggests that these lakes of cementite have been prevented from graphitising by iron sulphide.

Fig. 4.—× 200. Same Composition as Fig. 3, except Combined Carbon 0.91, and Manganese 0.10 per cent. Less Primary and Secondary Cementite Present.

Fig. 8 shows another of these lakes at 1,000 dias., and in this case the lake contains fine spots of phosphide eutectic in addition to iron sulphide and austenite. (This indicates, incidentally, that the solid solubility of the phosphide in this particular iron must be considerably below 0.03 per cent. phosphorus—the figure found by chemical analysis.) These white lakes of cementite, etc., it is suggested consist of eutectic mixtures of iron carbide, austenite, iron sulphide and iron phosphide, plus secondary cementite which has been deposited on and has joined up with the primary cementite.

Fig. 5.—× 200. Same Composition as Figs. 3 and 4, except Combined Carbon 0.54 per cent., Manganese 0.33 per cent. No Primary or Secondary Cementite Present, and some Pearlite has Decomposed into Ferrite, plus Graphite.

The fact that the specimen shown in Fig. 4 contains fewer lakes of primary-cementite and fewer dark patches of secondary-cementite than the specimen shown in Fig. 3 may be explained by assuming that the additional manganese it contains (0.10 per cent. instead of 0.02 per cent. Mn) has combined with some of the 0.03 per cent. sulphur to form MnS which does not stabilise and form a eutectic with primary-cementite and does not stabilise secondary-cementite. Similarly, with the specimen shown in Fig. 5, the higher manganese-content (viz., 0.33 per cent. Mn) has been sufficient to nullify any carbide-stabilising action of the 0.03 per cent. sulphur. It will be noted that between 0.10 per cent. and 0.33 per cent. manganese is required to effect this, and since 0.03 per cent. sulphur only requires 0.05 per cent. manganese to form MnS, it follows that the manganese must distribute itself between the sulphur and some other constituent. Further additions of manganese up to, say, 1.5 per cent. of manganese have relatively little effect on the combined-carbon content, their tendency is to increase it slightly and to make the pearlite more sorbitic.

Fig. 6.—× 1,000. Secondary Cementite Resolved. This Constituent Appears as Unresolved Dark Patches in Figs. 3, 4, 9 and 14.

The fact that such small quantities—*e.g.*, 0.03 per cent.—of sulphur are sufficient to stabilise and prevent the graphitisation of such large quantities of combined-carbon (viz. 1.29 to 0.54 per cent. = 0.75 per cent. combined-carbon) receives support from the work of Stead[11] and Hatfield.[12] Stead concluded that cementite can hold 0.1 per cent. sulphur in solid solution, and that such sulphur is mainly responsible—by making the carbide stable—for preventing the separation of graphite.

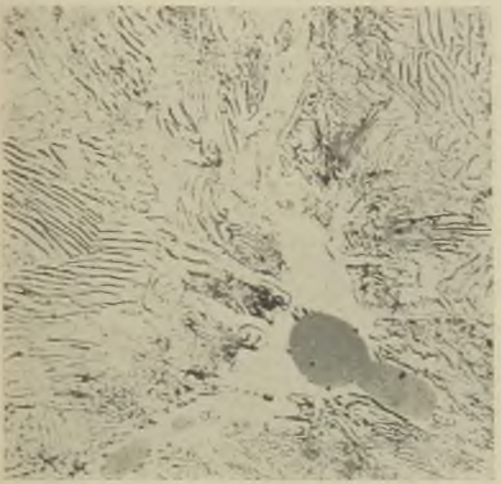


Fig. 7.—× 1,000. Yellow Sulphide in White Lake of Cementite. Same Specimen as Fig. 3.

Effect of Sulphur.

All the data considered so far have referred to cast irons in which sulphur has been present only in traces, *e.g.* below 0.03 per cent. Wüst and Miny[13] cast a number of grey iron 1.2-in. dia. test-bars with sulphur varying between 0.01 per cent. and 0.3 per cent. and with manganese contents of 0.09, 0.64, and 0.85 per cent. Piwowarsky and Schumacher[14] added sulphur up to 0.8 per cent. to eutectic and hypo-eutectic cast irons containing 0.8, 1,8, and 2.8 per cent. silicon and 0.2 to 0.3 per cent. manganese. In both these researches, consequently, the sulphur was, except in one or two cases, greater than that required to form MnS with the manganese present, and the results are consequently outside the range considered in the present Paper.

FIG. 8.—× 1,000. DOTS OF PHOSPHIDE EUTECTIC AND YELLOW SULPHIDE IN WHITE LAKE OF CEMENTITE. SAME SPECIMEN AS FIG. 3. P, 0.03 PER CENT.

In order to investigate the effects of small excesses of manganese, above that required to form MnS, in irons containing appreciable amounts of sulphur, the following experiments were carried out.

Three 1.2-in. dia. grey-iron bars were cast in sand. The first contained 0.03 per cent. sulphur, the second 0.13 per cent. sulphur, and the third 0.28 per cent. sulphur; the manganese content was 0.5 per cent. in each case, the total carbon 2.8 per cent., the silicon 1.7 per cent., and the phosphorus 0.03 per cent. If the sulphur combines with the manganese to form a sulphide, its action should be equivalent to reducing the amount of manganese able to influence the combined-carbon contents, as above.

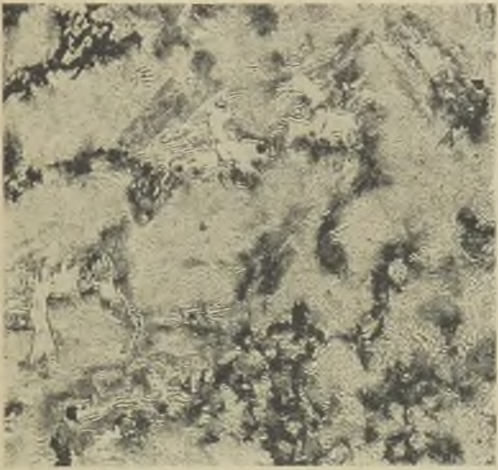


FIG. 9.—× 200. T.C., 2.8; SI, 1.7; MN, 0.47; S, 0.28, AND P, 0.03 PER CENT. MANGANESE (ABOVE THAT REQUIRED TO FORM MnS) 0.0 PER CENT., COMBINED CARBON 1.18 PER CENT.

The results obtained indicate that this occurred, since as the sulphur was increased the combined-carbon contents increased (viz., 0.56, 0.72, and 1.18 per cent. combined-carbon respectively), even though the bars showed no signs of chill. The results are shown in Table II, where the amounts of manganese present, above that required to form MnS, have also been calculated.

It will be seen that this assumption (that MnS is the sulphide formed) is approximately correct, since the combined-carbon content falls to normal when the "manganese above that required to form MnS" is between 0.28 and 0.48 per cent., a figure in approximate agreement with that already arrived at for irons containing only traces of sulphur. Further experiments are, however, being carried out to ascertain more accurately the excess manganese required.

FIG. 10.—× 1,000. KHAKI-COLOURED SULPHIDE CRYSTAL, CONTAINING PEARLITE. SAME SPECIMEN AS FIG. 9. MN 0.47, S 0.28 PER CENT.

The microstructure at 200 dia. of test-bar No. 9 is shown in Fig. 9, and is very similar in respect of its primary and secondary cementite contents to test-bar No. 1 shown in Fig. 3. This test-bar contained 0.47 per cent. manganese and 0.28 per cent. sulphur (the theoretical amounts required to form MnS), but the sulphide was khaki-coloured, indicating that it consisted chiefly of FeS, consequently the greater part of the 0.47 per cent. manganese present must be combined with some constituent other than the sulphur. A triangular crystal of the khaki-coloured sulphide in this specimen is shown in Fig 10 at 1,000 dia. magnification. It will be seen that this crystal shows an area of pearlite in its centre. It is not considered that this pearlite is the matrix showing through a hole in the sulphide, but that it is an inclusion, since its triangular shape is so definitely related to that of the crystal form of the sulphide. Test-bar 10 had a general microstructure similar to that shown in Fig. 4, while test-bar 11 had one similar to that shown in Fig. 5, except that the ground mass was pearlitic instead of pearlitic-ferritic.

Table II.—*Effect of small percentages of manganese and sulphur on the combined-carbon contents of 1.2 in. diameter sand-cast grey-iron bars.*

No. of test bar	9.	10.	11.
C.C.	1.18	0.72	0.56
Mn above that required to form MnS	0.00	0.28	0.48
Mn	0.47	0.50	0.53
S	0.28	0.13	0.03

T.C., 2.8 ; Si, 1.7 ; P, 0.03 per cent.

Figs. 11, 12 and 13 show test-bars 9, 10 and 11 at 25 dia. magnification after deep etching in 1.20 sp. gr. nitric acid. The white networks are due almost entirely to cementite, since the test-bars only contained 0.03 per cent. phosphorus. The decrease in cementite as the manganese, above that required to form MnS, increases from 0.0 to 0.53 per cent., is clearly shown. The test-bars shown in Figs. 3, 4 and 5 gave similar cementite networks when etched in this manner.

Fig. 14 at 200 dias. magnification shows a malleable iron containing 0.20 per cent. manganese and 0.16 per cent. sulphur. It has been etched in boiling sodium picrate which darkens the cementite. The secondary-cementite is seen as dark centipede-like patches at the crystal boundaries. Its stability after the prolonged annealing is noteworthy.

The mechanical properties and complete analyses of the test-bars referred to above are given in Table III. The bars were cast as follows:—About 50-lb. charges were made up of Swedish iron (T.C. 3.7; Si 0.3; Mn 0.05; S 0.03 and P 0.03 per cent.), Armco iron and ferro-silicon (11 per cent. and 40 per cent.), and melted in a Salamander crucible in a coke-furnace at 1,300 deg. C. to 1,400 deg. C., and poured at 1,350 deg. C. into green-sand moulds to give a 1.2 in. dia. bar, a 0.875-in. bar, a 0.6-in. bar and a 0.4-in. bar. Each bar was 16 in. long, was cast separately, and top-poured

Fig. 11.—× 25. Mn (above that required to form MnS) 0.00 per cent., Combined Carbon 1.18 per cent., P 0.03 per cent. White Network of Primary and Secondary Cementite and Phosphide. Same Specimen as Fig. 9.

Table III.—*Mechanical Properties of 1.2-in., 0.875-in., 0.6-in., 0.4-in. Sand-cast Bars containing low percentages of manganese and high percentages of combined-carbon.*

	Series A.			Series B.					Series C.		
Test bar No.	1	2	3	4	5	6	7	8	9	10	11
C. Carbon per cent. on 1.2-in. bar	1.29	0.91	0.54	1.29	1.09	0.97	0.87	0.84	1.18	0.72	0.56
Mn above that required to form MnS	0.00	0.05	0.28	0.00	0.04	0.13	0.17	0.36	0.05	0.22	0.47
Mn	0.02	0.10	0.33	0.06	0.11	0.20	0.24	0.43	0.47	0.50	0.53
S	0.030	0.030	0.030	0.040	0.040	0.040	0.040	0.040	0.279	0.128	0.028
T.C.	3.02	3.06	3.05	2.79	2.78	2.77	2.76	2.75	2.79	2.79	2.82
Si	1.83	1.95	2.01	1.53	1.53	1.53	1.53	1.53	1.67	1.72	1.74
Brinell No. on 1.2-in. bar ..	285	241	201	269	255	255	241	229	285	255	241
Drill-hardness on 1.2-in. bar ..	80	70	54	—	—	—	—	—	—	—	—
Tensile-strength on 0.798-in. from 1.2-in. bar	15.0	14.4	12.7	20.0	18.0	19.5	19.8	16.6	6.9	21.0	19.0
Transverse-modulus of rupture on 1.2-in. bar (in tons/sq. in.)	20	20	20	28	31	29	28	27	29	31	27
do. on 0.875-in. bar ..	21	23	25	27	26	27	28	28	31	30	—
do. on 0.6-in. bar ..	24	27	29	36*	42*	40*	42*	47*	29	42	—
do. on 0.4-in. bar ..	32*	24*	41*	34*	30*	43*	35*	41*	29*	45*	42*
Shrinkage per cent. on 1.2-in. bar	1.4	1.3	1.1	1.3	1.1	1.1	1.0	1.0	1.0	1.2	0.9
do. on 0.875-in. bar ..	1.4	1.2	1.1	1.4	1.2	1.3	1.3	1.2	1.3	1.1	—
do. on 0.6-in. bar ..	1.7	1.5	1.2	1.7*	1.5*	1.7*	1.9*	1.8*	1.8	1.2	—
do. on 0.4-in. bar ..	2.0*	2.2*	2.0*	2.0*	2.0*	2.0*	2.1*	2.0*	2.0*	2.0*	2.0*

* Mottled or white.

at an angle of about 30 deg. to the vertical. After casting a set of four bars, weighing about 10 lbs., the crucible was put back in the furnace, an addition of ferro-manganese made, and four more bars cast. All the bars in Series A were consequently cast from the same crucible full of metal with additions of ferro-manganese, similarly with those in Series B. In Series C additions of sulphur were made to the melt.

Fig. 12.—× 25. Same Composition as Fig. 11, except Mn (above that required to form MnS) 0.28 per cent., Combined Carbon 0.72, P 0.03 per cent. Less Cementite in Network than in Fig. 11 (Test Bar No. 10, Table II).

The bars were broken in transverse between 12-in centres. Drill-hardness tests ($\frac{1}{8}$-in. dia. drill) were carried out on the central core of each 1.2-in. bar. Brinell tests (10 mm./3,000 kg./30 sec.) were carried out on flat surfaces about $\frac{1}{4}$ in. below the surface of each 1.2-in. bar.

It will be seen in Table III that as the manganese increases and the combined-carbon falls, the Brinell-number falls, the drill-hardness falls, the tensile-strength falls in Series A where the third bar has a ferritic-pearlitic matrix (as shown in Fig. 5), but is little affected in Series B where the matrices of bars 7 and 8 are pearlitic (the low tensile-strength of 16.6 tons obtained on the last bar of Series B is largely due to the too-low temperature at which this bar was poured, while in Series C the high-S bar has given a low tensile-strength, possibly due to segregation). The transverse-strengths are little affected by variations in manganese and combined-carbon.

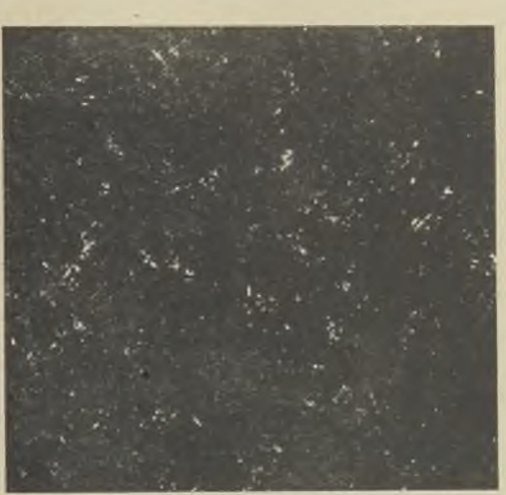


Fig. 13.—× 25. Same Composition as Figs. 11 and 12, except Mn (above that required to form MnS) 0.48 per cent., Combined Carbon 0.56 per cent., P 0.03 per cent. Little Cememtite in Network (Test Bar No. 11).

The shrinkage was measured by placing two pairs of pins exactly 14 in. apart in each mould (using a steel rod 14 in. long by ½ in. dia.), so that the head and about ¼ in. of each pin projected from the face of the mould and became cast into the test-bars. The distance apart of the pins in the cold test-bars was measured with an internal micrometer-gauge. The shrinkage decreases as the manganese is increased and the combined-carbon falls. In the white and mottled bars the shrinkage is not affected. The tendency to chill or solidify mottled or grey is not markedly affected by the manganese-content in these particular tests.

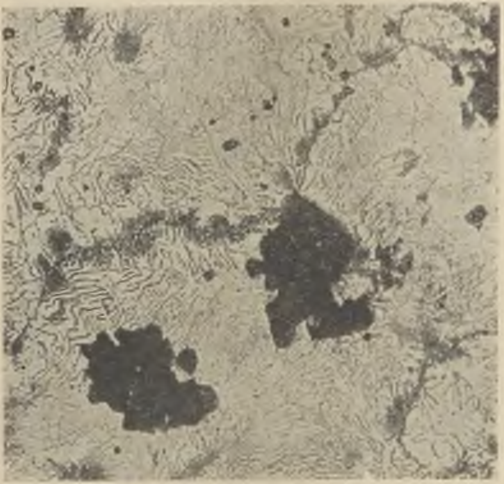
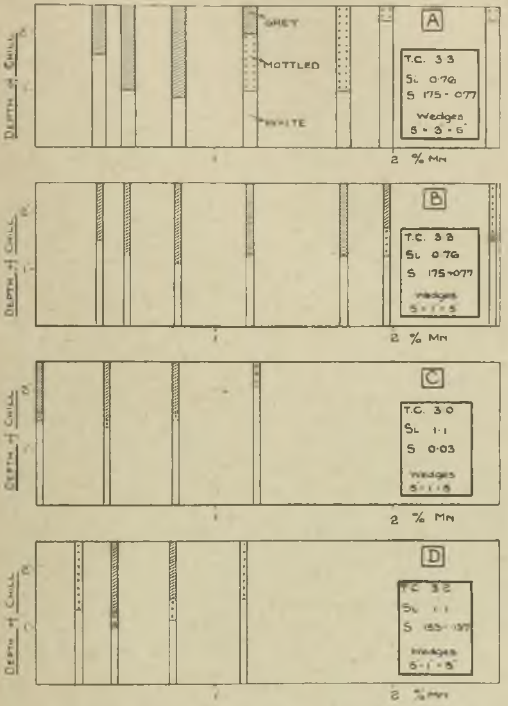


Fig. 14.—× 200. Malleable Iron; Etched in Boiling Sodium Picrate. Darkened Secondary Cementite at Crystal Boundaries.

Stabilising Action of Manganese on the Eutectic Cementite.

There is a considerable amount of evidence available that additions of 1, 2, 3 and higher percentages of manganese increase the tendency of cast iron to chill. Adamson[15] cast wedges $5\frac{1}{2}$ in. × $1\frac{3}{4}$ in. × 5 in. high against a 3-in. steel block and found that increasing the manganese from 0.5 to 3.0 per cent. (in irons containing T.C. 3.3; Si 0.74 to 1.07; S 0.04 and P 0.04 per



Figs. 15A, 15B, 15C, 15D.—Effect of Manganese on Depth of Chill produced by Casting Wedges against Metal Chill. (Figs. 15A and 15B Constructed from Data Supplied by Mr. J. Shaw.) In Figs. 15A and 15B the Sulphur Content fell from 0.175 to 0.077, with Increasing Manganese, and in Fig. 15D from 0.153 to 0.137 per cent.

cent.) increased the depth of chill and mottle very markedly. Coe[16] found that increasing manganese from 0.5 to 30 per cent. in a grey iron containing T.C. 3.7; Si 2.4; S 0.3. and P 0.05 per cent., caused the iron to become mottled with 17.5 per cent. manganese and white with 30 per cent. manganese.

Coe[17] cast small ingots in an open chill-mould. The compositions were T.C. 2.8; Si 1.8; S 0.01; P 0.01 and Mn 0.03, 0.18, 0.37, 0.81, 1.05, 1.20 and 1.47 per cent. He found no appreciable chill in those ingots which contained less than 1.0 per cent. manganese, but definite and increasing amounts of chill as the manganese increased above this figure. Dickinson[18a] cast chill-wedges 5 in. × 1 in. × 5 in. high against a block of steel, and concluded that increasing the manganese from 0 to 0.14 per cent. decreased the depth of chill, while further additions increased the depth of chill.

Shaw[18b] cast a series of large and small wedge chills against a block of steel. The cupola-metal used contained T.C. 3.3; Si 0.75; Mn 0.36 and S 0.175 per cent., chills were cast and then increasing amounts of molten ferro-manganese were added to the ladle, chills being cast after each addition. The results are plotted in Figs. 15A and 15B, where it will be seen that the first and second additions of manganese caused a decrease in the depth of chill, while further additions caused a marked increase. The initial sulphur-content (0.175 per cent.) would require $\frac{0.175 \times 55}{32} = 0.30$ per cent. Mn to form MnS. Consequently, there would be only 0.06 per cent. Mn above that required to form MnS in the original cupola-metal and this would account for the decrease in depth of chill caused by the first and second manganese addition.

Further confirmation of the chilling-action of manganese is given by the results plotted in Figs. 15C and 15D. Chill wedges 5 in. × 1 in. × 5 in. high were cast against blocks of cast iron. In the first series, Fig. 3C, the melt contained T.C. 3.0; Si 1.1 and S 0.03 per cent. Increasing the manganese from 0.22 to 0.4 per cent. decreased the depth of chill slightly, while further additions of 0.8 and 1.25 per cent. manganese increased it considerably. In the second series (Fig. 15D), the initial sulphur-content was made 0.15 per cent. (this would require $\frac{0.15 \times 55}{32} =$ 0.26 per cent. Mn to form MnS) and it will be seen that the first addition of manganese reduced the chill, while further additions increased the depth of chill, as before. Here again, the minimum chill is at approximately 0.3 per cent. manganese above that required to form MnS.

Stabilising Action of Manganese on Pearlite.

The following evidence indicates that manganese, if present in excess of that required to combine with any sulphur present, has a stabilising influence on the pearlite. Carpenter,[19] in experiments on the growth of cast iron, gave four bars containing 0.51, 0.74, 0.94 and 1.64 per cent. manganese, 151 heats at 850 deg. C.-900 deg. C., and found that the stability of the carbide increased with increase in the manganese-content. Taylor[20] found in a series of malleable-irons containing manganese up to 1.3 per cent. that with increasing manganese-contents—above that required to form MnS—the annealed irons become more pearlitic and less ferritic. Peace and Evans,[21] referring to blackheart malleable, state "if the excess (above that required to form MnS) manganese is more than 0.25 per cent., the manganese retards graphitisation."

Summary.

Grey cast irons which contain only traces of sulphur and manganese have abnormally high combined-carbon contents, *e.g.*, 1.3 per cent. Increasing the manganese from traces up to 0.3 per cent. causes the combined-carbon to drop to normal (*e.g.*, 0.8 per cent.) combined-carbon, and causes a decrease in the tendency to chill. Further additions of manganese up to 1 or 2 per cent. tend to increase the combined-carbon and increase the tendency to chill.

The explanation put forward is that the graphitising-action found on increasing the manganese from 0.0 to 0.3 per cent. is an indirect one due to the manganese combining with and nullifying the carbide-stabilising-action of traces of iron sulphide. It appears that about 0.3 per cent. manganese in excess of the amount theoretically required to form MnS is required to do this. Approximately the same excess of manganese, *e.g.*, 0.3 per cent., is required in irons containing higher sulphur-contents, *e.g.*, 0.1 and 0.2 per cent. sulphur. The high combined-carbon contents found in grey irons containing only traces of manganese and sulphur are due to hard-spots of cementite—austenite—iron-carbide eutectic plus secondary cementite, and to patches of secondary-cementite, stabilised in each case by traces of iron sulphide.

Apart from its indirect graphitising-action, due to its combining with and neutralising iron sulphide, the normal action of manganese is to stabilise iron-carbide and to increase the tendency to chill.

Applications in Foundry Practice.

Numerous instances have been noted which show that many foundries adjust the manganese-contents of their castings to obtain certain results which are explainable by the above conclusions.

(A) *Chill Rolls.*—In chill rolls, the manganese (in excess of that combined with the sulphur present) is normally well-below the 0.3 per cent. excess manganese figure (a typical roll analysis would be manganese 0.3 per cent., sulphur 0.15 per cent.). Consequently further additions of manganese reduce the chill. This has been repeatedly emphasised by Shaw.[22]

(B) *Mechanical Strength of Grey Iron.*—Lowering the manganese-content of a grey iron below the 0.3 per cent. in excess figure, results in the substitution of cementite and pearlite for some of the graphite, ferrite and pearlite. This is equivalent to introducing a hard brittle-constituent similar to iron phosphide, but at the same time reducing the graphite-content. The net effect is that the tensile and transverse strengths are not greatly affected in pearlitic irons but may be increased in pearlitic-ferritic irons.

(C) *Hard-Spots in Grey Iron.*—If the manganese-content is sufficiently low to allow the presence of hard spots of cementite, and patches of secondary cementite, the iron will be much harder and more difficult to machine. High-sulphur in the presence of low-manganese will give the same result.

(D) *Resistance to Wear.*—A low-manganese grey iron containing hard spots of cementite in a pearlitic-matrix should show good resistance to most types of wear.

(E) *Corrosion-Resisting Irons.* — A low-manganese iron containing cementite embedded in pearlite should be more resistant to most types of corrosion than one containing a more graphitic and ferritic matrix.

(F) *Shrinkage in Grey Iron.*—If the manganese (in excess of that combined with sulphur) is sufficiently low to increase the combined-carbon there will be a corresponding increase in the total-shrinkage.

(G) *Experimental Melts.*—Shaw[23] has pointed out that grey irons made synthetically from Swedish or American washed-iron usually contain much higher combined-carbon contents than those obtained in foundry practice. The high combined-carbons may be explained by the low manganese-contents of these pig-irons.

(H) *Black-heart Malleable Iron.*—Evans and Peace,[24] referring to black-heart malleable, state "the manganese must be present in sufficient quantity to neutralise whatever quantity of sulphur is present. The amount is not, however, the theoretical requirement to form manganese sulphide, *i.e.*, 1.72 times the sulphur-content, but is in excess of this. Actual practice has established that the excess required increases with the sulphur-content. With 0.04 per cent. sulphur the excess required is in the neighbourhood of 0.20 per cent. manganese. If the excess is more than 0.25 per cent., the manganese retards graphitisation."

(1) *White-heart Malleable.*—In white-heart malleable, the process depends on the removal of the carbide by decarburisation, rather than on its graphitisation (as in the black-heart process), consequently high sulphur, *e.g.*, up to 0.3 per cent., may be used, and though detrimental of itself, has an indirect beneficial action in so far as it stabilises the carbide and prevents its graphitisation.

Acknowledgments.

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THE PRACTICAL APPLICATION OF NICKEL IN CAST IRON.

By Arthur B. Everest, B.Sc., Ph.D. (Associate Member).

Introduction.

The use of nickel in cast iron is by no means new; in fact, it is surprising to find that the possible improvement of castings by the use of nickel was recognised as long ago as in 1799, when a patent was taken out by Hickling, covering the use of nickel in hollow vessels of cast iron. Since that date many other patents have been taken out, and there are records in numerous publications of recognition of the fact that the introduction of nickel produces beneficial results in ordinary cast iron. It has been of great interest to find that at least one well-known firm of engine manufacturers has used nickel in its castings for a number of years, and a Midland firm is known to have incorporated nickel up to 3 per cent. in pistons, valve-liners and piston-rings for ammonia compressors regularly since the year 1896.

The development of alloy cast iron, however, has only recently come extensively under the notice of engineers, and to-day the demand for higher quality material is becoming ever more insistent in the course of engineering progress. The demand for improved cast iron is an urgent one, for, although cast iron for some time has been considered the Cinderella amongst commercial metals, nevertheless engineers are now realising that it possesses some valuable and irreplaceable properties, other than its low initial cost, which render it superior in many applications to its more highly-refined and expensive competitors. These characteristic properties include ease of melting and casting into intricate forms, good machining and wearing properties, as well as certain useful electric and magnetic qualities. It is to make the most of these various properties that progressive engineers and foundrymen are now turning their attention to a consideration of the improvements which are obtainable in cast iron by various methods at an economic cost. In this connection the employment of alloy cast iron is being intensively studied, and the results of this development work are already to be seen in the rapidly growing interest in the use of such metals as nickel in the cast-iron foundry. The choice of nickel as an alloy element has been fully justified on physical and chemical grounds,[1] [2] as well as by the results of practical experience.

A great deal of extensive research, both at home and abroad, has recently established the theoretical and fundamental influence of nickel in cast iron of various forms, and the results of such work are, no doubt, too well known to require repetition here; they were summarised recently in a number of Papers, two of which, under the broad title of "Alloy Cast Irons," were delivered before the Institute of British Foundrymen.[2] [3] Foundrymen and engineers today are now keenly interested in the application of these results in industry, and the object of this Paper is to review briefly the current situation in the development of the alloy irons containing nickel and to describe some of the results now being obtained.

Application of Nickel in Cast Iron.

Clearly the successful application of any alloying element in a basic material such as cast iron must depend on obtaining an improvement consistent with economy in the production or service of the material. Under these conditions the added cost may be met either by the economies effected in production or by the enhanced market value of the special material on account of its improved properties, or clearly by a combination of these two. In the case of nickel there is already apparent a growing demand for the alloyed iron, which is based on the improved qualities which this material is daily being demonstrated to possess, and it is now thought only to be a matter of a short time before engineers will be specifying such special irons in their castings, and recognising the need for paying an adequate price for them. With the recognition of the superior qualities obtainable in cast iron by the use of alloy additions, it seems probable that an improved standard of prices for all classes of high-quality engineering castings will be obtained, which will benefit the foundry industry as a whole.

The successful application of nickel in the foundry is due largely to the fact that the benefits derived from its use are obtained generally with a comparatively small addition, and in most of the applications to which reference is made in this Paper the nickel content in the final product is of the order only of 1 per cent.

The benefits derived from the alloy addition may usefully be divided into two groups, those which assist in the production and manipulation of castings in the works and those which result in improved service from the cast part. The first of these groups may be sub-divided into improvements which are seen in the foundry and those which are seen in the machine shop. Knowledge of the first of these groups must necessarily be greater at the present time than is that of the second, for it requires the passage of considerable periods of time to obtain complete service records of engineering materials, and little value can be attached to accelerated service tests, such as wear and corrosion tests; results of service tests are already coming to hand, however, and a growing demand for the alloy iron, based on the improved service given, is now making itself felt.

Advantages of using Nickel in the Foundry.

The basis of the application of nickel in cast iron is undoubtedly its equalising action on the structure of thick and thin sections of a casting. It has been established that, whereas an ordinary iron cast in a $\frac{1}{8}$-in. section will show a white chilled structure, at the same time this iron will be open and soft in a heavier section of 1 in. or more; nevertheless, in the corresponding nickel-iron, with a content generally of 1 per cent. of nickel, the tendency to chilling is eliminated, so that the thin section is grey and machinable and at the same time the heavier section is appreciably hardened owing particularly to the action of nickel on the matrix of the iron.[2] Fig. 1 gives a typical example of the hardness figures obtained in normal and nickel-iron castings, and illustrates well the equalising effects mentioned. Records show that in some cases a hardness difference of about 200 Brinell between the $\frac{1}{8}$-in. and 1-in. section of a casting may be reduced to about 20 points in a casting suitably alloyed with nickel, and at the same time the iron is very appreciably hardened and strengthened in the heavier sections.

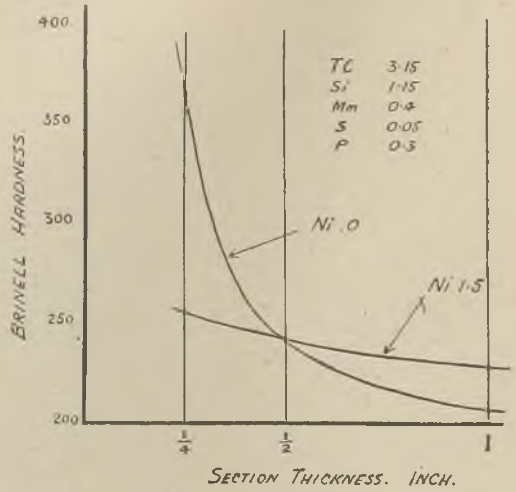

FIG. 1.—INFLUENCE OF NICKEL IN EQUALISING HARDNESS AND STRUCTURE.

Uniformity of Product.

The practical result of this equalisation is that the nickel-iron shows a much greater latitude as compared with the ordinary iron, so that uniform structure may be obtained over a wide range of section-thickness. This has a very important application in the foundry in enabling certain difficult castings to be made satisfactorily, in which high hardness and strength is required in heavy sections; or sections which cool slowly owing to casting design, whilst the metal quality is determined by the machinability of some thin section on the outside of the casting. As an example, reference should be made to the often-quoted case of motor-cylinder blocks, where the hardness and closeness of the cylinder bores and of the valve seats are of paramount importance in obtaining maximum wear, and yet the quality of iron is often determined by the machining requirements on some small water-exit boss situated in the middle of a thin-section water-jacket.[2] This particular application of nickel will, however, receive further attention under the heading of "The Properties of Nickel Cast Iron."

It is in this connection especially that great improvements in strength and properties can be demonstrated in cast iron by the use of nickel. Disappointment is sometimes expressed at the meagre improvements which may be shown by test-bar results, but, as the author has already pointed out,[4] the separately-cast test-bar is not capable of measuring the strength of vital internal portions of a casting, and it is by using an iron such as a nickel cast iron which possesses a greater uniformity in structure from section to section and a greater latitude, that appreciable improvement in these vital sections is obtainable, whilst uniform machinability is maintained.

For thin section, but somewhat intricate, castings (required to be tough and perhaps machined locally), such, for example, as manifolds for internal-combustion engines and switch covers, great uniformity of production is being obtained by the regular incorporation of a small percentage of nickel in the iron. A similar application is found in the production of small pistons, when perhaps five or six pistons are cast from one runner. Any tendency for the piston farthest from the pouring end of the runner to show chill and hard spots may be successfully combated by the use of nickel in the iron.

In virtue of the enhanced latitude of the alloy iron, a much greater uniformity of product may be obtained. This is especially the case when working with a "border-line" iron, when the normal fluctuation in the working of the furnace, and composition of the iron, would tend to give too wide a variation in production, even to the extent of obtaining castings scrapped through machining difficulties on the one hand, or porosity and open-grain troubles on the other.

From the foundry point of view, a very far-reaching result of the equalisation of structure which can be obtained with a nickel iron is the extraordinary closeness and freedom from porosity in heavy sections, and at junctions of sections where drawing is likely to occur. In foundry production, nickel is proving very beneficial in cutting down the number of scrap and waste castings owing to porosity and openness and is overcoming difficulties which repeatedly occur in certain classes of work.

The illustration, Fig. 2, shows one of these very important applications of nickel and is typical of many others. In many pistons, trouble is invariably found in obtaining a sound boss, in the middle of a skirt which has to be machined right up to the extreme edge. If silicon is increased in order to obtain the desired machinability, then porosity very frequently will make its appearance in the boss. Several firms interested in nickel have found its application in connection with the production of pistons eminently successful and are obtaining results such as are illustrated. The piston on the right shows the usual form of porosity which occurs in this particular design, when the mixture was controlled so as to give a uniformly machinable casting. By the reduction of silicon, this casting was rendered sound, but chill spots on the bottom of the skirt spoilt the machinability. By the addition of nickel this trouble has been entirely overcome, since nickel restores the machinability of the casting without giving any tendency to openness in the heavy sections. In Table I the analyses of these two pistons are given, and also comparative Brinell hardness figures for the boss and the skirt.

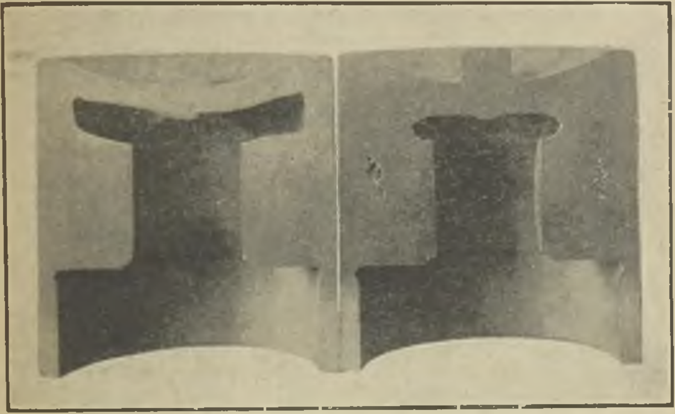

FIG. 2.—TWO PISTONS, OF WHICH THAT ON THE LEFT IS MADE FROM NICKEL IRON.

Such castings as couplings, and gear blanks requiring easy machinability on the flanges, often show porosity in the centre boss. As in the case of pistons, nickel has provided a solution of this trouble for many foundrymen. In such applications several firms have found that the addition of nickel results definitely in reduction of scrap and waste castings, thus maintaining the production rate of the foundry and giving a more reliable product. Each foundryman will no doubt find similar applications in his own work.

Soundness of Heavy Sections.

Remarkable results have been obtained on the use of nickel in castings of heavy section which require to withstand pressure. Illustrated in Fig. 3 is a section cut from the middle of a cylindrical block $6\frac{1}{2}$ in. dia. and 15 in. long and cast on-end. The analysis shown for this section indicates that the normal elements in the iron are present in the usual proportions, and 1 per cent. of nickel has been added. The hardness-figures taken across the section illustrate the remarkable soundness which is obtained in the very centre of this heavy block. The hardness-figures shown in the example is 196; other blocks of a similar nature have been prepared, and the analysis and hardness-figures obtained on these are given in Table II.

Table I.—*Comparison of Pistons in Normal and Nickel Irons.*

	Normal iron.	Nickel iron.
T.C.	3.35	3.35
Si	1.8	1.6
Mn	0.8	0.8
S	0.12	0.12
P	0.25	0.25
Ni	—	1.0
Boss	Unsound	Sound
Brinell—		
Boss	190	200
Skirt	241	235

They also illustrate this feature of remarkable uniformity throughout the section. It should be mentioned that no special casting precaution was taken except that a head about 6 in. high was cast on the end of the block, the casting being made in cold, dry-sand moulds. No figures are available at the moment for a comparison between these and ordinary cast iron containing no nickel, as sound castings could not be obtained in this latter case.

As a more practical application of this feature, certain castings were made up which were required to withstand extraordinarily high-pressures between holes bored right through the centre of heavy sections. A particular example of such a casting is virtually a solid block 20 in. square by 5 in. thick and contains only two small cores, apart from slight recessing on one side. The lower side of the casting has to be machined to give a working face and various ports and holes are bored through the casting, whose sections in most directions are on the average 6 in. thick. A pressure test of 4,000 lbs. per sq. in. is then applied between these various ports and the casting must prove itself absolutely pressure-tight. Nine of these castings were made by various methods from an ordinary cast iron and were all scrapped. In the present run, nine of these castings have been made up from a mixture whose typical analysis is:—T.C., 3.3; Si, 1.12; Mn, 0.8; S, 0.16; P, 0.4; Ni, 1.0; and Cr, 0.3 per cent.

TABLE II.—*Hardness Figures across Sections of Sand Cast Blocks* 15 *in. long* × 6½ *in. dia.*

	T.C.	Si.	Mn.	S.	P.	Ni.	Cr.
(*a*)	3.29	1.06	0.95	0.12	0.24	1.01	—
(*b*)	2.93	1.08	0.83	0.11	0.24	0.77	0.235
(*c*)	3.27	1.21	0.88	0.22	0.21	0.75	0.250
(*d*)	3.20	1.12	0.90	0.13	0.28	0.71	0.210

Hardness across section.

(*a*)	207	196	196	196	196	196	196	—
(*b*)	207	207	207	207	207	207	207	—
(*c*)	187	179	179	179	179	179	187	187
(*d*)	207	207	207	207	207	207	207	—

The castings were cast in cold, dry-sand moulds, and all of these have passed the tests satisfactorily. In this case, the opinion in the foundry is that the use of nickel in the iron has made this casting possible and has saved an extremely expensive and difficult machining job in steel, and incidentally the advantages of good wearing surfaces have been obtained in the iron casting. A similar application is illustrated in Fig. 4, a cast-iron plate which forms part of a modern type-setting machine. The form of casting, which is roughly about 9 in. square and 2 in. thick, is clearly seen, and the machined plate in the background illustrates the severity of the service requirements of the casting in that pneumatic pressure is applied to the various bored-holes and there must be no leakage between one hole to the next. The two sections in the foreground were taken from castings made under exactly similar conditions except that for the upper section, silicon had been reduced in the iron and nickel was added. The analysis of the two irons are given in Table III. The unsoundness of the ordinary iron is clearly seen; and these castings often required to have the holes drilled through them, subsequently bushed with cast-iron bushes in order to make

FIG. 3.—SECTION ACROSS THE CENTRE OF LARGE CYLINDRICAL BLOCK IN NICKEL IRON.

them pressure tight. The nickel-iron in this case gave a sound casting which has given entirely satisfactory service. These examples are typical of the soundness which can be obtained in heavy sections by the use of nickel in cast iron.

Many other applications in the foundry will occur in castings which give trouble due to openness and porosity. In this connection active interest is being taken in the use of nickel in locomotive cylinder castings, which notoriously give trouble with porosity at the junction of the sections where the piston-valve-chamber and steam-ports join the cylinder proper. In certain of these castings, caulking has been considered inevitable, but it is believed that, although this

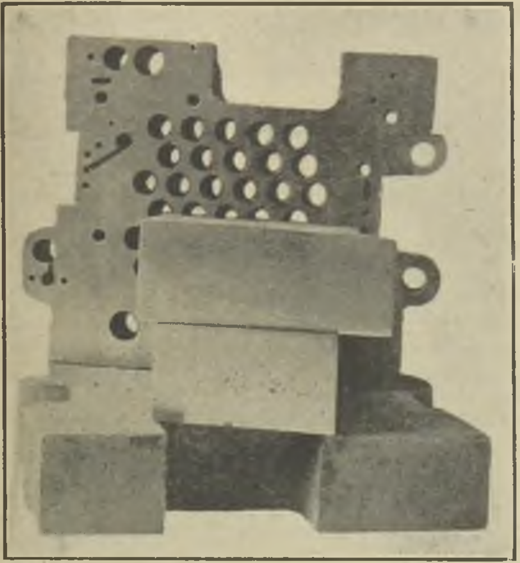

FIG. 4.—SECTION OF PLATE PRESSURE CASTINGS IN NORMAL AND NICKEL IRON.

may not be entirely eliminated, it may very easily be reduced by the use of nickel in an iron of suitable composition, and experiments are now proceeding on these lines.

Cylinder covers of all forms are also notorious for giving trouble with porosity at change of section or at the junction of varying sections, and here again nickel is being applied successfully to the production of sound castings. In the case of one jobbing foundry, one out of every two castings of a water-jacketed cover off a difficult pattern were scrapped; the silicon content of the iron was reduced from 1.8 to 1.5 per cent. and 1 per cent. nickel was added. Since then the scrap loss has been reduced, so that at least three out of four castings are now entirely satisfactory, and it is hoped that with further modification of the composition this figure may be improved upon further.

TABLE III.—*Plates subject to Pressure Test.*

	Normal iron.	Nickel iron.
T.C.	3.4	3.4
Si	1.8	1.54
Mn	0.8	0.94
S	0.14	0.07
P	0.25	0.12
Ni	—	0.91
Plate	Unsound	Sound.

Interest in the use of nickel in the production of sound and close castings is also reaching to the production of many small pump parts for valve castings and general hydraulic castings and for various gas-engine castings such as breach-ends.

The thoretical explanation of this benefit, which can be obtained by the use of nickel, lies undoubtedly, as mentioned before, in the equalising action of the alloy addition. In irons which tend to show coarse, open structures in heavy sections, improvement is obtainable by the reduction of silicon. The subsequent addition of nickel gives the necessary control of the machinability of the casting without tending to open up the structure in thick sections. The photomicrographs, Figs. 5 and 6, show the effect of the alloy on the pearlitic structure of the iron, indicating a very marked refining influence which

Fig. 5.—Cylinder Iron, cast 2.2 dia. × 500.

is associated with the improved hardness and density of the structure. As a general rule also, a finer form of graphite is associated with the alloyed iron.

Function of Chromium.

In some of the analyses and examples of applications of nickel, given in this Paper, chromium is found associated with the nickel. The action of chromium has been fully investigated and explained.[2] [5] Briefly, it may be repeated that to obtain the maximum benefit from nickel a suitable adjustment of composition should be made in the iron, so that the machinability of the casting is maintained; in other words, so that the iron before and after alloying should demonstrate a constant depth of chill under given conditions. In order to achieve this end, it is usually recommended that the silicon content should be reduced. Equivalent values for nickel and silicon in reducing chill have been worked out, and in practice it is usually found satisfac-

FIG. 6.—AS FOR FIG. 5, WITH 1 PER CENT. NICKEL ADDED. × 500.

tory to replace each part of silicon by three or four parts of nickel. Under certain circumstances, however, it is not easy, nor perhaps desirable, to make this silicon reduction, and it is under these circumstances that chromium is added with nickel so as to obtain the maximum benefit in the iron.

As far as experience shows up to the present, it is doubftul as to whether the maximum benefit in cast iron is obtained by the use of reduced silicon and the addition of nickel or by the simultaneous addition of nickel and chromium with no alteration in silicon-content. In general, however, with medium or higher silicon, a reduction of this element on making the alloy-addition is preferred, not only as giving undoubted improvement in properties in the iron, resulting perhaps in a greater elimination of porosity, and a general densening of the finished castings than would be obtained by the addition of chromium, but also, since this method is the cheaper as regards cost both of base iron and alloy additions.

It is frequently found, however, that in irons of low silicon-content used for heavy-section work, or in heat-resisting castings, under conditions where it would be difficult to reduce silicon further, very great improvement is obtained by the simultaneous addition of the two elements. Clearly then, in every case, economic conditions as well as current practice in the foundry must be considered in planning development work, and deciding on the optimum method of employing the alloy additions.

The influence of an addition of nickel and chromium on the matrix of the iron shown in Fig. 5 is illustrated in the photomicrograph, Fig. 7. These three micros were taken at the centre of the I.B.F. " L "-size bars (cast 2.2 in. dia.).

Influence of Nickel on Machinability.

Having considered briefly the application of nickel in cast iron from the point of view of the production of castings in the foundry, it is now proposed to give some consideration to the effect the use of nickel will have on the subsequent machining and other operations to which the castings are subjected. It has been shown in much of the earlier experimental work that perhaps the most important influence of nickel lies in its power to eliminate chill and hard spots.[3] Nickel accordingly is now finding extensive application where machining trouble has occurred through the occurrence of hard, chilled spots, and numerous examples of the application of nickel to overcome this difficulty are coming

FIG. 7.—AS FOR FIG. 5, WITH 0.85 PER CENT. OF NICKEL AND 0.25 PER CENT. OF CHROMIUM ADDED. × 500.

to hand. As an example, a firm which makes many hundreds of castings of a small connecting rod, which has to be drilled at each end, were having trouble with this machining operation, and, as will be appreciated, serious dislocation was liable to occur in production if a tool broke through encountering such a spot. It was not easy in this case to work a special mixture of iron for these castings owing to the fact that one or two standard mixtures only were run from the cupola, consequently it had become the practice to anneal these particular castings in order to obtain the machinability which was required. Fresh trouble arose here through warping during the annealing process, and yet another operation became necessary for checking up and straightening the castings. With the introduction of 1 per cent. nickel, however, into the iron, uniform machinability is now being obtained, and the subsequent annealing with its associated troubles has been entirely eliminated.

Such an example points to another useful application of nickel, in that in a jobbing foundry where a large number of castings of different sorts are produced, nickel may be used to cut down the number of different metal-mixtures, which are required to accommodate all the different classes of work in progress. Thus in the case of one foundry whose production varies from large cylinder-castings for Diesel-engines down to very small air-cooled petrol-engines, four grades of high-quality iron were usually run for the different classes of work. Now, however, following the introduction of nickel for certain of the castings, it has been possible to reduce the number of metal mixtures to two, and incidentally these mixtures are the cheaper ones to work in that they are of lower silicon-content and contain greater amounts of steel-scrap. The illustration Fig. 8 shows a small air-cooled petrol-engine which in the cast condition is overall just over 6 in. high and has a cylinder bore of 1½ in. This casting is being made in this foundry very satisfactorily and with uniform machinability from a metal mixture regularly run for much heavier castings, and 1 per cent. nickel is added in the ladle, this eliminating special charges for this work.

No evidence has been obtained of any loss of fluidity in cast iron by the addition of nickel up to 1 or 1½ per cent. even when the nickel is added in the ladle. Extensive experiments have also shown that the nickel iron has the same shrinkage as has the ordinary. The commonest example of the need for uniform machinability is perhaps found in connection with automobile-engine castings and pistons.

FIG. 8.—SMALL AIR-COOLED PETROL-ENGINE CASTING.

Fig. 9 gives an illustration of a normal automobile-engine casting, and it will be appreciated how much machining is required on the outer parts of the blocks, including the three faces on the side which are attached to the thin water-jacket, whilst the vital portions of the cylinder are not only of heavy-section but have their cooling seriously retarded through the mass effect of the casting and through the heat generated by the burning of the oil in the cores.

Many manufacturers of cylinders would prefer to use a hard iron, but in the normal operation of the cupola they dare not get too near the border-line for fear of having the castings unmachinable. By the incorporation of a small percentage of nickel, perhaps of less than 1 per cent., uniform machinability may be obtained, even in castings made from a harder and stronger mixture than had previously been used.

For obtaining uniform machinability, nickel is finding ever-increasing applications in various industries, and one important manufacturer of engine-castings is known to add ½ or ¾ per cent. nickel to a large proportion of his products for this purpose. Nickel is rapidly serving a similar purpose in other industries such as in the manufacture of textile and agricultural machinery; in fact in all cases where small castings are turned out on a mass-production basis, and the inconvenience caused by the breaking-down of a multiple tool through unmachinability of the castings becomes a very serious factor in hindering production.

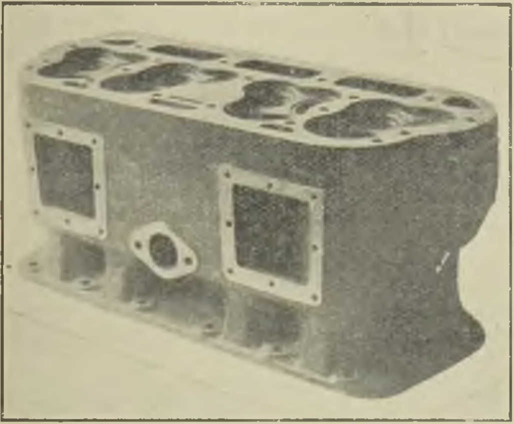

Fig. 9.—Automobile Engine Block.

The use of nickel, however, in this connection is not by any manner of means confined to small castings, for considerable interest is being shown in its use in even very large castings such as rollers for paper-making machinery, sugar-machinery, and so on. Usually, in these cases, the problem is to obtain a good machinable iron which will take on a high polish and a good hard-finished surface, for which a close-grain is clearly essential.

Properties of Nickel Cast Iron.

The influence of nickel in improving production in the foundry and machine shop has been considered, and it is natural to expect that benefit would be derived from that improvement, in the association of better properties with the castings made under these conditions. This improvement, resulting in better service from the castings, is being demonstrated daily, and a large part of the argument for the use of nickel depends on this enhanced quality of the final product. This improvement in properties is undoubtedly closely related to the improvement in production which has already been dealt with, and can very largely be referred to the equalisation of structure and resultant soundness in heavy sections which accompany the general closing-up and densening of the grain of the iron.

Improved Wear.

One of the first results of this denseness of internal sections is that castings can be obtained which show definitely improved wearing properties, and on this account nickel has already proved its worth in assisting in the production of castings which possess a longer life. Perhaps the best-known example of this is the case of automobile-engine blocks and liners. It is not yet possible to produce actual statistical evidence of this, since experiments which are in hand at the moment will take months, if not years, to complete in order to obtain reliable measurements of wear in service. No reliance can be placed in accelerated laboratory tests for measuring this property, since the life of an iron will depend entirely on considerations of loading, lubrication, and so on, which condition cannot be reproduced effectively in the laboratory. Several manufacturers, however, have demonstrated to their own satisfaction that improved wear is obtained by the addition of nickel-chrome to their ordinary iron, and one would expect that this improvement would be seen also in the corresponding low-silicon nickel-iron. Other manufacturers of both private and commercial motor-vehicles who have experimented for themselves confirm this and report, as a result of extensive bench- and road-tests, that a very marked improvement in the life of cylinder-blocks is demonstrated by the alloy-irons.

The call for improved life in connection with commercial and public-service vehicles is more urgent generally than is that in the case of the private car. One manufacturer, who made some nickel-chromium blocks containing an addition of 0.7 per cent. of nickel and 0.25 per cent. chromium in his ordinary iron for this heavier class of work, found, after the engine was run for an equivalent of 11,000 miles at 48 miles per hour, that there was no measurable wear at all. This is very surprising in that the initial wear of the cylinder block is invariably the worst in normal service.

In this connection a similar application of nickel-chromium is found in centrifugally-cast cylinder liners containing nickel and chromium, which are turned out on a production basis in order to obtain improved service from these castings. Other applications of nickel in cast iron to improve its wear are coming to light day by day, amongst which mention may be made of certain heavy machinery parts, such as lathe beds, in which well-finished, good-wearing surfaces are required.

Improved Mechanical Properties.

Nickel cast iron is finding extensive application also in consequence of the improved strength and resistance to impact which has been demonstrated for it,[6] which, added to the good wearing qualities of the material, render it eminently suitable for such castings as die blocks. It is recorded that certain firms are finding that a nickel-chrome, cast-iron block will often give better service than a steel block, and are now using regularly a nickel-chrome iron for this purpose. There is no special feature in this iron apart from the addition of nickel and chromium, as is shown by the following analysis, which is taken from a die block which successfully replaced a similar part in steel, and clearly at a greatly-reduced cost:—T.C., 3.45; Si, 1.24; Mn, 0.61; S, 0.137; P, 0.54; Ni, 1.67; and Cr, 0.39 per cent. The actual life of this block was several times that of its steel counterpart.

In virtue of its action in densening and strengthening an iron, considerable interest is now being shown in the application of nickel to grain rolls, for producing a harder and better wearing surface. In this application it would appear that the best results may be obtained by the use of nickel and chromium together in the iron, since initially the silicon in a roll iron is so low that it would be a matter of some difficulty to reduce it further without extensive modification of furnace charges and control. The improvement will also result in better wear of the roll journals and general improvement of strength, all of which will undoubtedly tend towards better service.

Other applications of nickel cast iron, in view of its increased strength and toughness, are too numerous to refer to here, but amongst such there are many small machinery parts, such as spindles and bushes, gear-wheel blanks and couplings, for which the improved strength, coupled with the possibility of getting a sounder casting free from porosity in the bosses with ready machinability on the flanges, renders nickel cast iron particularly suitable. Numerous other similar applications will occur in connection with each industry.

Machinable Hardness.

Castings which possess abnormally high hardness and are yet commercially machinable can be produced regularly in alloy cast irons containing about 2 to 3 per cent. of nickel. Castings of this type will show great uniformity of structure, and the nickel is especially valuable in obtaining these high hardness figures, since there need be no tendency to the formation of chilled spots in the castings. Irons of this type are in favour for various castings which are subject to excessive wear, in cases where the slower speed of machining which will be necessary with this type of material is not a serious drawback. It is not uncommon to hear of castings of this type being machined at speeds little below the normal and having Brinell hardness values of 260 or 280, and cases have been encountered in which irons having hardness values well over 300 have been satisfactorily machined.

Conclusion.

In this Paper consideration has only been given to the application of small amounts of nickel in grey cast iron. It should be mentioned, however, that nickel is finding extensive application in white and chilled cast iron, and also that higher percentages of nickel find use in cast iron of various grades in virtue of its influence in rendering the structure austenitic. Space, however, does not permit more than a passing reference to these applications.

The influence of nickel on the properties of cast iron has been well established as the result of extensive research work. In this Paper the practical application of nickel on the basis of this research has been considered. It has been demonstrated that the action of nickel leads to material improvement in the production of high-quality cast iron in the foundry and in the subsequent handling of the casting in the machine-shop. This improvement is due, in part, to the equalisation of structure brought about by the added element and the much greater latitude of the alloyed iron. The improvement thus obtained is proving of the greatest value to foundrymen and engineers, and enables difficult castings to be made successfully where normal compositions of iron, cast under ordinary conditions, have failed. This is especially the case where high-hardness and good-wearing qualities are required on certain parts of castings, which have to show uniform machinability across varying sections; and castings commercially machinable, yet showing very high-hardness values, can be obtained in the alloy iron. The use of nickel in cast iron tends towards a general uniformity of product, which is of great value in production work where variation in machinability is to be avoided.

In the foundry each particular casting presents its own special problems, but it is felt that the examples given in this Paper will give some indication of the lines along which nickel is successfully and economically finding application in cast iron, and indicates some of the benefits which are to be obtained, first by the foundryman and secondly by the engineer through the employment of this material.

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5 INFLUENCE OF NICKEL CHROMIUM ON CAST IRON. A. B. Everest and D. Hanson. "Foundry Trade Journal," January 3, 1929, p. 5.

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JOINT DISCUSSIONS ON THE FOLLOWING PAPERS.

"The Influence of Chromium in Cast Iron," "The Influence of Manganese in Cast Iron," and "The Practical Application of Nickel in Cast Iron."

Mr. H. Field, speaking with regard to the machinability of nickel cast iron, said Dr. Everest had only put forward data of an iron of one particular composition. The use of nickel seemed to be limited in application to a very small range of silicon irons, but it seemed that if the silicon was slightly reduced and some nickel added a more machinable iron was obtained. Could the author say what was the result of adding nickel to the higher silicon irons? Personally he was interested in cast iron with a Brinell hardness in a ¼-in. section of 70 to 75 and was there any possibility of nickel helping to obtain a result of that kind? There was no reference in the Paper to the application of nickel to the higher silicon irons, nor was the application of nickel to metal used for electrical purposes mentioned. He had in mind electrical-resistance grids and similar work. The Paper suggested a particular range of silicon as being more favourable to the addition of nickel in order to obtain the best results. In the case of electrical-resistance grids 3 to 3½ per cent. of silicon was used, and if nickel were added to obtain a better resistance, could the silicon be reduced to 1.8 per cent.?

Manganese and Shrinkage.

With regard to manganese, Dr. Norbury in his Paper dealt with the shrinkage in grey cast iron, and it would be useful to hear something with regard to the shrinkage which gives trouble in the foundry, viz., draw holes and shrinkages. A certain amount of work had been done by Cook and others, but in general, foundry practice had progressed little in the past 20 years in the control of draws and shrinkages, by way of the analysis of the iron used, and that was undoubtedly one of the greatest difficulties with which the general ironfounder, making a large range of work, had to deal. Therefore, he would like to know whether Dr. Norbury in referring to shrinkage intended to make any suggestion with regard to draws and shrinkages. He did not know whether he was in order in making any comparison between Northamptonshire and Derbyshire iron, but he believed it was generally recognised that Derbyshire iron gives less trouble with draws and shrinkage than Northamptonshire iron. He had proved that time after time in separate experimental heats numbering many hundreds, and had come to the conclusion that the manganese in the Derbyshire iron—which was greater than in the Northamptonshire iron—has much to do with the immunity of the Derbyshire iron from shrinkage. He might be totally wrong, but it served his purpose to work in that direction; at the same time, he would like Dr. Norbury, if possible, to enlighten him on the subject.

Lowered Phosphorus Reduces Shrinkage.

Mr. R. S. Macpherran (American Foundrymen's Association) remarked that experience in the United States entirely confirmed what was stated in Dr. Everest's Paper with regard to nickel, from ½ to 1 per cent. nickel was used in castings for cylinder liners, crankheads, etc., and in that way castings had been obtained which otherwise would not have been machinable. By adding 1 per cent. nickel something like 0.5 per cent. silicon was eliminated and a machinable casting was obtained. Had Dr. Everest made any definite tests for wear of such material on any standard wear-testing machine? So far there had not yet been developed in the States a satisfactory machine for testing wear in cylinders or frictional wear generally. As regards the point mentioned by the last speaker, viz., shrinkage, this had been reduced in the States by using a lower phosphorus content. In that way the good castings had been increased, keeping the phosphorus below 0.2 per cent.

Overcoming Gear-Blank Porosity.

Mr. J. Longden pointed out that although it was said that the addition of nickel results in the absence of porosity in castings, the findings given in the Paper related to sections which were really on the small side. In the case of a relatively small gear blank, 16 in. diameter as cast, with a rim face $2\frac{1}{2}$ in. wide and $2\frac{1}{4}$ in. deep, and on which the faces had been machined and teeth cut $1\frac{1}{2}$ in. deep, nothing could be hidden after the machinist had done his work, all the faults of the metal being laid bare to the world. At present these castings had the following composition:—Silicon, 1.3; manganese, 0.8; total carbon, 3.2 to 3.3; phosphorus, 0.4, and sulphur, under 0.1 per cent. From the Paper it seemed to him that if there were porosity trouble it would be necessary to lower the silicon a certain amount, add a definite quantity of nickel, and hope for better results. At present, in order to render the castings referred to sound, it was necessary either to chill or to feed, and he would like to know if Dr. Everest could say whether it is possible to obtain such a casting sound by the aid of nickel without either feeding or chilling. He did not think it could be claimed as a general proposition that the reduction of silicon to any extent was necessarily a step in the direction of increasing solidity. There must be a certain minimum line beyond which there was no reduction of cavity consequent on the lowering of silicon content. By reducing the silicon to the minimum possible or practicable, one could get a casting which would stand up to a pressure test; but it did not follow that the casting was free from cavities. He came across a case recently in which there was a spongy mass of material, leaving $\frac{3}{16}$ in. sound metal between a steam chest and the outer world which had held up for 30 years. Therefore it did not follow that with a pressure-tested casting there were no internal cavities, and all troubles were over. He was wondering whether in the case of a gear-blank such as he had mentioned the reduction of the silicon from 1.3 to 1.2 or 1.1 and the addition of a certain percentage of nickel would reduce the porosity, and if so, why? As a matter of fact he had recently cast one of these blanks without reducing the silicon but adding about 2 per cent. nickel, and was sorry to say that porosity showed itself in the rim. This was without, of course, any additional work by way of feeding or chilling. He had also tried a crystallisation shrinkage test on the same iron, and again the conclusion was that an iron of the character he had outlined containing about 2 per cent. nickel, cast in a green-sand mould, lost about 3 per cent. of its volume on freezing. This loss would have to be made good by one or other of the various methods known to the foundryman. Consequently, the value of nickel additions in such cases was very doubtful.

Nickel Additions and Internal Porosity.

Mr. R. F. Harrington (American Foundrymen's Association) said he was a firm believer in the use of nickel for the purpose of removing internal shrinkage, and he believed nickel had its definite application as suggested in the Paper by Dr. Everest in that it prevented waste castings by providing a more uniform structure. Indeed, he did not think that the use of the cast test-bar fully revealed the real value of the addition of nickel to a casting, and when a casting was broken up the evidence of the advantage of adding nickel was much more definitely shown. At the same time he did not think the elimination of internal porosity would come about by the use of nickel, and there were many investigators who held similar views.

Manganese Content and Chill.

Mr. John Shaw, speaking first in regard to Dr. Norbury's Paper, said he was pleased that the author had furnished further evidence that manganese up to at least 0.3 per cent. above that required to satisfy the sulphur present reduced the combined carbon. It was thought by some that he might have found a higher figure if he had not used synthetic materials, especially if tried on a thick section. Some twelve months ago Dr. Norbury had promised to try this latter out by casting two 3-in. bars in moulds heated to a high temperature, one containing a low manganese content, the second with about 0.6 per cent. above that required to form MnS. Could the author say if he had found time to test this out, because it was of some importance to those making very thick hydraulic cylinders. The hardening effect of manganese was not very apparent in Fig. 1. Coe's C.C. rose from 0.19 per cent. with 0.37 per cent. Mn to 0.51 with 2.09 per cent. Hamasuma's had 0.74 per cent. with 0.38 per cent. Mn and 0.87 per cent. C.C. when the Mn was 1.19 per cent., with little sulphur in either case. Wüst's figures in D and E were very similar. Although the Brinell numbers might increase, due to alteration of structure, and graphite, machining was not effected up to 1 per cent. Mn. Cook had frequently stated that he found anything above 0.4 per cent. manganese had a tendency to chill in cylinder work. This was due to the denseners he used in his body core, and the speaker thought he noticed in Fig. 15 some work he did years ago. Below were two other chill tests, 15 C and D. He would like to know how these figures were obtained and how melted. The analysis was unusual for a chill of 1½, as shown. It would also be better if the origin of the latter was put on the Paper. He had no wish to rob anyone of the honour of producing such a figure.

With regard to chromium, he personally had done very little except with a much higher percentage than that mentioned in the Paper by Dr. Donaldson, who had some bars of his which he wanted the author to try out. In that material there was a definite softening action on the structure without any graphitisation at all, but the material could be turned, but he doubted whether in the case of Diesel-engine cylinders or other similar parts which are comparatively straight and where there was no part temperature the middle and top portions would be free from trouble and whether there would not be some free-wearing part.

Nickel was being used by him for special purposes, and he knew that in the case of cylinders for air compressors which had to withstand a pressure of 3,000 lbs., whereas with a specially refined iron bad results were obtained, the addition of ·1 per cent. of nickel enabled castings to be obtained which indicated no leakage under this test. He knew very little about ordinary grey iron and the addition of nickel, but he had in his possession some samples containing 13 per cent. Monel metal, which had been for 12 months under conditions of alternate wet and dry, and this had had a great influence in preventing rust.

Mr. H. J. Young said that Dr. Donaldson's Paper was a continuation of the series started by that author some years ago, and which constituted, as he had suggested on a previous occasion, a cast iron research association in itself. It represented some of the most valuable work ever done, particularly because Dr. Donaldson never tried to prove what he wanted to be true, but merely offered such facts as he believed he had proved as the result of exhaustive and accurate observation. The present Paper drew attention to a fact which may prove important in relation to Diesel and internal combustion engines, namely that the addition of chromium increased the thermal conductivity by about 8 per cent. He (the speaker) had remarked previously that probably the greatest benefit from alloy additions would arise only when those additions were combined with the Lanz Perlit Process. At the moment he saw no reason to think that that prediction would not be realised.

"Sulphur-Manganese Balance."

As regards the Paper on manganese by Dr. Norbury, he noticed that the author when reading his Paper was unable to refrain from using the term "sulphur-manganese balance," but that same term, as far as he knew, did not appear in the Paper itself. Dr. Norbury omitted to mention the work of the present speaker published in 1921, when he coined the expression "sulphur-manganese balance," which he had heard used all over Europe since then. That particular Paper stated: "Irons in which the sulphur content is not more than balanced by the manganese content are relatively weak and hard, and possess poor foundry properties as compared with irons similar in composition other than that the sulphur is properly balanced. . . . From a tabulation of some thousands of results obtained in actual practice the author has found no exception to the rule, that the weak or faulty member of two irons of very similar composition is that one where the sulphur content is inadequately balanced by the manganese content. . . .

TABLE VII.

Transverse strength. Lbs.	Carbon. %	Silicon. %	Phosphorus. %	Sulphur. %	Manganese. %
2,342 ..	3.43	1.17	0.60	0.231	0.23
3,533 ..	3.47	1.27	0.61	0.220	0.41
2,025 ..	3.39	1.67	1.12	0.176	0.27
3,494 ..	3.40	1.64	1.08	0.172	0.49
2,352 ..	3.37	1.56	1.21	0.137	0.28
3,553 ..	3.35	1.52	1.15	0.132	0.44
1,747 ..	3.45	1.65	1.08	0.122	0.27
3,791 ..	3.41	1.62	1.05	0.129	0.51
2,223 ..	3.40	1.72	1.15	0.110	0.25
3,672 ..	3.38	1.73	1.14	0.112	0.58
3,732 ..	3.37	1.73	1.01	0.116	0.40

Table VII (reproduced) gives a typical selection of bars with varying sulphur content, and affected only by the amount of manganese balancing the sulphur.

"The author . . . offers these practical results and observations as something better to work on, something impersonal and more scientific. . . . For the moment, therefore, we may take it that there does exist a very vital equilibrium point between the sulphur and the manganese. . . ."

Anyone, particularly a research-worker, can see from the figures of Table VII what the excess of manganese over sulphur has got to be. For instance, an iron containing as much as 0.220 per cent. of sulphur gave the high transverse strength of 3,533 lbs. when the manganese was only 0.19 per cent. in excess. In all the other cases it so happened that the excess was about 0.3 per cent., and the speaker wrote as follows:—"It is to be most clearly understood that the examples are extremes, and that the nearer one gets to the critical point of equilibrium the more difficult does it become, by chemical analysis, to detect any difference between the two irons—but the physical properties remain either very good or very bad right up to each side of the equilibrium."

That Dr. Norbury should have overlooked this evidence and not even mentioned it may explain the redundant quality of much in his Paper. The speaker was unable to accept the author's statement concerning the graphitising action of manganese when it occurs up to 0.3 per cent. in irons containing only 0.01 per cent. of sulphur; why should it not be the effect of the manganese upon the sulphur, and did not the whole of the evidence point that way? In his Series B the author showed that an iron containing 0.03 per cent. sulphur and 0.06 per cent. manganese has 1.29 per cent. of combined carbon, but when the manganese-sulphur balance is corrected, namely, when the manganese is raised to 0.24, the combined carbon falls to 0.90 per cent. Moreover, an increase of manganese to a total of 0.43 per cent. lowers the combined carbon by only another 0.06 per cent., which is within analytical error. How then can Dr. Norbury talk about the graphitising action of manganese when all he did was to correct the balance between it and the sulphur?

Nor can the speaker accept Dr. Norbury's work where he distinguishes between iron sulphide and manganese sulphide by its colour under the microscope. That would need a research in itself, and a very difficult research it would be to carry out in an entirely unprejudiced manner on the cast irons of commerce.

Graphitising Action of Manganese.

It was to be noted that Dr. Norbury appeared to agree with himself and his opposites at one and the same time, for he states that the graphitising action of manganese occurs only in low-manganese irons (containing 0.01 and 0.03 of sulphur), and almost in the same sentence says that the presence of only traces (0.01 per cent.) of sulphur is sufficient to prevent graphitisation. The truth seemed to be that low manganese had no graphitising action whatsoever, but that mere traces of sulphur prevented graphitisation. That truth will not be entirely proved until work is done upon cast iron containing no sulphur at all.

Then, again, Dr. Norbury failed to observe the effect of high manganese, say, 1.5 per cent., where in large castings it caused a coarsening of the graphite, an effect known for many years past to those in control of a wide variety of work. Very large quantities of castings had been made by the speaker which contained manganese from 0.75 up to 1.75 per cent., and apart from the coarsening of the graphite and the greater heat-resisting properties of the iron there was no other effect. This was true with one exception, namely that if there was a chill inserted in the mould its chilling effect would be affected by high manganese content of the cast iron. In his summary Dr. Norbury presented several claims which in no way appeared to be justified by the work in the Paper. As an instance of this might be taken the following:—"A low-manganese grey iron containing hard spots of cementite in a pearlitic-matrix should show good resistance to most types of wear." There did not appear to be one iota of evidence in this Paper to prove anything of the kind, nor did Dr. Norbury say whether he was speaking of grey or of partly white iron. For example, one might make three cast irons, each containing the same amount of cementite in a pearlitic matrix, but one containing 0.3 per cent. of manganese, another 0.6 per cent., and the third 0.9 per cent. Which would wear the best? Would it be the one with the last manganese, and, if so, why?

Mr. Young said his own Paper of 1921 pointed out the poor mechanical and foundry properties of cast irons where the manganese-sulphur balance was faulty, and also presented figures to show that 0.2 per cent. excess manganese was sufficient to balance the sulphur. It might be pointed out that Series A and Series B given in Dr. Norbury's Table I appeared to confirm this, although Dr. Norbury later speaks of 0.3 per cent.

It would appear likely that the author spoiled his Paper by including too much in it. Chill rolls, grey-iron castings, wear-resistance, corrosion - resistance, mechanical strength, shrinkage, black-heart malleable and white-heart malleable were eight huge and separate subjects. and those who were saturated with one or the other of them were disinclined to accept a few isolated tests as proving all the many things presented here.

Nickel in Diesel-Cylinder Iron.

Concerning Dr. Everest's Paper, Mr. Young said the author was always an optimist, and he, the speaker, admired optimism. Few things would be either purchased or sold without it no matter what their nickel content. The other day at a meeting of leading metallurgists and head-foundrymen one of them stated that the use of from 0.5 per cent. to 1.0 per cent. of nickel has reduced the waster castings from 10 per cent. down to 5 per cent. or less. The difficulty arose when another equally good man from an equally good foundry gave a flat denial to that statement. It was exceedingly difficult to prove these things, but, nevertheless, it did appear likely that nickel used with scientific judgment will prove valuable to some foundries. He, the speaker, knew of foundries turning out automobile cylinders by the thousand with very few wasters and no nickel; equally did he know of other foundries having many failures in those same castings. If nickel helped the latter people one need not worry about the former; the market price of the product would decide. He would much like "to have a go" at locomotive cylinders with the help of nickel. Granted that the locomotive cylinder people—some of them—appeared to use any cast iron which their cupolas liked to serve up from one day to another; but apart from that it represented a casting where the last word had yet to be said, and the use of nickel might prove not only invaluable to the founders, but extremely helpful to the unfortunate machine and testing shops on that work. Dr. Everest suggested using Diesel-cylinder iron for automobile cylinders by alloying the former with nickel, but that entirely depended upon what Dr. Everest called Diesel-cylinder metal, and one would think that a foundry making those two types of castings would find some other expedient. However, all knew what Dr. Everest meant. Nickel in cast iron was to have its opportunity, and nobody would like to have the chance of experimenting with it in certain directions more than the speaker.

Ratios of the Elements in Irons.

Mr. F. J. Cook, speaking particularly with regard to Dr. Norbury's Paper on manganese, commented on the fact that in the discussion on the previous Paper Mr. Shaw had indicated that he did not agree with him. He had, however, been used to being disagreed with for about 30 years, but from time to time he found evidence that probably he was more right than some of those who disagreed with him, and he rather felt that Dr. Norbury's Paper was in the same category. Many years ago he was engaged in trying to get out ratios of the various elements in high-class irons—for which he had a weak spot—and he had tried to ascertain in a workshop manner the ratios of the various elements for different classes of work. This work varied in weight from a few hundredweight to many tons, and from $\frac{3}{4}$ in. thick to $1\frac{3}{8}$ in. thick for steam cylinders, and in order to obtain good wearing properties with these castings it was necessary to get away from porosity in the bore where the valve chest joins. There were generally two chills where the valve chest joins the body, and four others on the centre line where the pressure of the piston comes. He soon found there was a difficulty in avoiding hardness, due to the chilling action, and he was fortunate in finding out very quickly that manganese was the element that was causing the trouble. As a result he got out a balance which he had mentioned several times. The figures he arrived at were three times the sulphur with a maximum of 0.4 per cent. in this particular case, the silicon being 1.2; the sulphur, which was one-tenth of the silicon, as he had pointed out earlier during the morning, being 0.12 and the manganese 0.4. That seemed to give the best results. If he exceeded that percentage of manganese there was a tendency to chill. Having obtained that balance he never had any more trouble with chilling, and the result was due to the control of the quantity of manganese which Dr. Norbury's Paper seemed to prove. Dr. Norbury might have gone farther, because there was another factor which must be borne in mind, viz., the question of mass. So far as the work he had just referred to was concerned, it had dealt with castings from $\frac{3}{4}$ in. to $1\frac{3}{8}$ in., but in the case of hydraulic cylinders having thicknesses up to $4\frac{3}{4}$ in. there was a graphitising action up to 0.7 per cent. manganese, and in the case of chilled rolls up to 1 per cent. and more. Therefore, the mass action of the quantity of material being used must be taken into account, and if Dr. Norbury would continue his work and give graphs for three ranges of work, it would be extremely valuable for foundrymen generally. Recently he had come across some very peculiar phenomena in connection with manganese in relation to semi-steel cylinders in which there were large patches of glazed surface, which ranged from 4 in. to 1 ft. in length. Out of 151 cylinders, a large proportion showed this phenomenon in varying degrees. On investigating the cause of this trouble, he found that in every case where the manganese was less than 0.3 per cent. difference between that and the silicon, this phenomenon was apparent. At about 0.3. per cent. manganese, slight traces of this effect could be seen, and where the manganese equalled the silicon, it was very badly marked. On etching, these surfaces were found to be simply one mass of manganese sulphide. By making the manganese 0.5 per cent. below that of the silicon there was not a single instance where the trouble mentioned occurred. He did not know whether Dr. Norbury had any explanation to offer for it. Of course, he was aware of the differences in the melting temperatures, but it was a very striking phenomenon. Within a very short time of having to deal with this difficulty he encountered another one in regard to the cylinders and valve boxes for ammonia-compressors for refrigerating work. In this case the silicon was 2 per cent., and as this quantity had a tendency to give open porous places in the thick parts, this trouble was overcome by increasing the manganese in relation to the silicon. The method of increasing the manganese was by the addition of ferromanganese to the melt, and as this was done in a more or less rule-of-thumb method the manganese had increased till it amounted to about the same content as silicon, *i.e.*, 2 per cent. At this juncture porosity had been experienced, and large glazey patches were noted on the machined faces, when, however, the manganese was reduced to 1.5 per cent., the glazed surfaces disappeared and porosity improved. If Dr. Norbury could give any scientific reason for this he would be extremely thankful, because at the moment he could see no reason for it unless it was a question of the melting temperature.

Referring to Dr. Donaldson's Paper, particularly as regards Diesel engine work, Mr. Cook said he was a convinced believer in the stabilising effect of chromium, and he had used it on many occasions, up to 0.5 per cent., and found it exceptionally good for wear under heat conditions.

Commenting on Dr. Everest's Paper on nickel, Mr. Cook said he was one of the committee which drew up the programme of work in this connection, and he could bear out the remarkable lowering of the chilling effect by the use of nickel. As a matter of fact, Dr. Everest could have given even more striking examples than those he had mentioned in the Paper, and one was an ordinary air-cooled motor-bicycle cylinder, the fins of which were absolutely white when ordinarily cast, but by adding nickel these all became grey, and yet the hardness in the bore of the cylinder was increased.

Mr. R. F. Harrington (American Foundrymen's Association) asked for information with regard to the elimination of shrinkages in such straight-line cylinders as those for Diesel engines.

Mr. E. Longden asked Dr. Everest for information as to the cost of adding nickel to cast iron. With regard to Dr. Norbury's Paper, he said he had been carrying out experiments and was wondering whether Dr. Norbury could tell him exactly the effect of adding 0.35 per cent. manganese to a metal containing 2 per cent. silicon, sulphur 0.15 per cent., and the usual amount of carbon in grey iron. The practical result was that the metal was absolutely unmachinable.

Mr. R. S. Macpherran (American Foundrymen's Association) said he had found nickel has an indirect effect in making iron harder, but the addition of plain nickel to any particular metal he had not found had any decided effect. He would therefore like Dr. Everest, if he could, to differentiate between the direct and the indirect effect of the addition of nickel.

AUTHORS' REPLIES.

Dr. Donaldson, replying to the discussion, said he was glad to hear that Mr. Cook's practical experience confirmed the results that he himself had been able to obtain in the laboratory. As to Mr. Young's remarks on the increase of thermal conductivity on the addition of chromium, the work described in the Paper was carried out in order to obtain data for Diesel engine work, and it might be interesting to state that the chromium and tungsten of the metals investigated were the only ones which increased the thermal conductivity. With regard to Mr. Shaw's question concerning the test-bars he had provided, these contained 1 per cent. of chromium and 1 per cent. of nickel—a higher percentage of chromium than he had experimented with—and in each case the stabilising effect of chromium was maintained after heating for 200 hours at 150 deg. C. There was no change in the combined-carbon content or the Brinell hardness. At the same time, the 1 per cent. of nickel did not lessen the stabilising effect of the chromium and it rendered the iron more machinable.

Mr. Shaw suggested that the method adopted by the author of heating up was not true annealing because the metal was heated up during the day and allowed to cool during the night. Ordinary annealing was more or less rapid heating and cooling, and that was where the softening effect came in.

Dr. Donaldson suggested that the softening was due to the presence of nickel.

Mr. Shaw remarked also that whereas the author stated he did not find the Brinell was lowered, he himself had found it was seriously lowered.

Dr. Donaldson said that was probably due to the difference in treatment, the method adopted by Mr. Shaw being true annealing and the other a heat-treatment process.

Dr. Norbury, replying to the discussion so far as his Paper was concerned, said Mr. Field had referred to the lower shrinkage of Derbyshire pig-iron as compared with Northamptonshire pig-iron, and suggested that it was due to the higher manganese. That was probably the case. Mr. Shaw was quite right in disowning two of the chill diagrams on page 170, and the difference between these and the other two diagrams was due to the fact that they were cast from synthetic melts of Swedish white iron, Armco iron, ferro silicon, etc. Synthetic melts made in a certain manner could be made to give much greater depth of chill than ordinary cupola melts. The effect of manganese on sulphur was, however, the same in the two cases. Mr. Shaw wanted him to experiment with thicker sections, but his point of view at the moment was that a more important problem to solve was to find out where the missing manganese went to and exactly how it distributed itself between the sulphur and the other elements present, and then they would be able to understand what happened in thicker sections. He would, however, carry out experiments on the lines indicated by Mr. Shaw. At the moment his impression was that with thicker sections, which cool more slowly, less manganese would be required to neutralise whatever sulphur was present, and not more manganese. The case would be more comparable with the annealing of malleable iron, where less manganese was required, because the manganese can diffuse and get to the sulphur and neutralise it. He apologised to Mr. Young for not referring to his work, but so many people had done work on this subject that it was not possible to refer to them all. He also had noticed, as Mr. Young and Mr. Shaw had done, the risk of coarse graphite in high manganese irons. In the cases in which he had noticed it, it was because the ferro-manganese which was added contained 6 or 8 per cent. of total carbon, which, of course, increased the graphite content and made the iron very open and of very coarse grain. He did not know any other explanation to offer to Mr. Cook in respect of some castings of his with very marked manganese sulphide segregations than that the higher the manganese to sulphur ratio the higher would be the melting point of the sulphide and the higher would be the temperature at which it separated out, consequently the greater the possibility of it segregating. Mr. Longden had stated that a metal containing 0.35 manganese, 0.15 sulphur, 3.2 per cent. total carbon, and 2 per cent. silicon was white when sand-cast in the form of a 1-in. diameter bar. He would have expected it to be grey, but the low manganese and relatively high sulphur would increase the tendency to form hard spots and chill.

Dr. Everest, replying to the discussion on his Paper, mentioned first the point raised by Mr. Field as to the possibility of the use of nickel in high-silicon iron. At present, he said, we do not know very much about the influence of nickel in irons which are predominantly ferritic. However, the point really was, not the silicon content of the iron, but rather the amount of combined carbon present in the casting, that was of importance, since nickel acts predominantly on pearlite rather than on ferrite. There were cases in which, with silicon as high as 3.0 per cent. in engineering castings, nickel up to 2.0 or 3.0 per cent. could be beneficially added. Such a case was a thin-sectioned casting for a light piston skirt, which in the cast condition was only about $\frac{1}{20}$ of an inch thick, and in such a case nickel could be used to advantage in obtaining a uniform and machinable casting. Again, the case of resistance grids might be cited when, even in the presence of high silicon, 3.0 or 4.0 per cent. of nickel could be added to obtain a tough, strong casting. This did not refer, however, to the special case of resistance grids with higher nickel contents, where the nickel was used to confer special electrical and magnetic properties on the iron. He took exception to the suggestion that nickel was to be put forward as a "cure-all." It was definitely not. Nickel would improve a good iron, but it would not necessarily render a bad iron good.

Mr. Macpherran referred to wear tests on cast iron. The author did not attach much importance to accelerated laboratory tests on wear, as there were no means by which the conditions of wear inside a cylinder, say, of an automobile engine, could be reproduced. It was impossible to reproduce the conditions of lubrication, the correct bearing-pressure, speed, reciprocation, etc., and in the wear of cast iron it was a matter of general experience that any change in one of these conditions might totally alter the results. If one took a soft iron and worked it under a given load, the surface would become glazed, and a long service could be obtained with little apparent wear. If the load was increased a little more, however, then the conditions were often entirely upset and a rapid wear would very likely be initiated. It was suggested that this was a problem in the automobile industry to-day, for there had been an increase in the power output of engines, with consequent increase in compression ratios, bearing pressures, and so on, with the result that soft irons which up to the present had been perfectly satisfactory were now showing bad wear. This was no doubt in great measure the contributory cause to the interest which was at present being taken in improved material in automobile engine construction. Mr. Macpherran also referred to a nickel : silicon ratio of 2 to 1. It was generally found, however, in this country that for the range of compositions normally employed in engineering castings, that 3 parts of nickel were equivalent to 1 part of silicon in reducing chill in a cast iron. This ratio, however, would not be considered to hold definitely for abnormal silicon contents already on the low or on the high side.

Mr. J. Longden raised the question of the possible improvement in soundness which might be obtained in gear-blank castings by the use of nickel, and mentioned an experiment in which he added 2.0 per cent. of nickel to his ordinary iron, which contained 1.3 per cent. of silicon. Porosity was found at the base of the cut teeth in these gears, and the nickel addition had proved ineffective in removing this. The author pointed out that the 2.0 per cent. of nickel added was equivalent to about 0.7 per cent. of silicon with regard to the graphitising action in the iron, consequently he was really casting his gear-blanks with an equivalent silicon content of 2.0 per cent., which would be expected to give too soft and open an iron. The author pointed out that especially for the elimination of porosity the maximum benefit of nickel was obtained when the silicon was reduced by an amount equivalent to the nickel addition. For the gears in question he would suggest that a composition showing 1.0 per cent. of silicon with 1.0 per cent. of nickel would be very likely to show an elimination of this porosity.

This point connected up with the question raised by Mr. Harrington. He agreed broadly that in the elimination of porosity the reduction in silicon was perhaps the crux of the situation, and that it was due to this that improvement in soundness was often obtained. The function of the subsequent addition of nickel was to restore the machinability and toughness of the casting, without opening up the structure again as a further addition of silicon would have done.

Mr. Harrington (American Foundrymen's Association) said he was glad Dr. Everest had pointed out that fundamentally the reason for the improvement with the use of nickel was in the reduction of silicon, but his own observations suggested that something more than that happened. There must be a change in the elements other than the silicon, and he agreed that nickel could not be regarded as a cure-all, because it was not.

The author said he did not agree with Mr. Harrington that this improvement was due to incidental changes in the amount of the other elements present. On the other hand, the author wished to say that many cases had come to hand in which porosity had been effectively removed by the addition of nickel, without any change being made in the composition of the iron that was in use, even though nickel added in this way was not recommended for the specific purpose of eliminating porosity. This was at the moment difficult to explain, and all that could be said was that there appeared to be a refining action of the matrix in the iron which seemed to give a close-grained structure, showing greater uniformity in the castings. Referring to the inquiry as to the use of nickel in simple cylindrical castings, it was said that experiments had been carried out on piston-valve-liners for locomotive work, and nickel had proved effective in eliminating porosity in these castings. In this country many castings of this type would be made centrifugally, and the question of porosity would probably not then arise. This was the tendency to-day, particularly in connection with the automobile industry.

Mr. H. J. Young raised the question of locomotive cylinders. This was a problem in itself, but it was of special interest in that it was generally known that there were certain designs of locomotive cylinders which would practically never give a sound casting, and caulking was in this case almost inevitable. Some experimental work in this field had been initiated, and the results obtained up to the present were very promising, and the author was most optimistic about this application of nickel. Cylinder-covers for locomotives, which carried a heavy boss to which a guide rod was subsequently attached, had given a great deal of trouble with porosity through the cover, at the root of this boss. In one case twelve of these covers were ordered off a certain pattern, and made in ordinary iron. The whole set were scrapped on account of leakage. Satisfactory results have, however, been obtained by reducing the silicon by about ½ per cent. and adding 1.0 per cent. of nickel, and up to the present every cover had passed its tests.

Referring to the question of Diesel iron for automobile cylinders, it has been found in certain foundries making cylinder castings for both purposes, that the low-phosphorus, low-silicon Diesel iron had proved a very effective basis for the addition of nickel for automobile work. The Diesel iron in question would be for small castings and would carry about 1.3 per cent. of silicon, and an addition of 1 to 1¼ per cent. of nickel was made to this for automobile work.

Dr. Everest thanked Mr. Shaw and Mr. Cook for their sympathetic remarks and for the examples they had mentioned in support of the statements made in the Paper.

WRITTEN CONTRIBUTIONS.

Chromium Reduces Sea-Water Corrosion.

Mr. F. Hudson, commenting on Dr. Donaldson's Paper on "The Influence of Chromium in Cast Iron," wrote that the industry was much indebted for the very valuable work done by Dr. Donaldson in this and other Papers he has published. For his own part he was particularly interested in the results obtained from corrosion tests, and especially those relative to the milder forms experienced in the handling of sea-water, river-water and tap-water flowing through pipes and valves in the various public service and industrial plants of to-day. The need for corrosion-resisting cast irons was probably greater than that for non-growing cast iron. Corrosion tests conducted by Messrs. Glenfield & Kennedy relative to alloy-additions to cast iron confirm the results obtained by the author. The results obtained, in brief, point to the fact that the harder and closer-grained the cast iron then the greater the resistance to corrosion by sea-water. For example, semi-steel mixtures are superior to soft iron mixtures, and the additions of alloys which increase the combined carbon, such as chromium, reduce corrosion. Nickel, on the other hand, increases corrosion in sea-water. In regard to river-water, the difference between various quality cast irons with and without alloy additions, is not nearly so apparent. In regard to corrosions by acids, conditions are very often opposite. It would appear, however, that the addition of chromium is certainly of benefit to lessen corrosion by sea-water.

Dr. Donaldson wrote that he thanked Mr. Hudson for his contribution to the discussion. It was extremely interesting to know that tests carried out by him confirmed the corrosion results obtained with the various chromium additions. He could also confirm his remarks regarding the resistant powers of hard close-grained irons to sea water. This was experienced when experimenting with low-silicon (Perlit) irons, and irons containing tungsten additions.

Resistance of Nickel to Corrosion.

MR. E. J. L. HOWARD wrote that he had read Dr. Everest's Paper with considerable interest. His remarks *re* accelerated corrosion and mechanical erosion tests being of little value were only correct to an extent. Valuable information of a comparative nature could be obtained if suitable methods of testing were adopted, that is, methods which would as nearly as possible represent the conditions for which the material was required. The resistance to abrasion or mechanical erosion may be readily tested by rotating discs of the material under test in the abrasive media, and it has been found that tests made under these conditions and the actual service tests have approximately the same figure, and are an indication of the suitability of the material for a definite purpose.

Corrosion tests, of course, could only be comparative. The addition of nickel alone does definitely increase the resistance of iron to mechanical erosion, and this increased with the amount of nickel added, up to 3.5 per cent., but better results were obtained with a simultaneous addition of about 0.5 per cent. of nickel and 0.5 per cent. chromium.

Resistance to corrosion did not seem to be materially affected by small additions of these alloys. It was his experience that cast iron with the nickel addition alone was rather more viscous and did not tend to retain entrapped gases, causing blow-holes, unless considerable care was taken. These difficulties appeared to be overcome if a combination of nickel and chromium were used, especially if the additions were made through the cupola. He had always found the iron to which additions had been made through the cupola was definitely better than one to which additions had been made in the ladle or spout of the cupola. Was this Dr. Everest's experience, and, if so, could he offer any explanation?

It was interesting to note that nickel additions do not have a marked effect on the test-bar results, but the engineer, who is probably the chief consumer of cast iron, was not so concerned with the strength of cast iron as an improvement for resistance to wear, mechanical erosion and corrosion.

Wherever anything stronger than the average cast iron was required, he usually used steel, either as a casting or a forging. The addition of nickel to cast iron for couplings was surely an expensive method, and one would imagine troubles due to porosity could be overcome by correct methods of moulding.

He would be interested to hear if Dr. Everest had any information regarding the effect of higher percentages of nickel or nickel and chromium for withstanding corrosion. Also if there was any advantage to be obtained in the use of some form of heat treatment of these alloys.

Mr. J. E. Hurst wrote that since Dr. Donaldson's discovery, announced by him in 1925, of the remarkable phenomenon of the shrinkage in volume after repeated heatings of cast iron containing chromium, they had looked forward to his further investigations into this matter.

The present Paper, containing his further investigations along the lines which he has made familiar, confirm this remarkable phenomenon. Although he makes certain tentative suggestions by way of explaining the erratic behaviour of the specimens of high chromium content, the most remarkable fact disclosed by the experiments is the shrinkage in volume in the low-chromium irons. This in spite of the decrease in combined carbon content amounting to 47.3 per cent. in the case of the iron containing 0.39 per cent. chromium. It had been supposed hitherto that this decrease in combined carbon content and the commensurate increase in graphite is largely responsible for the volume increase.

The writer has always been interested in the temperature-strength curves of the type shown in Figs. 11 and 12. The temperature-strength curves of the material in the "as cast" conditions pass through a minimum, in the case of the "Plain Iron" at a temperature of 300 deg. C. and a strength value of about 14.5 tons per sq. in. It appears to be a matter of some significance that this minimum is hardly apparent in the "as cast" condition shown in Fig. 12 for the 0.39 per cent. chromium iron. Reference to Dr. Donaldson's Paper in 1925 shows a minimum in the temperature-strength curves of the "as cast" condition in all the alloys examined with the exception of the chromium irons.

The writer has always suspected this minimum to be connected with some change in the internal-stress conditions in the iron. Whatever conditions it indicates, however, these are "apparently almost absent in the chromium-bearing iron, and it may be possible that a further investigation of this point will throw some light on the observed behaviour of the chromium irons.

The writer desires to add his appreciation of the very great value of the information contained in this Paper.

Author's Reply.

Replying to Mr. Howard, Dr. Everest stated that, in his remarks on the value of accelerated corrosion and wear tests, he had in mind primarily tests in which, to obtain measurable effects in a minimum of time, conditions were used which were not strictly comparable with those occurring in normal service. It was under these conditions that little reliance could be placed in the results of such tests. In a test such as the mechanical erosion test described by Mr. Howard, service conditions were more nearly reproduced, and consequently the results were undoubtedly of greater value.

The author was very interested in Mr Howard's note that the addition of nickel alone increases the resistance of iron to mechanical erosion, but would point out, however, that the suggested addition of about 0.5 per cent. nickel and 0.5 per cent. chromium would markedly increase the tendency of the iron to chill, and for this reason could not be recommended for general purposes. One-half per cent. of chromium would require in usual conditions a simultaneous addition of about 1.5 per cent. of nickel to eliminate this effect.

Slight improvement in the resistance of cast iron to chemical corrosion may be obtained through the use of small additions of alloys. In general, however, there is no very greatly marked influence until the addition is large enough to alter the constitution of the casting.

It has not been the author's experience that nickel cast iron is more viscous than ordinary cast iron, and, moreover, experiments which have been conducted to compare the fluidity of these materials have led to the conclusion that nickel cast iron is not generally less fluid than is the ordinary iron. This may be due to the lengthening of the freezing range. In these circumstances no difficulty would be anticipated from the inclusion of entrapped gases in the castings. If the nickel is added in the ladle, then clearly a certain chilling effect will be produced in the iron, balancing the heating up of the nickel. It has been found, however, from extensive experience, that within ordinary practical limits, this chilling effect does not lead to any trouble in obtaining sound castings from the iron. Limits which have been given elsewhere are for the addition of up to 2 per cent. of nickel in a bulk of iron of over $\frac{1}{4}$ ton when the iron is at normal temperature. Clearly, when the nickel is passed through the furnace with the charge, this chilling effect is eliminated, and it is possible that for certain special castings a somewhat better result might be obtained by passing the nickel through the cupola, due to the slightly higher casting temperature. It might be mentioned in this connection that, when larger quantities of nickel cast iron are being made up, for convenience in handling the material, it is generally recommended that the nickel should be added in a suitable form with the charge in the furnace.

Referring to Mr. Howard's remarks concerning couplings, it is a matter of common experience that certain castings which have light sections requiring to be machined, may have also heavy sections which must at the same time be sound. Sometimes it is possible, by careful control of casting conditions, to meet all the requirements for such a casting, but in the use of nickel iron it is found that, through the latitude of the material, the desired effect may more easily be produced, and that, without any special casting precautions, and frequently without the use of denseners.

Finally, referring to the corrosion resistance of the higher nickel cast irons, it is known that certain alloy irons of the austenitic type possess good corrosion resistance; some of these irons, containing high nickel, with or without also copper and chromium, have been developed commercially. This subject, however, is receiving the active attention of many workers at the present time, and more information will probably shortly be available on this subject. As in the case of steels, some of the alloy cast irons are amenable to heat treatment in order to produce certain desired effects, as, for example, in the case of certain air hardening cast irons which have been referred to in the technical Press.*

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* FOUNDRY TRADE JOURNAL, August 16, 1928, 39, 626. p. 112.

THE ELIMINATION OF SULPHUR FROM THE ALLOYS OF IRON.

By K. Gierdziejewski, Met. Eng.

[Polish Exchange Paper.]

Sulphur is the most detrimental impurity in iron, and its elimination is extremely difficult, primarily on account of its great affinity for iron. The prejudicial effects of sulphur are evidenced by the lowering of mechanical properties as well as by a deterioration in casting properties (reduced fluidity and greater contraction), and, generally speaking, from the physical point of view—brittleness of the iron, especially at higher temperatures, and so forth. The limiting amount of sulphur that can be tolerated depends on the quality of the metal: for ordinary cast iron the maximum permissible content is 0.15 per cent.; for steel and wrought iron 0.05 per cent., but even these amounts are detrimental.

Sulphur enters cast iron from the pig and the coke. Because of the presence of sulphur in coke, when cast iron is produced by the remelting of pig-iron in a cupola, its content is raised by 40 to 50 per cent. If the charge contains large quantities of bought scrap it is possible to obtain a very high sulphur content. During the production of steel in the open-hearth furnace it can also be observed that there is an increase in the sulphur content due to furnace gases, but metallurgical processes, especially in basic-lined furnaces, make it possible to reduce the sulphur to 0.03-0.02 per cent. in the finished metal. The ideal conditions for the maximum practical elimination of sulphur are to be associated with the electric-furnace process.

Sulphur forms the following compounds with iron and manganese:—(*a*) Iron sulphide, FeS, which has a melting point of 1,200 deg. C.; (*b*) manganese sulphide, MnS, with a melting point of 1,620 deg. C.; (*c*) iron-manganese-sulphide eutectic (93 per cent. FeS+7 per cent. MnS), which has a melting point of 1,181 deg. C.; and (*d*) iron-iron sulphide eutectic (85 per cent. FeS+15 per cent. Fe), with a melting point of 980 deg. C.

Iron sulphide is very easily dissolved in molten metal, whilst manganese sulphide shows the reverse phenomenon, and since it has a low specific gravity (3.8-4.0), it rises easily to the surface of the metal bath and thus can readily be eliminated with the slag.

The desulphurisation of the bath is based on this property, therefore the best conditions for allowing the reaction, $FeS+Mn=MnS+Fe$, to take place, must be determined. Prof. Grum-Grzymajlo† has studied these conditions systematically, founding his arguments on physico-chemical and thermo-chemical data. The author proposes to expound a similar treatment.

Desulphurisation of the Bath by Cooling.

This method is based on the following exothermic reaction — $FeS+Mn \rightleftharpoons MnS+Fe+44{,}101$ calories, which, according to Le Chatelier's law, can only take place in a cooling bath. Desulphurisation in non-heated metal-mixers follows this law, since, as the bath of metal cools, the above-mentioned reaction takes place in the direction of the upper arrow and the manganese sulphide formed enters the slag. In ordinary cast-iron foundry practice this method cannot be generally employed, since a metal cooled for too long will be unable to fill the moulds. When the cupola is operated in such a way that the metal reaches a high temperature, it is possible to allow the metal to cool slightly, say, down to 1,350 deg. C., but the resulting desulphurisation is only partial and insignificant. When the metal is to be blown in a converter it is also important that it should have a high temperature, therefore cooling is not recommended, so it is only when producing steel with an open-hearth furnace that a preliminary cooling of the

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† Prof. Grum-Grzymajlo, "Manufacture of Steel," 1925, page 209.

metal in the mixer is possible and even necessary. When the manganese content and the temperature of the bath are correct, it is possible to remove 75 per cent. of the total sulphur by this method.

Desulphurisation using Higher Contents of Mn in the Metal and in the Slag.

This method is based on the following well-known law of solutions: "When to two immiscible solutions (such as the metal and the slag) a solvent, which is soluble in both solutions, is added (FeS and MnS), this solvent divides itself between the two solutions in such a manner that its proportional concentration in the two solutions is constant." In other words,

$$\frac{\text{FeS.MnS in the slag}}{\text{FeS.MnS in the metal}} = \text{K (constant)}.$$

The best results are obtained when K is at a maximum, that is to say, when the MnS and FeS content of the slag is at a maximum; metallurgy postulates that the maximum solubility of sulphides in slags is obtained when the slags contain large amounts of the oxides of the same elements, in this case MnO and FeO. Therefore it would appear that it is to be recommended that the slags contain a maximum amount of these oxides.

Under the conditions existent in the cupola, it is possible to raise the MnO and FeO contents in the following manners: (1) Raise the amount of manganese in the charge; (2) introduce into the charge a manganese-rich flux (such as manganese ore or manganese-rich slags), and (3) by the use of basic slags.

By increasing the amount of manganese in the charge and by conducting the melting operation at a high temperature and in the presence of an excess of oxygen, a greater loss of manganese is obtained which under the form of manganese oxide passes into the slag and facilitates desulphurisation. The same refers to iron. The advantages of using charges running high in manganese cannot be questioned, therefore the use of high-manganese pig should be strongly recommended, and especially that of the quality employed for open-hearth steel furnaces. The author has personally more than once had proof of the advantageous effect of an increased Mn-content in the charge, and strongly advises that selection should be made in such a manner as to obtain a minimum of 0.7 per cent. Mn in the cast metal. Besides this, the cast iron run from the cupola should be sufficiently hot to be able to stand for a time in order that the exothermic reaction, $FeS+Mn=MnS+Fe$, may take place under the most favourable conditions.

In 1902 Reusch* tried out the effect of the introduction of high-manganese fluxes into the cupola; technically the results were fairly good, but the process was too costly. Further experiments by Wedemeyer,† Wüst,‡ and others showed that this method was not practicable, for in order to melt this surplus of flux it was necessary to increase the coke in the charge, and by this very fact increase the contamination of the metal with sulphur.

In Stahl und Eisen, 1925, page 197, there is a note to the effect that the Gütehoffnungshütte works are employing, on a large scale, the desulphurisation of cast iron by means of open-hearth steel slags; the economy of such a procedure can only be explained by exceptional local conditions.

Desulphurisation by means of Basic Slags.

This method and the former one are based on the same theoretical facts. From the formula cited one can postulate:
FeS.MnS in slag=FeS.MnS in metal X "K," that is to say that the concentration of FeS.MnS in the metal can be brought down to zero when the concentration of FeS.MnS in the slag is made to approach zero. The latter can be obtained by replacing FeS and MnS by other sulphides which are not soluble in the metal, such as, for instance, CaS or MgS. Calcium sulphide is not

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* Stahl und Eisen, 1902, page 415.
† Stahl und Eisen, 1903, page 1134.
‡ Stahl und Eisen, 1904, page 1316.

soluble in the metal, therefore, from the above considerations, it follows that its use also tends to the elimination of sulphur.

In practice, however, complete desulphurisation by this method is not feasible, since the thermal reactions—

$MnS+CaO=MnO+CaS-13{,}481$ cal. ...... (1)
$FeS+CaO=FeO+CaS-6{,}573$ cal. .... (2)

are not of great intensity.

The reaction expressed by formula (1) explains why it is that desulphurisation is best effected when the temperature of the furnace is high, since this produces the best conditions for this endothermic reaction.

Everyday practice entirely proves the correctness of the above theoretical conclusions. J. W. Bolton,§ in his very explicit article developed on the subject of cupola slags, shows diagrams giving the relation between the percentage of $CaO+FeO$ in the slag and the degree of desulphurisation, taking the total sulphur contents of the bath as being 100 per cent. One of these diagrams is reproduced in Fig. 1. From this diagram one can gather that the best desulphurisation is obtained when using a slag running to 35 to 45 per cent. total $CaO+FeO$ contents. Bolton points out that a slag of this composition possesses, to a great degree, the quality of forming what is called "slag-wool" when expelled from the cupola, and since his experiments show that this "wool" usually contains more sulphur than the slag, desulphurisation is greatly enhanced. R. Spodlers and F. Schulte‖ also support this opinion.

However, complete desulphurisation cannot be effected by this method, since very basic slags are not easily melted, and require, in the cupola, additional fuel, which will introduce more sulphur, whilst in the converter and open-hearth processes they cause practical difficulties which do not enable one to reduce the sulphur contents to less than 0.03 per cent. in the finished metal.

It should here be noted that in recent litera-

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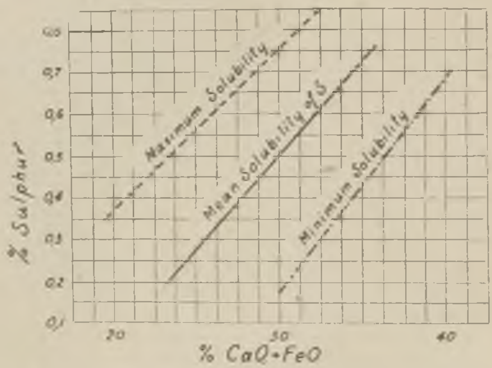
§ "The Foundry," 1921, page 675.
‖ "Die Giesserei," 1924, page 281.

ture relating to foundry practice it has many times been mentioned that calcium-fluoride, CaF_2, favours desulphurisation. This is easy to explain, since the addition of fluorspar greatly increases the fluidity of slags, or, in other words, enables one to run on more basic slags, the effect of which on desulphurisation has just been discussed.

Electric furnaces present the best conditions for desulphurisation with basic slags, since (1) it is possible to conduct the whole process at very high temperatures, and (2) the atmosphere of the furnace is neutral and not oxidising. Under these conditions it is possible to keep up the reactions in the presence of carbon.

$FeS+CaO+C=CaS+Fe+CO-30{,}710$ cal. ... (3)
$MnS+CaO+C=CaS+Mn+CO-74{,}811$ cal.... (4)

These reactions are intense in the presence of the high temperature of the electric furnace, and since CaS is not soluble in the metal, it is possible almost completely to desulphurise the metal. The slag thus obtained has approximately the following analysis:—$SiO_2=31$; $CaO+MgO=60.5$; $FeO+MnO=3.5$; and $S=0.15$ per cent., the sulphur content in the metal being 0.008 per cent.



Solubility of Sulphur in relation to the CaO+FeO contents

Fig. 1.

In iron foundries there has been of late an increasing use of the alkali metal compounds, especially those of sodium, for desulphurising. Since in the first place, at the temperature of the molten bath, sodium carbonate is decomposed into the oxide of sodium and carbon dioxide, the reactions which take place afterwards can be summarised in the following formulæ:—

$Na_2O + FeS = Na_2S + FeO + 36{,}313$ cal... .. (5)
$Na_2S + 2FeO = 2Na + 2Fe + SO_2 - 153{,}466$ cal. (6)
$Na + FeO = Na_2O + Fe + 34{,}187$ cal. .. .. (7)

Similar reactions also take place with manganese.

In the presence of the silica contained in the slag, the following reactions also take place:—

$Na_2O + SiO_2 = Na_2O.SiO_2 + 45{,}200$ cal. .. .. (8)
$Na_2S + FeO + SiO_2 = Na_2O.SiO_2 + FeS + 8{,}887$ cal. (9)

These latter reactions can actually cause the return of part of the sulphur into the metal.

For all practical purposes, Walter solved the problem by marketing desulphurising briquettes the composition of which is such that if added to the extent of 0.5 per cent. by weight to the charge, it is possible to obtain a total reduction of 80 per cent. of the sulphur in the cast iron.*

Effective desulphurisation is only obtained if the "desulphurising medium" does not come into contact with the slag containing SiO_2. For this reason the medium should not be added through the charging door. The elimination of sulphur in the ladle also does not give good results on account of the large quantities of sulphur dioxide which are evolved, contaminating the atmosphere, and on account of the slag which is always present in the ladle.

At the present the best means of overcoming these difficulties is to employ cupolas of a special design with a slag reservoir, patented by C. Rein, in conjunction with a Durkopp-Leyken overflow arrangement. In a cupola so designed the slag and the metal are separated in the furnace so that only clean iron reaches the

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* Stahl und Eisen, 1922, page 506.

mixer, the slag being collected in Rein's lateral reservoir.

The desulphurising medium is added to the metal in the mixer, which is surmounted by a flue for carrying off the sulphur dioxide.

J. Mehrtens* gives the following results for the elimination of sulphur by this process:—

Before adding briquettes: 0.099, 0.074, 0.107, 0.090 per cent.

After adding briquettes: 0.045, 0.053, 0.066, 0.065 per cent.

Thus the mean reduction of sulphur is 35 to 50 per cent.

Where cupolas are not provided with mixers, the elimination of sulphur is carried out in a specially-constructed tapping spout having an overflow arrangement for the rapid separation of the slag. This process is adopted in America, but exceptional results cannot be expected, since the metal comes into contact for only a very short time with the desulphurising medium.

Attention should be paid to the fact that one of the qualities of Walter's desulphurising process is that the intensive activity of the reactions reducing Fe and MnO and decreasing the chemical losses reduces favourable conditions for the elimination of the dissolved gases by making the metal boil. This gives a superior casting metal possessing high mechanical properties.

DISCUSSION.

Inter-Relationships with Silicon and Manganese.

Mr. F. J. Cook said that, whilst the Paper would undoubtedly be an interesting and useful one, he could not subscribe to what he called the underlying idea of it. The author seemed to point out that sulphur in any degree is bad for cast iron, and he personally could not subscribe to that. Generally speaking, he believed it would be found that it had been proved by a good many workers, and particularly by Coe and the late Dr. Stead, that there is no gain in physical properties in cast iron where the sulphur

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* Stahl und Eisen, 1925, page 449.

was below 0.07 per cent. Another point which cropped up in connection with this matter was mentioned when Coe presented his Paper at the Cardiff Convention many years ago, viz., the relation of the sulphur to the silicon. In getting out data in connection with high-duty iron, some 33 years ago, he himself had been struck with the fact that the highest physical properties were obtained when the sulphur was in the proportion of one-tenth the silicon. That was borne out very strikingly by Coe's work, but he had not noticed it at that time, and he (Mr. Cook) drew attention to it in the discussion on Coe's Paper. He had had subsequent correspondence with Coe, who, as the result of checking over his results obtained during a number of years, said he was surprised to find how frequently this ratio of 1 to 10 was associated with the highest physical properties of each series of tests. As the result of practical observations in the foundry, both with malleable iron and grey cast iron, this fact had impressed him, and had continued to do, although he had no scientific proof why it should be so, and it would be of value if the author could give any data on the subject, as well as in confirmation of the statement in the Paper that the physical properties are improved by the total elimination of sulphur.

Mr. John Shaw said he was not in agreement with Mr. Cook's suggestion as to the sulphur being one-tenth the silicon. This was satisfactory when dealing with an iron in which the silicon was 1.2 and the sulphur 0.12 per cent., but when dealing with a soft iron in which the silicon was 3 per cent., should the sulphur be 0.3 per cent.?

Mr. Cook: Yes.

Mr. Shaw said that was contrary to anything he knew. His experience, especially in the lower grades of iron, was that a great deal more depended upon the relation of the managanese to the sulphur than upon the relation of the silicon to the sulphur.

Mr. J. T. Mackenzie (American Foundrymen's Association) said that the sulphur problem is not particularly keen in America at the moment, but at one time during the war it was very serious. In the casting of a pipe when the metal might fall 16 ft., there might be motion at the bottom of the mould, and anything like a sulphur ratio of one-tenth the silicon would result in the accumulation of manganese sulphide in the bottom of the casting if the metal was sufficiently hot. If it were not sufficiently hot, there would be blow-holes in the bottom. Through the reduction of the sulphur from 0.12 to 0.07 per cent. that difficulty was overcome. He did not think the silicon/sulphur ratio was quite the determining factor, and the manganese must be brought in.

Mr. E. J. L. Howard wrote that he had read with considerable interest the above Paper. Three years ago he had occasion to attempt to reduce the sulphur content of the iron being used in the foundry, and thought that the most simple method to adopt would be the use of soda ash. It was found that $\frac{3}{4}$ lb. of soda ash to each 1 cwt. of metal placed in the bottom of the shank affected a reduction of 30 to 35 per cent. of the sulphur content. The higher the sulphur content, the greater appeared to be the percentage reduction, and with irons containing 0.06 per cent. sulphur only about 10 per cent. was reduced. After treatment the metal seemed to be much more fluid and appeared to run better, although considerable difficulty was encountered in getting rid of the slag, sodium silicate being very thin, but if lime or fine sand were thrown on to the surface of the metal it could be readily skimmed quite clean. The linings of the ladle were badly cut into by this slag, and had a very short life. He understood that there is a lining, suitable for ladles in which this treatment is carried out, now on the market. He would be interested to know if the author considered there was much advantage to be gained by de-sulphurising metal containing less than 0.66 per cent. sulphur, and if the metal so treated has a lower viscosity than the untreated.

PRACTICAL POINTS FROM THE METALLURGY OF CAST BRONZES.

By H. C. Dews (Member).

Metallurgy is not always a welcome dish to serve before foundrymen. The environment in which the foundryman has to grapple with the rugged problems of daily production does not conduce to that detached thinking which scientific theories often demand. In the foundry considerations which appear to offer no immediate prospect of facilitating or cheapening the work in hand are apt to be ruthlessly pruned away and a short-sighted policy inimicable to the well-being of the industry is apt to develop. Without an occasional pause to survey the progress of knowledge, the foundryman becomes intolerant of the work of the pure scientist who is striving to advance the borders of knowledge and ultimately to improve practice in the foundry.

The metallurgist is not without responsibility for the unsympathetic reception which his work often receives in the foundry. The greatest disability under which most scientific workers suffer is their incapacity to present their work in language which the ordinary person can easily understand. Probably the most difficult part of any scientific research is to explain it in non-technical language. However clearly the scientist himself may see the light it appears invariably to be his lot to leave the layman floundering in a welter of words. The critical test of a scientific theory, however, can only be applied by putting it to practical use, and a scientific worker must be measured by his ability, not only to make his work applicable to practice, but to make it understood by those whose practice it is intended to modify. Before he can do this it is often necessary to convert the practical man to a scientific method of thinking, and when the practical man's interest is deepened in appreciation of scientific reasoning his ability and usefulness will be increased in no small measure.

The essence of scientific thinking—that there can be no effect without a cause—does not always appear to permeate foundry technology, or else there would be more searching for the cause of those abundant troubles now blamed on the foundry "imps." To discover the cause of a failure is to go a long way on the road to finding its remedy and, what is more, it is the straight road. To try and remedy a fault in ignorance of its cause is frequently as progressive as running round in a circle.

The production of gun-metal castings is a practical job; but more than practical knowledge is needed to carry out the job successfully. Some knowledge of the underlying theory is emphatically necessary, and the more these theoretical questions can be worked out alongside practical production the more will the practice benefit. The points which are to be discussed in this Paper the author believes to be of practical importance, and their theoretical aspects are dealt with for that reason.

It is a commonplace at the present time that engineering science is progressing faster than the improvement in materials. In many branches development is restricted by the apparent limitations of available materials, and new materials are being eagerly sought. At the same time that research into new alloys is being explored there is still a demand for improvement in the old materials. This is particularly true for bronze alloys. The choice of bronze for certain parts of steam and hydraulic machinery is inevitable, whilst at the same time the higher temperatures and pressures at which such machinery is now being driven imposes considerably more responsibility on the bronze parts. If bronze is to continue to hold its unique position in these fields, the engineer must be satisfied of its improved reliability and freedom from internal defects Eliminating the uncertainty often cherished by engineers in regard to the internal solidity of a cast-part would allow a reduction in the factors of safety, and thus automatically improve the value of the casting.

In bronze-founding there are a multitude of potentialities for failure, and there is need for a higher degree of technical control than is commonly realised. A casting which on the outside appears to be perfectly good, may be distinctly weak internally, and that such internal weakness leaves no indication of its presence on the outside of the casting, is the bronze foundryman's chief pitfall. It is only by careful production and stringent testing that failures in service can be avoided. Furthermore, it is apparently only slight variations in technique that may introduce such grave defects. Take, for instance, the provision of test bars in Admiralty gun metal. The British Admiralty specification calls for 16 tons per sq. in. tensile strength, and this result can be readily obtained in normal foundry practice. Yet wide variations in test results are frequently reported. It is easy, as a matter of fact, to cast two test-bars out of the same ladle of metal, one of which will have a tensile strength of nearly 20 tons per sq. in., and the other only about 8 tons per sq. in., and yet both on the outside will appear to be perfectly good metal. The different strengths of the bars will be due to the fact that one will be built up of solid and continuous metal, whereas, the other will be honeycombed with spaces. In the first case the apparent section is the real section of metal carrying the load, while in the second case the load is carried actually by a real section of metal much less than the apparent section. In Fig. 1 is shown a photomicrograph of a section cut from a weak bronze. The black areas are holes in the metal, and from the extent of these holes it can be seen how little solid metal there is to carry the load. A section from the same bronze, but cast correctly, is shown in Fig. 2, and it can be seen to be perfectly good and sound.

It is necessary to produce bronze which shall consistently be free from internal porous-places in order that the castings shall have the maximum strength of which the bronze is capable, but before such a desirable standard can be attained one must know what causes some bronzes to be porous. It can be said at once that the porosity is due to the effect of two peculiarities of the freezing. In the first place bronze freezes over a range of temperature, and, secondly, it contracts in volume during the process of freezing. These two features account for the majority of troubles experienced in bronze founding, and it would appear to be profitable, therefore, to study them closely.

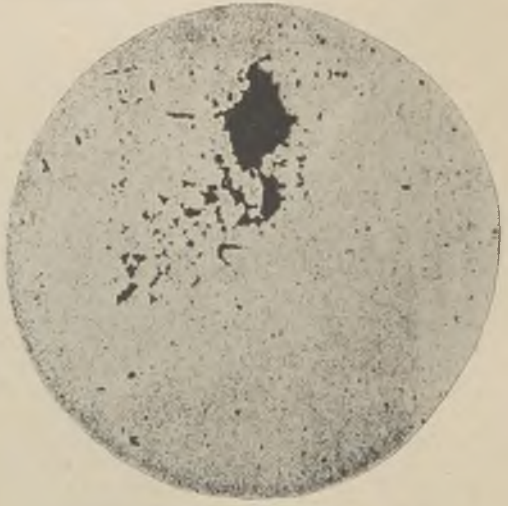

FIG. 1.—POROUS BRONZE. × 25.

The Solidification Process.

When a mould is filled with molten metal and it begins to cool, the metal in contact with the cold face of the mould cools quicker than the interior. The temperature at which solidification commences is thus first reached by a layer of metal near the mould face, and each layer of metal will reach the temperature at which solidification commences at a later and later time. In the case of a pure metal, which solidifies at a definite temperature, the casting would thus solidify layer by layer as each layer reached the solidification temperature. In the case of bronze, the alloy does not solidify at a definite temperature, but over a range of temperature. It cannot, therefore, form a wall of solid on the outside, gradually thickening to the interior, as in the case of a pure metal. When the outside of a mass of molten bronze reaches the temperature of commencement of solidification, only a portion of the outside layer solidifies, and the bulk of the layer remains liquid until the temperature has fallen considerably below the temperature of commencement of solidification. In the meantime, the next layer into the casting has reached the temperature of solidification and has started to form solid, and so on. In this way it can be seen that solid has started to form a good way into the casting before the first layer has passed through its pasty stage.

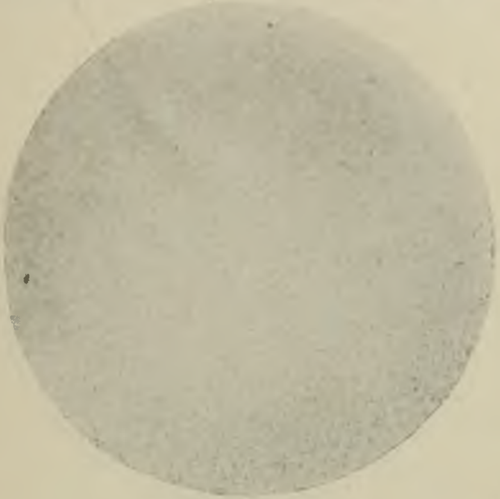

FIG. 2. SOUND BRONZE. × 25.

The first stage in the freezing of the outer layer is the formation of a network of solid metal, and from this network arms of solid metal then grow into the liquid interior. From these first arms, or dendrites as they are called, as the temperature falls smaller dendrites branch off at right angles, first at the base and then gradually up the length of the shoot. From these secondary branches a third set of branches then begin to grow out again at right-angles. With each fall of temperature the spaces between the branches are being filled in making the trees of solid metal gradually thicker at the bases, while the tops are continually pushing onwards into the liquid. In Fig. 3 is a photomicrograph of a section of bronze polished and etched to show the dendrites.

FIG. 3.—DENDRITES IN BRONZE. × 25.

Now, during this process of freezing, bronze contracts considerably. The solid metal occupies less space than the liquid from which it is formed. The formation of each branch of solid metal tends to leave a space around it. While any liquid metal is available, it will flow up to the dendrites and fill up the space left by the solidification contraction. If for any reason liquid metal is not available, then voids will be left surrounded by solid metal. In the resultant casting these voids will be found in the shape of the outline of the partly-formed dendrites. This is illustrated in Fig. 1, where the contraction cavity shows a dendritic outline. Further proof may be obtained by breaking open a bad casting, when the dendrites may be frequently seen projecting into space.

Contraction cavities will not form if liquid metal is continually available to flow up to the solidifying dendrites. To ensure that each section of a casting, as it freezes, shall be in communication with liquid metal either from a thicker section, from a section filled later, and therefore containing hotter metal, or from a runner or riser is no small part of the foundryman's difficult art. Even when a supply of liquid metal is available, it has to flow through a maze of dendrites to fill up all the spaces. It is advisable, therefore, to shorten its path as much as possible, to be sure that it is adequately fluid and that there are no mechanical obstructions to impede its easy flow.

Thus, there are many factors which affect the proper filling up of the cavities left during freezing, and to produce sound castings consistently all these factors must have their proper weight of attention. Unfortunately, few of the important details have been sufficiently worked out by research workers. The foundryman, indeed, has a legitimate cause for complaint that the essential data is greviously lacking. Much of the work which should be put on a quantitative and rational basis is still only guess-work, because that portion which can only be dealt with in the research laboratory has not been investigated.

The Contraction on Freezing.

The whole process hinges on the contraction on freezing, but the exact value of this figure is conspicuously lacking. Recently a few figures for the contraction on freezing for some of the pure metals have been determined, and reliable figures for some of the common alloys, particularly those of low melting-point, have been slowly making their appearance. One still waits in vain, however, for a series of determinations to be made on a range of bronzes and on a scale comparable with that with which other physical properties, such as the tensile strength, are now determined. There seems little prospect of the foundryman being provided with data in the same lavish manner as the engineer. A mass of research work has been expended on the determination of the mechanical properties of the common alloys, and it is by means of these values that a choice is made of each particular alloy for specific service purposes. The foundryman is seldom consulted as to his capacity to produce the necessary castings free from flaws. It remains for him to protest when unsuitable alloys are demanded. But he can only protest feebly that the alloy does not cast well, and for lack of data to make his protest convincing it is often over-ruled with the result that expensive and faulty castings find their way into service. For example, an alloy with a contraction on freezing of only 3 per cent. of its volume would be definitely easier to cast than one with, say, 5 per cent. contraction. There is reason to believe that comparatively small variations in the composition of the bronzes may alter the contraction on freezing to the extent of 2 or 3 per cent., and if a reduction of this order could be secured, it would be a consideration of no small value to the foundryman. Besides increasing his chance of producing sound castings, there would be other savings. For example, smaller runners and risers could be used. The saving in melting-costs on this account alone would go a long way towards paying for some research on the value of the contraction on freezing.

The Temperature Range of Freezing.

If there were no contraction on freezing, then it would be perfectly easy to make good, sound castings, regardless of the cooling rate and the freezing range. The effect of casting temperature, amongst other things, would cease to be of much importance. Practical experience indicates, however, that all commercial bronzes contract on freezing to a greater or less extent, and it is necessary to take account of the freezing range. The longer the freezing range for a given value of contraction and the more difficult it is to cast the alloy free from porosity. It can be appreciated that, if the freezing covers a wide range of temperature, then a considerable depth of metal will be freezing at the same time, and the feeding liquid will have to traverse a thick maze of dendrites to fill up the last cavities. It is thus desirable that the freezing range should be as narrow as possible.

Fortunately, there are more data relating to the freezing range than is the case with regard to the value of the contraction on freezing. The freezing range of bronze depends, of course, on its composition, and the subject is expressed in metallurgical science by means of the equilibrium diagram. Such a diagram is shown in Fig. 4.

The temperature of the beginning and the end of freezing are shown by the two thick lines passing across the diagram. Pure copper, it is seen, starts and finishes freezing at the constant temperature of 1,083 deg. C. The addition of tin lowers the freezing temperature and introduces a range of freezing. For instance, an alloy with 5 per cent. tin starts to freeze at 1,050 deg. C. and an alloy with 10 per cent. tin starts to freeze at 1,000 deg. C. These temperatures are indicated by the points on the top thick line, which corresponds to the compositions 5 per cent. and 10 per cent. tin. The temperature of the end of freezing cannot be read off at once in such a simple manner on account of a certain sluggish behaviour of the bronzes. The diagram is an equilibrium diagram —that is, it represents conditions which would eventually come about if ample time were allowed for all the changes possible to proceed to their conclusion. In ordinary foundry practice bronzes are cooled too quickly to reach equilibrium. In fact, it would need such a slow rate of cooling that the actual solidification of a casting would be spread over several weeks in order to reach equilibrium conditions. If such a slow rate of cooling were possible, then the alloy would finish freezing at the temperature indicated by the point on the lower thick line corresponding to the composition of the particular alloy. Actually, on account of the relatively rapid cooling, the freezing finishes at a point farther to the right of the diagram. Instead of the course of cooling falling down the straight dotted lines, it follows a path, such as is shown by the lines bending off to the right immediately after passing the beginning of freezing. The exact point where the end of freezing is to be found for any particular set of conditions cannot be worked out very easily; it can only be

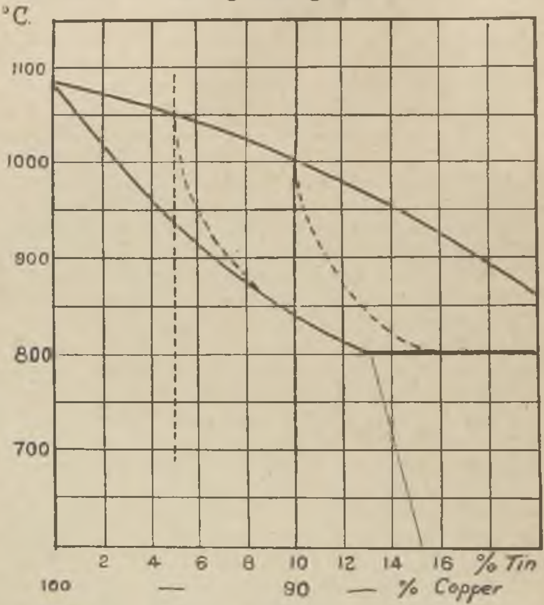

FIG. 4.—BRONZE EQUILIBRIUM DIAGRAM.

estimated empirically. The curved dotted lines in Fig. 4 for the 5 per cent. and 10 per cent. alloys represent fairly closely the course of freezing for these two alloys when cast in medium-size sand castings under ordinary foundry conditions. The 5 per cent. alloy is seen to finish freezing at about 875 deg. C., while the 10 per cent. alloy finishes at 800 deg. C. The range of freezing for these two alloys is, therefore, about 175 deg. C. and 200 deg. C. respectively.

Effect of Other Metals.

The copper-tin alloys are seldom used in practice in the pure state, but generally have added to them definite quantities of other metals. Few bronzes are cast, for example, without the addition of either zinc or phosphorus. These additions all affect the freezing range of the bronze, and hence need to be considered from the point of view of assisting or retarding the elimination of contraction cavities.

The effect of phosphorus on the freezing range of bronze is greater than that of any of the other usual additions. Small amounts of phosphorus materially lengthen the freezing range by depressing the temperature at which freezing is completed without a proportional lowering of the temperature at which freezing commences. The addition of 1 per cent. phosphorus to a bronze containing 10 per cent. tin lowers the temperature of commencement of solidification from about 990 to about 950 deg. C., that is, by 40 deg. C., and the temperature at which solidification is completed is lowered from about 800 deg. C. in the pure 10 per cent. tin-bronze to about 630 deg. C. for the phosphor-bronze. There is, therefore, a drop of 40 deg. C. in the beginning of freezing and a drop of 170 deg. C. in the end of freezing. The net result, then, of adding 1 per cent. phosphorus to the 10 per cent. pure bronze is to increase its freezing range by 130 deg. C. This is a very serious matter for the foundryman. A freezing range of 300 deg C.—a common value for phosphor-bronze—makes it exceedingly difficult to produce good, sound castings in sand moulds from such an alloy.

Care must be taken to prevent phosphorus in unexpected amounts finding its way into gun-metal, or it is liable to play havoc with the test results. It is common practice in some foundries to add a little phosphor-tin or phosphor-copper for the purpose of "deoxidising" bronze. Generally good results attend this practice, but in some foundries nothing but disaster follows such additions. This is due to appreciable and unknown quantities of phosphorus being left in the alloy, with consequent lengthening of the freezing range.

Zinc affects the freezing range in the first place by lowering the temperature of the beginning of freezing. A rough idea of the effect of zinc can be had by assuming that each 2 per cent. of zinc has the same effect as 1 per cent. of tin. Thus an alloy with 8 per cent. tin and 4 per cent. zinc would have a similar freezing range to an alloy containing $8 + \frac{4}{2} = 10$ per cent. tin. The exact value of the freezing point can be obtained from an equilibrium model constructed on the lines of the diagram in Fig. 4, but, as this is a rather complicated matter, it will not be dealt with further here.

The Fracture of Bronze.

The metallurgical points which it is so vital to understand before sound bronze castings can be confidently produced have not been adequately discussed in the past, and many failures have been blamed to minor effects. The appearance of the fracture of a bronze casting in particular appears to have been a fruitful source of misconception, and, on account of the advantage to the practical man in being able to read the fracture correctly, one might advisedly deal at length with this subject.

If a bronze casting is broken open, its fracture will clearly indicate whether the casting is good and strong or whether it is weak and porous. In the latter case, there may be noticed some red and brown patches instead of the clear yellow, somewhat silky appearance associated with sound metal. An explanation of the discoloration, which it would appear slightly ridiculous to mention were it not widely quoted, is that the bronze is not mixed properly. Trade literature, either through ignorance or with a deliberate intention of misleading the foundryman, does not hesitate to trade on this fallacy. One sees advertisements of deoxidisers, fluxes and other rubbish the use of which is alleged to promote proper mixing of the bronze, but which actually have no such effect. For the same purpose one is advised to cast in special moulds, to purchase ingots with a fancy name (and usually at an enhanced price), and to indulge in a variety of other dodges. It can here be stated definitely that it is impossible to melt and pour bronze in the foundry without invariably securing perfect mixing. There is another aspect of this mixing question. Some foundries make a practice of never using new metal for castings without first ingotting and remelting it. Twice-melted metal is supposed to be better mixed. On the other hand, there are foundries who dislike scrap or ingot metal, and for all but the least important work they insist on new metal only. From the point of view of thorough mixing, there is nothing to choose between either method. It does not matter whether one starts off with new metal, ingots, runners or a mixture of any proportion of scrap and raw metal, the ultimate alloy is bound to be properly mixed.

Another explanation of the peculiar appearance of the fracture of a porous casting is that the metal is oxidised. It must be admitted that this is at any rate a reasonable explanation, since the fracture does appear to show oxide tints. But why should the oxidised metal be confined, as these bad places generally are, to a local area of the section? If the metal is oxidised, surely the oxide tints should permeate the whole section. Sometimes they do, but generally the discoloured area is only local. To avoid this so-called oxidation, one is recommended not to stew the bronze, to melt it rapidly and to use a deoxidiser. All these remedies will, under certain circumstances, help in producing sound castings, but their effect is not due to avoidance of oxidation. For instance, slow melting is supposed to produce oxidised metal. Now, in actual practice, to get rapid melting in the ordinary bronze foundry, working with natural-draft coke furnaces, the draft pressure must be high and the furnace atmosphere must be oxidising. As a matter of fact, there is plenty of experimental evidence that an oxidising atmosphere is essential to produce good-quality bronze. At least, one well-known foundryman has put on record that, where an oxidising atmosphere could not be secured in the furnace, sound castings could not be made unless an oxidising agent was added to the alloy just before casting. He found that, when bronze was melted under reducing conditions, the addition of lead-oxide was necessary to induce soundness.

A false analogy has been drawn between the behaviour of copper and bronze towards deoxidisers, and this has led to the extended use of certain copper deoxidisers in the bronze foundry. Very frequently, however, much money is wasted on these deoxidisers, with no technical gain.

The oxide of copper, which is formed when copper is melted in an oxidising atmosphere, is soluble in molten copper, and, although recent researches have shown that copper oxide is not the bugbear that less enlightened metallurgy believed it to be, yet still, for certain purposes, it is desirable to remove this oxide from the metal. To do this, some element is added which will reduce copper oxide to copper and take to itself the oxygen to form an oxide of the added metal. It is then necessary that the new oxide which is formed should be easily removed as slag, or it should be sufficiently volatile to burn off. If the new oxide is not readily removable, the last state will be worse than the first. There are several available deoxidisers suitable for copper. For example, there is silicon, which, when added to copper containing oxide of copper, reduces the copper oxide to form copper and silicon oxide. The silica is insoluble in copper, and it is much lighter than the molten metal, so that it rises to the surface of the melt, and is either skimmed off or slagged off. There is also phosphorus, which will readily reduce copper oxide, forming an oxide of phosphorus, which again is insoluble in the melt, and readily rises to the top, either to volatilise or to form a slag. Many other materials also may be used, such as manganese, iron and zinc. The essence of the whole process is that the oxide of copper is in solution, and a chemical reaction can therefore readily take place.

Now, in bronze there is an entirely different condition. There are no soluble oxides in the alloy. It can be shown that tin and zinc both reduce copper oxide. In the making of bronze, therefore, copper oxide is reduced, and in its place zinc or tin oxide is formed. These oxides are both insoluble in bronze. Zinc oxide is not only insoluble, but it is not even wetted by the alloy. It is very light, moreover, and it quickly rises to the surface of the melt, where it may be skimmed off. It is only when proper precautions are not observed in skimming and pouring that zinc oxide will be found in the castings. These oxide inclusions are readily apparent without the aid of a miscroscope, and appear as patches of greenish-white sandy material or sometimes looking like a bit of paper which has been screwed up and thrust into the metal. Apart from the unsightliness of such patches of oxide on the machined surface of a casting, it must be remembered that the oxides are of low mechanical strength, and therefore they break up the continuity of the metal and lower its strength. Oxide inclusions may also impede the liquid flow during the freezing and contraction of the casting, and thus lead to porosity.

The elimination of tin oxide is not so easy as it is to free the bronze from zinc oxide, because the tin oxide is nearly as heavy as the metal, and therefore does not readily rise to the surface of the melt, but remains disseminated throughout as insoluble particles. Frequent comment has been passed on the fact that phosphorus, the most popular deoxidiser for bronze, will not reduce tin oxide. As phosphorus is usually only added to the extent of about 1/10 per cent., it is difficult to see how it can be expected to react with any oxide distributed, as is the tin oxide in the form of fine insoluble particles. A much larger proportion of any reducing metal would be required to react under these conditions.

It is essential, therefore, to prevent oxide finding its way into the casting by mechanical rather than chemical means. The first precaution is to see that the skum from the top of the melt is properly skimmed off. Even then there is the oxide which forms on the stream of metal as it is being poured into the casting, and to prevent this oxide being carried into the mould, choke-runners should be used. Finally, there is a danger of oxide forming during the flow of metal about the mould, particularly where large, flat surfaces are exposed uppermost. Only a modification of the method of running can avoid this trouble.

It is the author's considered opinion that arguments which seek to blame the cause of porosity in bronze castings on to oxides, gas occlusions, improper mixing or similar secondary matters without full reference to the volume change on freezing and the freezing range are liable to be very misleading; and that these two latter effects are of supreme importance. There seems to have been a general avoidance in the past of any discussion of such a point of view, and on account of this remission there is at present a disappointing paucity of important fundamental data thereon, but if foundrymen were to develop a more sympathetic attitude towards research and a greater freedom in discussing their troubles, there is little doubt that research could quickly be guided into channels of profitable incidence on practice.

DISCUSSION.

Fracture Judging.

The PRESIDENT (Mr. Wesley Lambert), emphasising Mr. Dews' remarks with regard to the interpretation of the fractures of bronze, said it was his experience that the majority of engineers could not interpret the fracture of a non-ferrous metal. When a bronze of the nature of, say, an Admiralty gun-metal was ruptured, it was not unusual to hear such remarks as "It is not even mixed properly," "It is made up with a lot of scrap brass; look at those yellow and red patches," etc. Such remarks evidenced the fact that the people who thus commented on a fracture could not interpret the fracture of a bronze. It was essential that the founder should have a correct knowledge of the fracture of each individual alloy, and he should be able to judge by the fracture whether the metal had been correctly compounded, whether it had been cast at too low or too high a temperature, and also whether the mould was sufficiently dry. With the knowledge obtained from the correct interpretation of the appearance of the fracture, combined with the knowledge obtained from the testing laboratory of the tensile and other tests, one should get a good idea of the best standard fracture to work to. The President also emphasised the necessity of adopting a standard method of producing the fracture. It was quite possible, by varying the method of fracture, to produce fractures of quite different appearance from one bar of uniform character. It was quite possible, in the case of both ferrous and non-ferrous metals, to break a bar in such a manner that the rupture would occur around the crystal grains, or in such a way that it would occur through the crystal grains, thereby producing a fracture which appeared to show that the structure was coarsely crystalline, or, on the other hand, that it was of an amorphous or of a fine granular structure.

Two Types of Contraction.

MR. A. H. MUNDEY said he was particularly interested in Mr. Dews' work, especially in connection with the mechanism of solidification, which had to be studied very closely in connection with die casting. The contraction of the metal due to crystalline contraction during solidification, and the contraction which occurred after the metal became solid, were two separate functions. Certain metals contracted very little due to crystalline contraction, but they all contracted very considerably afterwards, according to the simple law of lineal contraction—a fact which was often forgotten. It had been suggested to him that surely, seeing that there was such a magnificent sharp impression of the mould, there could be no such contraction. That was not true, however, and that second contraction must be legislated for most definitely. Every patternmaker's rule had a little spare—a 1-ft. rule was a little longer that 1 ft.—so that he might legislate for lineal contraction, but that lineal contraction was quite different from the contraction which occurred during solidification, because the latter varied according to the constitution of the alloy.

Equilibrium Diagram as a Basis.

Mr. A. Logan, emphasising Mr. Dews' plea that foundrymen should try to take an intelligent interest in equilibrium diagrams, said it was only by studying such things and trying to grasp what actually occurred during the solidification of an alloy that they could anticipate with intelligence what would happen inside the mould, and cater for it. Mr. Logan also emphasised the importance of a study of the liquid contraction which occurred on freezing. It was undoubtedly a point about which we knew very little, and the sooner we knew more about it the better.

Mr. W. Cartland pointed out that, although a large number of Papers was published giving the results of investigations of the various alloys from the purely scientific point of view, and occasionally some very severely practical Papers were published, there seemed to be very few links between the theoretical or scientific and the practical. Mr. Dews was to be congratulated on this Paper, because it did form one of the links between the two extremes, and it was to be hoped that many more Papers of the same character would be published.

Effect of Virgin Metals.

Mr. Henry Milner, discussing the relations between works metallurgists and foundrymen, complained that these two departments seemed to be quite distinct in aim and object. Reference had been made by the President to the necessity for educating the foundrymen to a scientific interpretation of fractures, but the only fractures which the metallurgist put before the foundrymen were the bad ones; he never showed and explained the metallurgical points of a good fracture.

Referring to a bronze consisting of, say, 10 per cent. tin, 0.5 per cent. phosphorus, and the remainder copper, he asked Mr. Dews for information with regard to the beads of white material which came back very often on the riser, but not so often on the runner. Also, discussing a bearing bronze, of a composition similar to that of the bronze already referred to, except that it contained 8 per cent. less copper, for which 8 per cent. of lead was substituted, he said that much slag was produced, and he had found it impossible to eliminate it. It seemed to form on the sides of the pot, even though it had been skimmed. It had been stated in some quarters that the trouble could be overcome by the addition of nickel, and he asked whether Mr. Dews had had any experience of the use of nickel in bearing bronzes. With regard to the examination of bronzes, he said that, although the Admiralty called for a tensile strength of 16 tons per sq. in., and an elongation of 10 or 15 per cent., the inspectors acting on behalf of other large customers did not worry about physical tests; they had the bars machined and broken, and examined the fractures, and they contended that that was sufficient. He asked whether Mr. Dews considered that the fracture was a better guide than the physical tests, or *vice versa.*

AUTHOR'S REPLY.

Phenomenon of "Tin Sweat."

Mr. Dews, replying to the discussion, said it was unfortunate that some works metallurgists got into the habit of telling the foundry workers about the bad work only. At the same time, it was the metallurgist's job to root out the bad work and to try to put matters right. Furthermore, they were sometimes reluctant to say what was correct, because conditions constantly improved, and what they one day regarded as perfection would the next day be improved upon. Their attitude was probably also due to the training they received; in science, no sooner did one look upon a thing as being a definite fact, than someone would come along with a new theory, which showed the old ideas to be only partly true.

With regard to the bronze containing 10 per cent. tin and ½ per cent. phosphorus referred to by Mr. Milner, who said that during the cooling he noticed beads of white material on the tops of the runners and risers, the author said that this material was a tin-phosphorus rich alloy, and it sweated out of the bronze just as the bronze was cooling from red heat to black. If the casting being made was a fairly light one, and if a fairly heavy runner was used, one need not worry much if a few of these beads appeared; but if the casting were a heavy one, and beads appeared on the top of the runner, one could be certain that the casting was useless. The beads appeared only when phosphor bronze was cast too hot; if it were cast cooler, the runner top, instead of being level or bulging out like a cauliflower, would sink, and there would be no beads of tin-phosphorus-rich compound on the runner. In the case of a light casting, one could not cast phosphor bronze cold enough to produce this sinking on the riser and runner, which were necessarily heavier than the casting. With the heavier casting, one could pour the metal cooler and could keep the tin sweat down. As a matter of fact, phosphor bronze of this description should be poured as cold as it was possible to run the casting sharp; the temperature should be just a little above that which would result in a cold shut or mis-run.

Leaded Bronzes.

With regard to the bronze containing 8 per cent. lead and 0.5 per cent. phosphorus, he said a slag was produced consisting of lead and phosphorus—a complex lead phosphate. This slag was continually being formed, and would rise to the top of the molten alloy. It was liquid at temperatures below that at which the casting began to freeze, so that one could not thicken it and skim it off the alloy before pouring. At ordinary casting temperatures the slag was so liquid that it was liable to run into the casting. When casting a high-lead phosphor bronze in his foundry, it was the practice to use either a "strainer" head or a fairly large cup with a plug in it, so that one was able to maintain a good head of metal in the runner and to allow only the clean slag-free metal to run into the work. He did not believe there was anything in the proposal to use nickel for the purpose of eliminating that slag, and he knew of no way of overcoming the trouble other than by preventing the slag getting into the work by means of special pouring devices.

Fractures of Physical Tests.

There was a good deal to be said for the practice of examining only the fracture of bronze and disregarding the physical tests. It was possible to pour two test-bars from one pot of Admiralty gun-metal, one of which would have a tensile strength of 8 tons and the other 18 or 20 tons per sq. in. It was obvious, of course, that both of these were not representative of a casting poured from that pot of metal, nor representative of the quality of the bronze. The only way to ensure getting a test-bar to represent the quality of the bronze was to cast about six bars, commencing at a temperature higher and finishing at a temperature lower than that at which one would cast the work. One could then plot the test results on a curve and take the peak as representing the best test one could get out of that mixture. That method was hopelessly inconvenient for practical work, however, and applicable only to experimental work. There was thus a good deal to be said for nicking a piece of metal and examining the fracture, but one needed a good deal of experience before one could rely upon such a method. Founders were familiar with one type of inspector who came to their works occasionally, and, by encouraging such a method of test, we should have, sooner or later, a very inexperienced inspector visiting the works, who would reject castings on what he considered to be a bad fracture, and which the founders themselves might consider to be a good fracture.

Co-operation between Works and Laboratory.

The PRESIDENT said that on several occasions he had pointed out that the founding of metals was not an exact science, and, in view of the many variables that were introduced in the manufacture of castings, especially those of complicated shape, he doubted whether this could ever be expected—a fact which was often overlooked by the purchasers of castings. The purchaser seemed to think that, with the present-day science at our command, one ought to be able to turn out perfect castings, but until the founding of metals became an exact science, one could not always ensure standard conditions. Commenting on the complaint which had been voiced to the effect that the works metallurgist approached the foundryman only when things went wrong, he pointed out that, after all, such a condition of things was more or less to be expected. On the other hand, it was up to the foundryman to educate himself, and there was no reason why the foundryman should not cultivate a sufficiently friendly feeling, between himself and the works metallurgist, to ask assistance from the metallurgist. In a good many instances the metallurgist took it for granted that the foundryman was able correctly to interpret fractures, and that a good fracture would give good test results; if the foundryman did not know what test results to expect from a metal, which he considered to be good, he should ask the works metallurgist to make some tests and to furnish him with the results. He (the President) did not think a works metallurgist, if he was worthy of his position, would ever refuse such information.

With regard to the equilibrium diagrams, he said the ordinary craftsman could hardly be expected to understand or to digest the many diagrams that one found even in the technical literature devoted to the foundry craft. As far as possible, he adopted the practice, when lecturing, of dealing only with that portion of the curve which had relation to the usable foundry alloys, and he carefully avoided dealing with the complete curve and its ramifications. It was, however, advisable for the foundryman to study that portion of a curve which covered the alloy or range of alloys with which he was likely to have to deal. In this connection he (the President) offered to help any foundryman who had difficulty in mastering an equilibrium diagram. If any such would write to him and explain their difficulty, he would be glad to interpret that portion of the curve which related to their particular alloy.

"Tin Sweat"

Discussing the "tin sweat" which appeared when casting bronze as mentioned by Mr. Milner, he confirmed that the constituent which sweated out was obviously the constituent which was the last to solidify. One must regard the first-formed tin-copper casting as a sponge containing in its interstices a constituent which had not solidified. As soon as the matrix or sponge had solidified and had begun to contract, there would be a tendency for the liquid constituent remaining in the interstices to be squeezed out. Obviously, as Mr. Dews had pointed out, it was best to arrive at a temperature for casting the bronze at which as much as possible of the low-melting-point constituent would be trapped in the casting. At the same time, there was something to be said in favour of a little of the tin constituent sweating out, because when that occurred it indicated that the mechanism of solidification of the casting as a whole was proceeding along normal lines.

Discussing further the interpretation of fractures, he suggested that one should fracture specimens in various ways in order to arrive at a standard method, and also ask the metallurgist to favour with a short lecturette on the interpretation of any fractures so produced. He urged the foundryman to make friends with the metallurgist; if this was done both the metallurgist and the foundryman would learn something to their mutual advantage. Too often a foundryman was inclined to regard the metallurgist as a policeman, and in many instances foundrymen themselves were to blame for not making friends with the metallurgist. Foundrymen did not always appreciate the introduction of scientific instruments intended to aid them in their work. For instance, when a pyrometer went wrong they were inclined to say " Pyrometers are of no use," but if a pyrometer was handled as it should be handled, instead of meeting with the rough usage to which it is often subjected, far less trouble would be experienced and confidence in the use of the pyrometer would soon be established.

Nickel Additions to Leaded Bronzes.

Referring to the bearing bronze mentioned by Mr. Milner, and containing 8 per cent. of lead, he said that, with all respect to Mr. Dews, he would have suggested less phosphorus in the mixture, unless bound by a specification figure. Personally, he could see no valid reason for including a high amount of phosphorus in a bearing bronze containing a heavy percentage of lead. Much slag is invariably formed, which may, and sometimes does, find its way into a casting unless means are adopted to keep it out. With regard to the addition of nickel in lead bronzes, he said that such practice was resorted to more particularly in the case of alloys having a higher lead content than that mentioned by Mr. Milner. Nickel was one of the reagents which were sometimes introduced into bearing bronzes containing 25 or 30 per cent. of lead, the object of the introduction of the nickel being to "hold up" the lead, *i.e.*, to prevent segregation, and in this respect it was effective. Sulphur, plaster of Paris, and other reagents were also used in some foundries for a similar purpose.

Soluble Oxides in Bronzes.

Mr. A. Logan, commenting on Mr. Dews' statement that there were no soluble oxides in bronze, said that although he did not dispute that statement, it might be profitable to consider what happened when a bronze was maltreated. It was possible to melt in a reverberatory furnace a large amount of scrap—borings. and other metal of that type—and obtain thereby a mixture which a foundryman would refer to as being oxidised. If that metal were run into a ladle it would look very pasty, and a casting made from it would be full of porous places, gas-holes, etc., even though it were cast at the correct casting temperature. Mr. Dews had stated that there were no soluble oxides in the alloy, but the foundryman wanted to know the reason for the state of affairs mentioned, and how it could be remedied. In such castings there was a tendency to excessive segregation, and there was evidence of the "tin sweat" to which Mr. Milner had referred.

Remelted Bronze Borings.

Mr. Dews said that the point raised by Mr. Logan was very important indeed. He believed that the statement in the Paper, that there were no soluble oxides in bronze, was correct, and he made the statement quite definitely. The oxides which caused trouble in the casting of bronzes were, he believed, insoluble, and were held in suspension. Mr. Logan had visited his foundry on the previous day and had seen there a reverberatory furnace which was employed entirely in melting very fine bronze-borings which were taken from the lathes in the shops. These were turned out into ingots, and the ingots were re-melted—with new metal, he admitted—and poured into castings, and this metal never gave any more trouble than other metal with oxides, blowholes, or anything else. In fact, provided the metal were properly melted the second time, he defied any foundryman to tell the difference between a casting made from new copper and tin and one made from the dirtiest old borings swept up from the floor of the shop. It was merely a question of allowing sufficient time for the oxides, scum, dirt, and so on, to rise to the top of the metal, and then skimming it off. One could add a little phosphorus, to make it more fluid in order to allow the oxides to get to the top so that they could be skimmed off. He had never noticed any tendency for tin sweat to occur in metal made from borings or scrap any more than in new metal.

Gas Content in Metals.

Mr. A. H. Mundey said that many foundrymen missed or overlooked the fact that, of the oxides in gunmetal, tin oxide was not deoxidised by phosphorus. Copper oxide was deoxidised by phosphorus, but tin oxide must be coaxed to the top of the metal and skimmed off. It had been pointed out by Griffiths, two or three years ago, that tin oxide was some two and a-half times as hard as tool steel, and the presence of little bits of it in a bearing bronze was bad. Again, metal which had been melted very quickly, or had been standing very hot for a long time, occluded a very large quantity of gas. That gas had to be removed, but if the metal were cast badly or at too high a temperature it did not get rid of the gas. The conditions were the same as in steel casting.

Reclaimed Scrap Metal Satisfactory.

The President said there was a tendency among foundrymen, when having to make a casting wholly from a scrap mixing, and which casting failed to turn out quite right, to blame the trouble on to the use of scrap. The point to be considered, however, was the nature of the scrap. If, for instance, one had supplied a number of perfectly good castings to a customer, and for some reason or another those castings were returned, one could not justly refer to those castings as scrap in the general acceptance of the word. Foundrymen should be too proud to attribute many of their troubles to the use of scrap; the fault was in the treatment of the metal rather than inherent in the metal itself. In the ordinary way one could make very good castings from remelted scrap.

Second Melting.

MR. A. H. MUNDEY agreed that better results were obtained on second melting than on the first melting, and emphasised the point by means of an analogy. If one went to a chemist's shop and asked for a bottle of medicine according to a prescription, the chemist would not prepare it by putting into the bottle a teaspoonful of Epsom salts, fill the bottle with water, and then add sugar and a little cochineal, and charge 2s. 6d. If he did that, one would not be prepared to pay the 2s. 6d. for it. What the chemist did was to pour into the bottle a strong solution of Epsom salts, and add to that a solution of sugar and water and cochineal, and in that way produced a homogeneous solution. Similarly, a good foundryman did not make up a copper-tin alloy directly by melting copper and adding tin to it; he always prepared what he called a white mixture—which was analogous to the chemist's strong solution—and, therefore, he gave it a second melting and obtained a better solution.

MR. MILNER discussed the call in the specifications of some firms for the use of virgin metals, and said that his foundry had had to meet orders for very light castings, of not more than 4 or 5 ounces, in a mixture similar to a red bronze, *i.e.*, 85/5/5/5, and the customers had insisted upon the use of virgin metal—electrolytic copper, electrolytic zinc, and so on. The results obtained with the new metals, however, were not so good as those obtained by first melting the metal, running it into ingots, and running the castings from the second melt with an addition of zinc to make up the amount lost by oxidation on the first melt.

Twice Melting.

The President, discussing the problem of "twice melting," said that, when compounding an alloy, the major portion of which was copper, it was necessary not only that the copper be rendered molten, but it must be superheated. All metals, at high temperatures, have a tendency to absorb gas and to give off that gas during solidification. It was far better that the gas should be given off when the metal was cast in the form of an ingot for remelting than that it should be found in the ultimate casting. Therefore, it was considered better practice to cast first into ingot form and to remelt at a lower temperature for the ultimate casting into shape than to attempt to make the metal and cast direct. The latter method was not, however, impracticable, provided one exercised the greatest care and paid particular attention to relative temperatures.

Mr. Victor Stobie said that the President's remarks with regard to gases coming off from the metals on solidification applied to the ferrous as well as to the non-ferrous. If one made a steel by a highly oxidising process without further treating it, one found that, the moment it solidified, carbon monoxide and a complex range of gases came off; roughly in proportion to the severity of oxidation of the melting process. That could be avoided in the main by deoxidising prior to casting. He asked whether the de-gasifying of a non-ferrous metal prior to casting would be less advantageous than a premelting and ingotting of the metal.

The President pointed out that Mr. Stobie had rather jumped to a conclusion. He (the President) had not mentioned oxygen, but had referred to "gases." One could deoxidise an alloy, but there were other gases with which it was not so easy to cope.

Mr. A. Logan said the general concensus of opinion was that a double melting was better than direct melting, and possibly that was so in the majority of cases, but it was not absolutely necessary.

The **President** pointed out that that was what he had stated, namely, that castings can be produced satisfactorily without resort to double melting, but only when the necessary precautions are taken.

Mr. Logan agreed, and said he merely wanted to confirm that statement.

On the motion of the **President**, seconded by **Mr. W. Cartland**, a hearty vote of thanks was accorded Mr. Dews for his Paper.

DIE CASTINGS.

By A. H. Mundey (Member).

The art of die casting is of the greatest interest to the foundryman, yet it is feared that this interest is not wholehearted as a general rule. The attitude is apt to be one of good-humoured tolerance, not unmixed with a trace of contempt. It is easy to understand this, for the foundryman's craft is essentially that of the moulder in sand and loam, and any process which aims at the displacement of this highly-skilled craft must of necessity be viewed with suspicion, even if this displacement be only in respect of a minute fraction of the total output of the foundryman.

It has been pointed out several times recently that when an intelligent person, who has no intimate knowledge of the work, visits a foundry and sees the large and beautifully-prepared moulds ready for a casting—moulds, so costly in money as well as skilled effort and time—and the visitor learns that the mould is used but once, that it is destroyed in giving birth to one casting only, the natural question arises, cannot moulds of a permanent or at least a more-lasting character be employed? Die-casting, in a limited measure and in respect to small castings which are required in large numbers, is the attempt to furnish a practical answer.

Die casting has been studied during recent years by a number of metallurgists, both from the point of view of scientific research and as a technical problem of industry. Many Papers have been read and lectures given and discussed. The author has had some small share in these efforts to obtain and disperse reliable information. It will, therefore, be impossible to present to the Institute details which are entirely new and unpublished, as the investigators have honestly reported results of experimental and explorative work, whether successful or not, to the great advantage of all engaged in the industry.

Die casting may be defined as a method of production of castings in a highly-finished or semi-finished condition, accurate to form and dimensions, with holes and inserts as required, screwed parts, both internal and external complete, by pouring or by forcing under pressure, molten metal into well-finished permanent or long-life moulds. These moulds are frequently called dies; this is probably on account of the fact that they are produced by highly-skilled tool-fitters and die-sinkers and not by the moulder, as in general foundry practice.

The process is distinguished from that usually known as chill casting, in that the latter usually requires a subsequent machining operation, or even forging and machining before the article is ready for use, on the other hand, die-castings are very largely polished and plated after casting and trimming.

Die casting is not a newly-invented process, for the ancient armourers used more or less permanent moulds of stone or burnt clay for the production of spearheads, axes and other weapons, these castings being of bronze. The method of production, by simply pouring molten metal into the mould, is now usually called "gravity" die casting, as distinguished from the employment of pressure, either by a pump-plunger or high-pressure air when it is designated "pressure" die casting, thus excluding the term chill casting altogether.

Type casting is the oldest-established branch of die casting, and it is probable that the printing industry employs an amount of die castings in the form of type and stereo-plates, which far exceeds in weight the whole output for all other trades.

The early dies were simple, consisting of three members, two forming the mould for the body of the type, and the other the matrix for the type face, the metal being poured from a small ladle, whilst the mould was held in the hand. Type-casting machines are excellent examples of automatic die casting. Here, in a belt or single-unit motor-driven machine, molten metal is pumped into a three-part mould, which is carried to a nozzle to receive it, the mould is opened, the casting ejected, the tang removed, the cycle of operations is now repeated, each movement being effected by appropriate cam-mechanism. The composing machines, of which the Linotype and the Monotype are the most notable examples, are developments of the type casters.

A few specimens of the products of these machines will be of interest to foundrymen, whose usual work is of such different character, one specimen only will be specially mentioned; a Monotype type, one-sixth of an inch-square section. On this small surface the whole of the Lord's Prayer is cast, the definition being perfect, as viewed under a low-power microscope.

At the other end of the scale of castings for printers there is the stereotype foundry. In the office of one great London daily newspaper no less than 40 tons of metal is cast into plates (all of which are of outstanding merit as to workmanship) nightly. Bullet casting was probably the next operation in which die casting was employing in an extensive way.

Anderson and Boyd, in an American Exchange Paper to this Institute* gave an excellent classification, and Capt. George Mortimer adopted this in his Paper† in 1926; it was as follows:—(A) Slush casting; (B) gravity casting; (C) centrifugal casting; (D) corthias casting; and (E) pressure casting. Cartland, in a lecture to the Coventry Engineering Society, 1928, expanded this, as set out in Table I.

Die casting can be classified into two main divisions, *i.e.*, pressure die casting and gravity die casting, but before passing on to discuss these in detail it is proposed briefly to describe the three other processes.

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* Proceedings, "Inst. British Foundrymen," Vol. XV II, p. 46.
† Journal, "Inst. of Metals," Vol. XXXV, p. 371.

Slush Casting.

The first is slush casting, which is used for the production of articles of decorative rather than engineering value, such as toy soldiers, statuettes and chandelier fittings. The metal is poured into the mould, and the mould is then almost immediately inverted and the majority of the metal poured out again, but a thin lining solidifies against the cool surface of the mould, thus producing a light hollow casting without any elaborate method of " coring."

TABLE I.—*Classification of Die Castings.*

Slush			
Centrifugal			
Corthias			
PRESSURE	Plunger	Tin base	
		Tin-antimony	
		Lead base	
		ZINC BASE	Tin, copper, hardened
			Copper, aluminium hardened
	Air	All above	
		Aluminium	
		Alloys	
GRAVITY	All above		
	Aluminium alloys		
	Aluminium bronze		
	Cast iron		

Centrifugal Casting.

This is a method by which centrifugal force is employed to bring pressure to aid in the filling of the mould. Its application is very limited indeed, but castings of very close, even grain can be produced.

Corthias Casting.

A measured amount of metal is poured into the mould and a tightly-fitting core attached to a plunger is then immediately forced into the mould with pressure. This gives the effect of pressure die casting, but the process is naturally limited to the comparatively few designs in which the pressure can be applied by the insertion of the core.

Pressure Die Casting.

This is one of the two main divisions of the die-casting industry, and by pressure methods castings can be produced with a high degree of finish, a remarkable dimensional accuracy, and with holes correctly spaced, true to size, with internal and external screw threads, with bushes and inserts placed as required and cast at a great speed, when once the dies have been correctly designed, made and tested.

The apparatus used is simple in principle. Imagine a melting-pot formed essentially like a teapot; the vessel is filled, or nearly so, with molten metal, the lid is replaced by a plunger, the mould or die is attached firmly to the spout; a sharp application of pressure to the plunger forces a supply of molten metal up the spout and into the die, which is so arranged as to be capable of ready opening for the release of the casting. A small hand-operated machine, patented in 1872, worked exactly on these lines, and, although modern machines of the plunger type have become relatively complicated in design, the same general principle applies.

The general equipment for die casting by this method usually includes several melting-pots, normally of cast iron, and gas- or oil-heated, placed handily for supplying molten metal to the actual casting-machine, which has a reservoir containing metal, kept hot by gas-burners, enclosed in a chamber lined with firebrick.

The pump with plunger is attached to the reservoir and the plunger is operated by means of a long lever. The mould or die is fastened to a swinging or hinged plate and is brought into communication with the spout by swinging the plate into position and fastening with clips The mould, being in two parts at least, is held together by means of a toggle-joint which admits of quick release, thus parting the mould. The parts of the mould are kept in register by means of dowels. Holes in the casting are formed by means of cores which are removed by rack-and-screw mechanism. Internal threads are formed by means of screw cores and external ones by screwed collars. The air is displaced by the incoming metal through vents which are placed at suitable positions—the success of any particular casting often depends largely on skilful venting of the die. The vents themselves are frequently very thin, flat apertures through which air can pass, but on account of their small sectional area the metal is unable to follow.

Dies are generally of steel—the main portions of mild steel, the special parts of alloy steel, such as nickel chrome, whilst as much of the body of the die as can be, is made of cast iron. The choice of material is controlled by the class of alloy to be used and the character of the casting.

The operation of casting in a plunger type of machine is as follows:—The reservoir is filled with molten metal and the lip of the nozzle cleaned from dross and partly-solidified metal. The die is opened, cleaned, oiled, and, in some cases, dusted with French chalk, cores are racked and screwed into position, and inserts or bushes placed in position. The die is then closed and by means of the plate, on which it is fastened, is brought with the aperture pressed close against the nozzle of the metal reservoir. The stroke of the plunger is actuated by a bell-crank lever, the long arm being manipulated by the operator. The kind of pull on the lever is very important; in some cases a sharp stroke is necessary, whilst in others a steady, strong follow-through is required. The workmen become remarkably skilful in maintaining the kind of pull to give the best result as well as in general management of the whole machine. The dies and cores are generally water-cooled; the adjustment of the rate-of-circulation to maintain the best die-temperature is important.

After completion of the casting, the spout is severed and removed and the mould opened, a set of ejector-pins which lie flush with the surface of the die is operated and the casting gently pushed out immediately after solidification. The marks of these ejector-pins are just visible on practically all zinc-base die castings. The die is now ready for a further cycle of operations. The casting is given a preliminary inspection and then passed on for trimming, polishing, plating, etc., if required, before final inspection.

The plunger-type of pressure die casting already described is suitable for all alloys of low melting-point, that is, up to about 450 deg. C., and under this heading are:—

(1) *All tin-base alloys* for bearings of every description. This section of the die-casting industry is one which is almost complete in itself; castings can be produced with great precision and excellent finish. The subject of die-cast automobile-bearings is one which will probably be well known to the members of this conference.

(2) *Special tin-antimony alloys*, which are used for gas-meter parts. These also produce castings of a high degree of accuracy and finish.

(3) *Antimonial lead alloys* for battery plates, grids, and terminal nuts for batteries, and also for certain weather-resisting window-fittings and other special purposes.

(4) *Zinc-base Alloys.*—This is probably the largest class produced as pressure die castings in the plunger-type machine. Their application covers a vast range of engineering and general commercial work, as will be seen from the specimens exhibited. Gramophone and other musical instrument parts, wireless details, automobile accessories, domestic articles, camera and cinematograph fittings and general instruments.

There are two main classes of alloys used:—(A) Zinc-hardened with tin and copper, and (B) Zinc-hardened with copper and aluminium. The actual composition varies with the work to be done. Special more-complex alloys are sometimes used, but the following can be regarded as typical of the two classes concerned:—(A) Tin, 7 to 10 per cent.; copper, 4 to 7 per cent.; and zinc, balance. (B) Copper, 3 to 5 per cent.; aluminium, 4 to 4.5 per cent.; and zinc, balance.

In general, Class (A) are used where dimensional accuracy is of the greatest importance; Class (B) where strength and toughness are the chief consideration.

The most notable contribution to the available information on die casting at the moment is the series of Papers presented to the Institute of Metals at the Autumn Meeting at Liverpool in September last year. The Papers report work carried out by the British Non-Ferrous Research Association, with the active support of the Department of Scientific and Industrial Research and the valuable co-operation of the manufacturers and their associations.

The Papers deal with three distinct sections of the industry:—(1) Die-Castings Alloys of Low Melting-Point by Russell, Goodrich, Cross and Allen, under the direction of Professor C. H. Desch, of Sheffield University; (2) Properties and Production of Aluminium-Alloy Die-Castings by Archbutt, Grogan and Jenkins, under the direction of Dr. W. Rosenhain at the National Physical Laboratory; and (3) Die-Casting of Copper-Rich Alloys by Genders, Reader and Foster, under the direction of Dr. Harold Moore, of the Research Department, Woolwich.

The Papers are arranged in this order because it is considered that it corresponds with the relative magnitude and commercial importance of present-day manufacture. The first Paper, dealing with alloys of low melting-point confines itself to zinc-base alloys of two types: (A) Those in which the hardening-constituents are tin and copper, and (B) examples of alloys employing aluminium and copper as hardeners, other constituents, such as nickel, cadmium, lead and magnesium, have been introduced as individual cases, as shown in Table I.

Pressure-casting was employed throughout. Flat test-pieces were made in sixteen alloys. The examination was for tensile strength, hardness, bending, porosity, and also as to the effect of casting temperature, temperature of mould, size of gate and vent and type of pull on lever. Further, the effects on the strength and on the permanency of dimensions after atmospheric ageing and of accelerated ageing by the action of hot air, hot moist air and steam at 100 deg. C. were examined.

The form of test-piece particularly in respect to the radius at the junction of head and parallel portion is most important. The pieces having a small radius broke at the shoulder. It was found that the most suitable form was a 2-in. parallel test length with 1.5-in. radius.

The alloys of the second class, having aluminium and copper as hardener, have about twice the tensile strength of those in which copper and tin are so employed, together with what is perhaps of more importance, a useful measure of ductility and toughness. Variations in the size and form of gate within reasonable limits were found not seriously to affect the strength of the test-pieces, but, as was shown in the discussion, are of importance in connection with industrial production. Temperatures of the metal in the bath did not greatly affect tensile-strength of test-piece casting, but high temperatures gave rise to surface pinholes.

It was elicited in the discussion that the relative temperature of the bath and mould is of importance; with moderately low temperature in the metal bath and a warm mould good results are obtained in usual circumstances. The type of pull leaves much to the skill and discretion of the operator, who from experience learns that some castings require a short, sharp pull and others a sustained and steady follow-through. Variation in actual composition in the casting was shown to have been obtained by manipulation of the lever when casting metal whilst passing through the long temperature-range of solidification.

It was found that the aluminium-copper-hardened alloys are more difficult to cast, requiring a stronger action on the lever, and in this, commercial manufacture had advanced beyond the resources at the disposal of research and had overcome the difficulty. The influence of the external surface which is chilled is very great on the strength and hardness of the casting. Machining away the surface alters the conditions in a serious manner.

Permanence of Zinc Base Die Castings.

It was shown that the prejudice against aluminium-copper-zinc alloys, which formerly existed, is not justified in the high-grade alloys now being produced, and that so far as can be authoritatively determined there is little difference between the two types of alloy under examination. It was further pointed out that a copper-tin-zinc alloy casting of a difficult design had been in use as a component of a commercial instrument for seven years, and although required to be accurate to 0.001 in. was found to be not sensibly altered in dimension or form.

TABLE II.—*Composition of Alloys under Investigation. Zinc Base.*

Alloy. Mark.	Cu	Sn	Al	Ni	Pb	Mg	Cd	Density.
6 RM	3.17	5.67	0.41	—	—	—	—	7.148
7 RM	3.16	7.40	0.36	—	—	—	—	7.143
8 RM	3.72	9.73	0.98	—	—	—	—	7.085
9 RM	3.07	13.83	0.44	—	—	—	—	7.070
10 RM	3.11	22.31	0.29	—	—	—	—	7.202
11	1.2	9.7	0.98	—	—	—	—	—
12	1.06	8.35	0.37	1.09	—	—	—	7.131
13	3.66	9.65	0.86	—	—	—	0.97	7.128
14	2.72	—	3.95	—	—	—	—	6.77
14B	3.07	0.28	4.64	—	—	—	—	6.73
15	5.14	—	4.16	—	—	—	—	6.85
16	7.02	—	4.02	—	—	—	—	6.905
17	3.03	—	3.87	—	0.80	—	—	6.78
17 AC	3.04	—	3.44	—	0.75	—	—	—
2 AE	3.02	—	4.07	—	—	0.095	—	—
2 AH	2.94	—	4.02	—	—	0.107	—	—

It is found that porous castings are more liable to dimensional change than sound castings. The rate of growth depends primarily on the condition of the casting—namely, its size and shape, its mass per unit of surface, its porosity, crystalline size, etc.; whilst the effect of composition alone is (within fairly wide limits) comparatively small. It is considered that the presence of certain impurities adversely affects the permanence of die castings in these alloys in addition to increasing the difficulty in the actual casting operation.

The second class of die castings, the aluminium alloys, so ably investigated by Archbutt and his co-workers, is of increasing interest. In the investigation gravity-feed was employed throughout, but here again commercial practice under scientific guidance is racing ahead of research reports, and pressure-feed is being employed with striking success. Naturally there is much to learn; unexpected difficulties arise; extended experience in tool and machine design as well as manipulation is demanded.

Five alloys were employed in the National Physical Laboratory investigation; the object was twofold. First to examine the properties of the products and determine the best method of production. Second to explore the phenomenon of hot-shortness, which is the ever-present cause of anxiety in production. The alloys were 4 per cent. copper, 8 per cent. copper, 12 per cent. silicon, 4 per cent. copper plus 3 per cent. silicon, and Y-alloy (copper 4 per cent. nickel 2 per cent., magnesium 1.5 per cent.). Two types of casting have been investigated: (A) a shouldered test-piece of circular section suitable for testing direct without machining; (B) a hollow tubular casting, requiring use of cores in moulding, and incorporating flanges and changes of section, features which cause difficulties in casting. Design and treatment of moulds, and conditions of working in respect to mould-temperatures, pouring, stripping, etc., and the effect of the different alloy compositions on these are described, together with the testing and properties of the castings obtained. To overcome defects due to air-locks, shrinkage, sticking of cores, etc., very careful control of the working conditions was necessary, including metal and mould temperatures, rate of pouring, interval between filling the mould and operations of drawing cores, opening the mould and stripping.

By means of a practised team of workers these operations were carried out with the degree of

Table III.—*To show the Effect of Type of Pull on lever actuating Plunger.*

Alloy No.	Quick pull.		Slow pull.			
	Porosity. Per cent.	Tensile strength. Tons/in.^{2}	Porosity. Per cent.	Tensile strength. Tons/in.^{2}		
6 RM ..	—	—	3.69	9.81		
7 RM ..	6.04	9.75	3.40	10.34		
8 RM ..	7.3	9. 7	3.09	10.66		
9 RM ..	7.40	8.84	2.37	10.12		
10 RM ..	—	—	4.09	9.00		
11 ..	—	—	—	9.11		
12 ..	—	—	3.16	7.62		
14 ..	6.90	18.00	3.63	17.61	Standard gate.	Average of 20 tests.
14 ..	5.40	18.84	3.70	18.14	Enlarged gate.	,, ,,
15 ..	7.37	19.16	2.33	20.73	Standard gate.	
15 ..	4.87	21.22	4.23	20.96	Enlarged gate.	
16 ..	6.70	21.11	4.17	22.10	Standard gate.	
16 ..	4.80	22.13	3.27	23.24	Enlarged gate.	
17 ..	4.25	17.51	4.10	17.24	Enlarged gate.	Average of 20 tests.
ZAE ..	—	22.02	—	—	Enlarged gate.	,, 11 ,,
ZAH ..	—	22.27	—	—	Enlarged gate.	,, 5 ,,

accuracy needed, and considerable success was thus obtained. Satisfactory castings were produced in the tubular form from all the alloys studied. With the test-piece form castings of satisfactory mechanical strength were obtained in "Y"-alloy, 12 per cent. silicon and 4 per cent. copper, plus 3 per cent. silicon, but less satisfactory results were obtained with the binary copper-aluminium alloys owing to hot-shortness.

The moulds were of grey cast iron annealed, and the cores from wrought 3-per-cent. nickel steel. Morgan crucibles were used. Pyrometric control was employed and every precaution was taken to ensure uniform conditions, and a degree of scientific accuracy observed so that any part of the experiment may be repeated under similar conditions, a feature which is so valuable and which is a characteristic of the work of the Metallurgical Department of the N.P.L.

TABLE IV.—*Mechanical Properties of Die-cast Test-Pieces. Tested direct Without Machining.*

	Condition.	M.S. Tons per sq. in.	E. Per cent. on 2 in.
	Large Test-Piece.		
"Y"-alloy ..	As cast ..	14–14.5	1.5–2
	Heat-treated ..	17–17.5	2
Si 12 per cent.	Modified ..	13–13.5	10
Cu 4 per cent, Si 3 per cent. ..	As cast ..	9.5–10	1.5–2
	Heat-treated ..	14·5	2
	Small Test-Piece.*		
"Y" alloy ..	As cast ..	14–14.5	1.5
	Heat-treated ..	18–19	2
Si 12 per cent...	Modified ..	13.5–14	10
Cu 8 per cent...	As cast ..	9–10.5	3–4
Cu 4 per cent. Si 3 per cent. ..	As cast ..	9.5–10	4–5
	Heat-treated ..	14.5	3

* Elongation measured on 1-in. gauge length.

The moulds were dressed with either:—(A) Whiting 11 lbs., plumbago 1 lb. and water 4½ galls.; or (B) whiting 11 lbs., water-glass 18 fluid ozs. and water 4½ galls. The cores were dressed with:—Plumbago 8¾ lbs., commercial rouge 2¼ lbs. and water 4½ galls. The rate of pouring the metal was determined by trial. Over-rapid pouring causes air-locks, whilst too slow pouring causes incomplete filling, cold shuts, bad skin and flow marks. The results of test-pieces are set out in Table V.

These should be compared with results from 1-in. chill-cast bars.

The test-bars were cast in form, thus avoiding subsequent machining; all went well excepting the two binary alloys of aluminium and copper. These were weak, or hot short, and, due to contraction on solidification, suffered before they could be stripped (see Fig. 1). The typical casting was well chosen; it gave excellent comparative results and introduced many of the difficulties which occur in commercial or works practice. It is certain that the team of skilled workers who prepared the specimens appreciate the troubles of the works production man very thoroughly.

Table V.—*Comparative Tensile Properties of the Aluminium Alloys Investigated, in the Form of 1-in. diam. Chill-cast Bars.*

Alloy.	M.S. Tons per sq. in.	E. Per cent. on 2 in.
Cu 4 per cent., Si 3 per cent. ..	12	5
" Y " alloy	14	2
" Y " alloy (heat-treated) ..	20	5
Cu 4 per cent.	10	12
Cu 4 per cent. (heat-treated) ..	16	22
Cu 8 per cent.	10	4
Si 12 per cent. (modified) ..	14	12

Tubular Castings.—The general form of cast-iron mould is shown in the illustration Fig. 2. After experimental work a set of conditions was reached which enabled the operators to overcome such difficulties as incomplete filling of the mould, sticking of cores, air-locks, cracking and breaking and internal and external shrinking. To effect this it was found necessary to regulate:

(1) Temperature of the mould; (2) temperature of the metal on pouring; (3) time taken to fill the mould; (4) period of waiting, if any, before drawing cores after solidification had occurred;

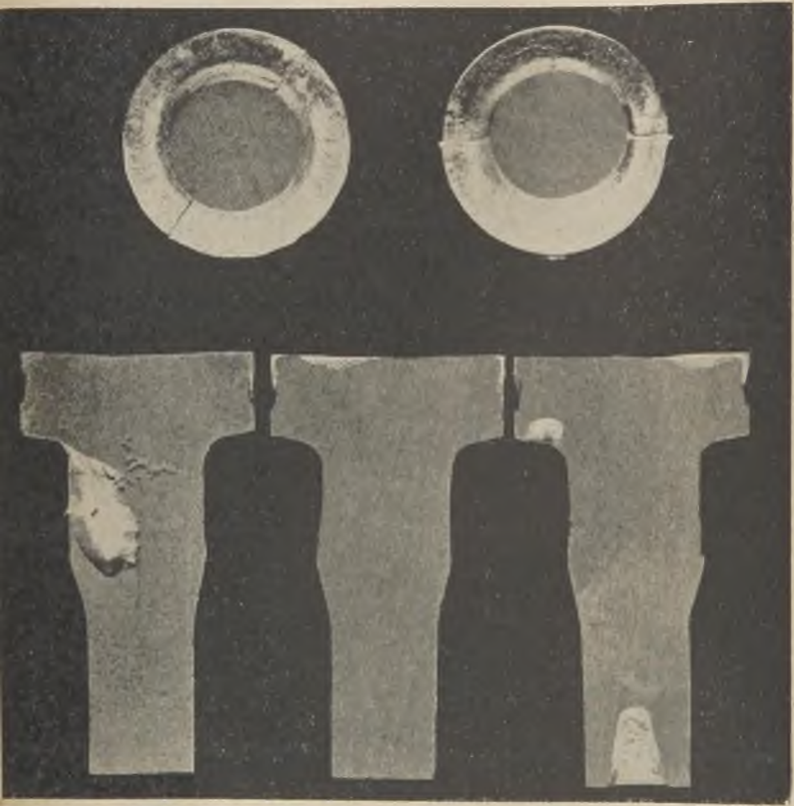


Fig. 1.

and (5) period of waiting, if any, before final stripping.

The Y-alloy gave less trouble than the others, as it was less hot-short and gave a greater latitude as regards temperature limits. The 12-per-cent. silicon alloy is relatively tough at high temperatures, but is subject to localised shrinkage.

Figs. 3, 4, 5, 6 and 7 illustrate the difficulties encountered in the production of the tubular casting. The tests carried out on these castings were:—(1) Tensile tests; (2) density measurements; (3) microscopic and visual examination of sections; and (4) porosity tests with water and with petrol under pressure. The results of tensile testing are set out in Table VI:—

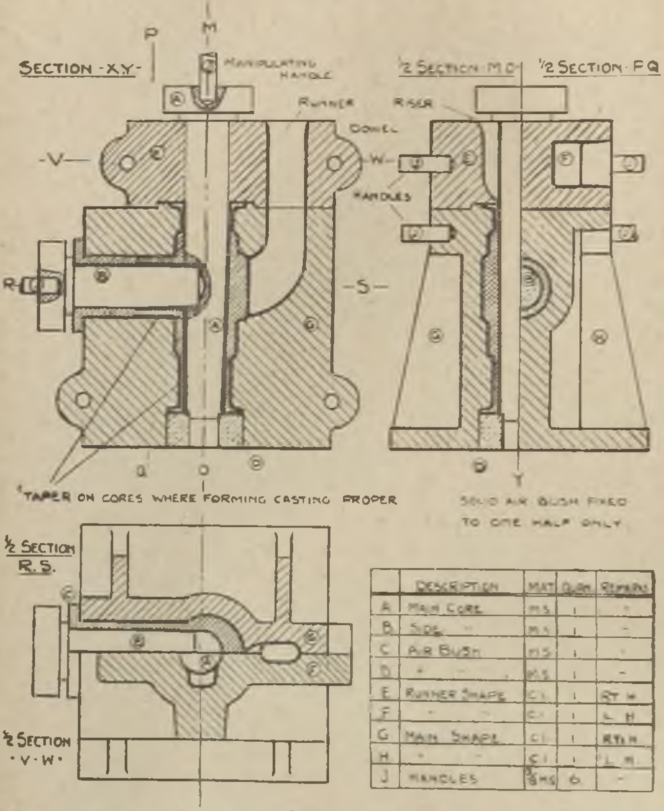
TABLE VI.—*Mechanical Properties of Tubular Castings.*

Alloy.	M.S. Tons per sq. in.	E. Per cent. on 0.44 in.
"Y" (as cast)	13.2	3.5
"Y" (heat-treated) ..	15.0	3
Cu 4 per cent. (as cast)	10.0	10
Cu 8 per cent..	12.5	6
Si 12 per cent.	11.6	7 (modified)
Si 12 per cent.	10.6	8 (unmodified)
Cu 4 per cent., Si 3 per cent.	10.7	2

The 12-per-cent. silicon and the copper-silicon alloys yielded sound castings with good density values and an absence of cavities. All the castings were subjected to a hydraulic pressure test, up to 1,000 lbs. per sq. in., for 30 mins. All withstood this test without leaking. Mr. H. J. Lavender also permitted at his works a special test of all these castings (with the exception of the copper-silicon alloy) with petrol at 30 lbs. per sq. in. The 4-per-cent. copper alloy revealed a fine crack; the others passed successfully.

Copper Rich Alloys.

The investigation by Genders, Reader and Foster into the die-casting of copper-rich alloys, dealt with a large range of alloys which had either been in actual industrial use, or, from their known properties, offered a promising field for selection of material for this work. The selection of mould material was also investigated with great care. It was shown that low carbon and general engineering steels were rapidly attacked. High-carbon and heat-resisting steels



	DESCRIPTION	MAT	QUAN	REMARKS
A	MAIN CORE	M.S	1	-
B	SIDE "	M.S	1	-
C	AIR BUSH	M.S	1	-
D	" "	M.S	1	-
E	RUNNER SHAPE	C.I	1	RT H
F	" "	C.I	1	L H
G	MAIN SHAPE	C.I	1	RT H
H	" "	C.I	1	L H
J	HANDLES	BMS	6	-

FIG. 2.

withstood the action of the molten metal, both still and in rapid motion, fairly well, but the highest-grade alloy-steels were required for severe service. Cast iron in contact with aluminium-bronze is required to be low in phosphorus.

The alloys used in the very large series of tests were:—A series of chill-cast test-bars was prepared under varied conditions and their mechanical properties closely investigated and compared with die-cast test-pieces, both flat and round.

Fig. 3.

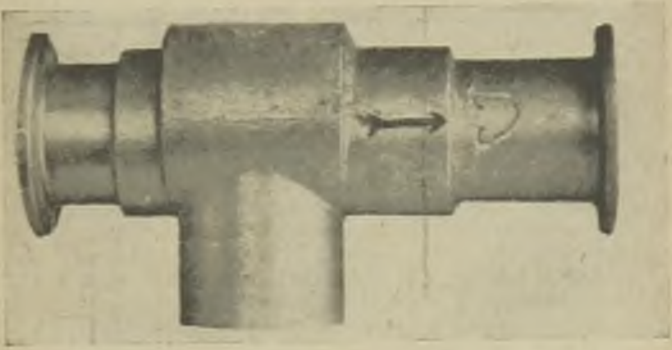


Fig. 4.

The chill castings were:—(A) Aluminium-bronzes with added iron; (B) aluminium-bronzes with added nickel and with nickel and iron;

(C) aluminium-bronzes containing manganese and manganese and iron; (D) complex aluminium bronzes; (E) brasses with added iron; (F) brasses containing nickel; (G) high-tensile brasses; and (H) nickel-brasses with added aluminium.

These were cast at about 150 deg. C. above the liquidus of the alloy into a cast-iron stick-mould giving a casting of about 1 in. dia., 8 in. long, with a taper of 0.1 in. The die-cast test-pieces were made so that a round and a flat test-piece were attached; one end was elongated in each case, which enabled a piece to be cut off for other tests. These were:—(1) Aluminium-bronze; (2) aluminium-bronze, with varying percentages of iron; (3) aluminium-bronze containing 2 per cent. of lead; (4) aluminium-bronze containing 7.5 per cent. of nickel; (5) aluminium-bronze containing iron and manganese; (6) high-tensile brass (copper 58, zinc 35, aluminium 3, manganese 4 per cent.); and (7) aluminium-nickel-zinc-copper alloy.

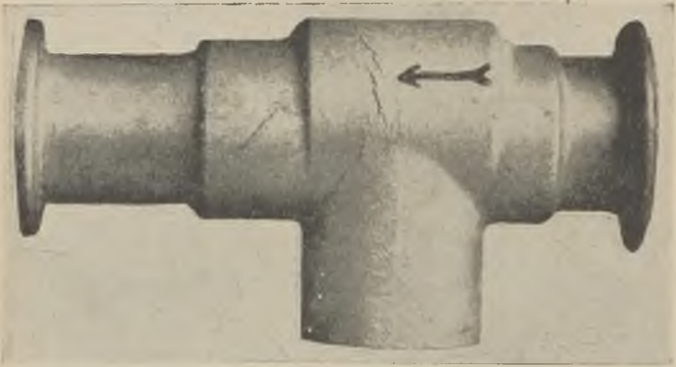


Fig. 5.

All of these alloys were also used in the preparation of die castings using moulds of various design as in commercial practice. The alloys containing zinc showed less "fluidity" than those based on "aluminium-bronze," and consequently required in some moulds a runner of larger cross-section.

The results of the exploratory work suggest that a large range of useful alloys is available for adaptation to die-casting manufacture, fulfilling requirements for materials either of low strength or high ductility. The alloy containing 1.5 per cent. of aluminium with iron and manganese was observed to give particularly good surface-quality.

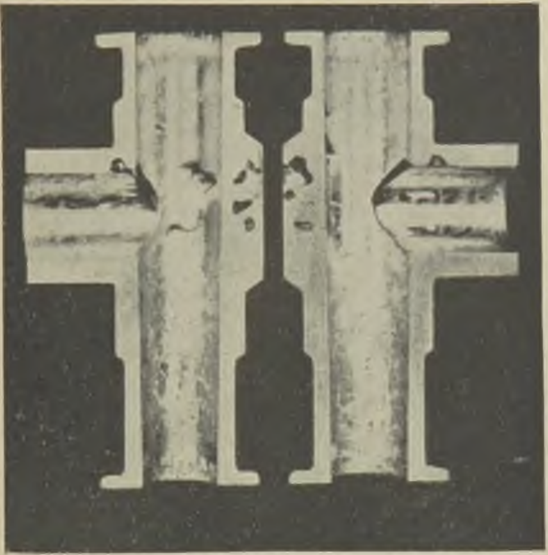


Fig. 6.

The effect of added iron up to about 4 per cent. on " aluminium-bronze " is to increase the maximum proof-stress and tensile-strength of the die-cast alloy. Nickel added to the extent of about 10 per cent. raises the maximum proof-stress to a greater extent, but is accompanied by a marked lowering of the ductility. The addition of iron and nickel together to 12-per-cent. "aluminium-bronze" produces a strong alloy having a tensile strength of about 50 tons/sq. in; this type of alloy was the only one tested showing distinct liability to cracking in the double test-piece mould. The total shrinkage of this alloy (about 2.4 per cent.) is greater than that of all the remaining types tested ("aluminium-bronze" about 2 per cent., high-tensile brass about 1.9 per cent.), and its utility would probably be limited to castings of simple form. "Aluminium-bronze" is weakened slightly by the addition of lead, which also appears to introduce small surface defects. The high-tensile brass included in the tests showed mechanical qualities as high as those of the alloys related to "aluminium-bronze." The nickel-brass (Cu-Zn-Ni alloy), containing aluminium, gave a high ratio of proof-stress to breaking load. The machining qualities of the alloys have not been considered in detail, but none of the castings made gave any great difficulty in turning or sawing. The "aluminium-bronze" containing lead appeared slightly easier to machine than the other alloys.

Many tests on brasses, 70 Cu : 30 Zn; 60 Cu : 40 Zn; and 55 Cu : 45 Zn; each with added aluminium, were made with both 60 per cent. copper and 70 per cent. copper alloys with about 4.0 per cent. of aluminium replacing a corresponding amount of zinc, about 40 tons maximum load is obtained. Some comparative results of tests of die-cast test-pieces are given in Table VII.

The results of these investigations, which were carried out with all the care and precision of highly-trained workers in the best scientific conditions possible, confirm the author's personal experience obtained in practice. He finds that when a new die is put into operation that there is almost invariably a period of trial whilst small corrections are made, adjustments of gates and vent effected, before the most skilful workers are able to produce regularly and continuously satisfactory castings. As regards aluminium alloy, he is fairly convinced that if satisfactory

Table VII.—*Tests of Die-Cast Test-Pieces.*

Material.	Maximum proof stress. Tons per sq. in.		Maximum load. Tons per sq. in.		Elongation. Per cent.	
	Round piece.	Flat piece.	Round piece.	Flat piece.	Round piece.	Flat piece.
Aluminium-bronze (Cu 89.6, Al 10.4) ..	10.2	14.3	33.6	28.4	23	5
Iron-aluminium-bronze (Cu 87.8, Al 10.2, Fe 2.0)	12.1	13.0	33.4	35.0	14	10
High-tensile brass (Cu 59.2, Al 3.5, Zn 33.1, Mn 4.2)	27.9	20.7	41.8	38.0	7	4
Aluminium-brass (Cu 59.9, Al 3.5, Zn remainder)..	21.4	18.6	42.0	33.2	7	4
Aluminium-brass (Cu 69.2, Al 4.3, Zn remainder)	19.1	21.7	37.6	36.1	17	7
Pure 60 : 40 brass (Cu 59.6, Zn remainder) ..	7.6	9.0	24.0	25.3	29	28

castings cannot be produced under commercial manufacturing conditions in 12-per-cent. silicon alloy, they cannot be produced at all, for as a general rule they are less liable to "hot-shortness"; they are easier to cast, have good tensile strength, generally greater elongation and impact values, and are more resistant to corrosion.

Capt. Mortimer compares aluminium-alloy die-castings produced by pressure and gravity methods. In his opinion gravity castings will always have superior mechanical properties to those cast under pressure. This view is based upon the argument that in gravity die castings the flexibility of the pouring-rate enables the crystalline shrinkage to be taken up by the automatic feeding from the molten layer above. In pressure die castings the metal is shot into the mould and the shell in contact with the walls of the die solidifies instantly, leaving a space between two thin castings which sets to an open porous structure within a beautifully finished exterior.

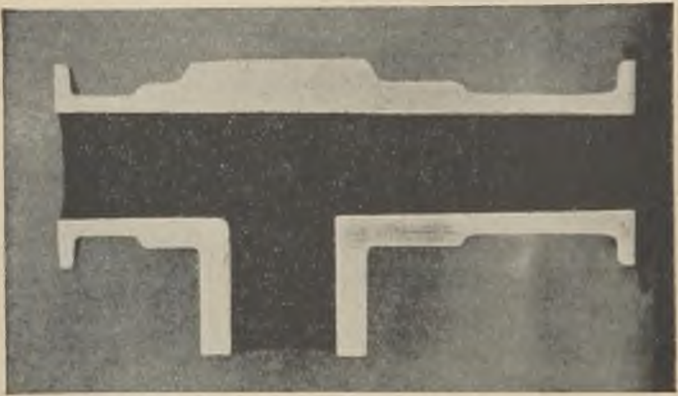


Fig. 7.

From this it would appear that (A) gravity die castings are preferable when the mechanical properties of the finished casting are the chief consideration and (B) pressure die castings are to be preferred where accuracy of dimension and the elimination of machining are of first importance.

In spite of these conclusions, with which one is bound to agree in some measure, the very marked success achieved by the author's works in the production of die castings in air-pressure machines makes one feel that there is little to be desired as to soundness of castings when prepared under the best conditions. Much industrial research has been done to overcome all the difficulties by the Doehler Die Casting Company in the U.S.A., by some firms on the Continent, and by the author's colleagues in Fry's Metal Foundries, Limited.

TABLE VIII.

	M.S. Tons per sq. in.	E. Per cent. in 2 in.	Impact. Ft.-lbs.	Specification.
3L.11 ..	9–11½	3–4	1.2–1.6	2.87
2L.5 ..	11–15	3–9	2.5–3.0	3.01
11 per cent. Si mod.	13–14	10–15	6–8	2.66

Air-pressure machines are also employed with the most gratifying results with zinc-base alloys, especially those of the copper-aluminium-hardened series, which possess high tensile strength with good elongation. Some general working data for aluminium pressure die castings is given by the Doehler Company as under: *Maximum weight*, 5 lbs.; *maximum limits for wall thickness*, $\frac{1}{10}$ in. for small castings and $\frac{1}{4}$ in. for large castings; *variations from drawing dimensions*, 0.0025 in. per in. of length or diameter; *holes*, 0.093 in. minimum diameter and not deeper than 1 in. (smaller holes may be "spotted"); *draft*, cores 0.075 in. in length or diameter; and *side walls* 0.005 in. These rules are good for general design purposes, but the limits may be improved upon in certain cases.

It is largely due to the work of Dr. A. G. C. Gwyer, Chief Metallurgist of the British Aluminium Company, that the aluminium-silicon alloys have been developed so rapidly. He has, together with other eminent workers in this country and in Germany and America, studied with great persistence the phenomenon known as "modification." It was found that the addition of certain elements, particularly sodium and some of its compounds, to aluminium-silicon alloys when in the molten condition caused a very marked change in the crystalline structure of the metal.

It was also found that this modification was accompanied by greatly improved physical properties, to a limited extent in the tensile strength, but more particularly in the elongation and resistance of shock. These phenomena belong to the realm of physical metallurgy, and it is suggested that members who are keen to follow up the theoretical consideration of the subject should study Dr. Gwyer's Paper.* Dr. Gwyer's work emphasises the value of the most advanced theoretical research in relation to its application to industry.

The comparison between the modified 11-per-cent. silicon alloys and the well-known industrial alloys 3 L.11 and 2 L.5 as to physical properties is shown in Table VIII.

It will be noticed that the Izod impact-figure shows a very marked improvement. The total linear contraction is about the same in each of these alloys, but the crystallisation shrinkage is much less in the modified alloy. It is easier to make good castings as it fills the moulds. It is not hot-short to such an extent; it is, therefore, easier to remove from the mould. It is less corrodible than most unmodified aluminium alloys.

Much excellent work has been done with regard to these alloys by the Light Alloys Company, Limited. Mr. Deeley's valuable Paper† on Alpax, did much to inform industry as to

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* "Journal, Inst. of Metals," Vol. XXXVI.

† Proceedings, Inst. of British Foundrymen, Vol. XXII.

the value of this process in the case of die castings as well as ordinary sand castings.

Magnesium Alloys.—Two or three years ago, Mr. W. R. D. Jones presented an important Paper to the Royal Aeronautical Society on "Magnesium and its Alloys." In it he compared the physical and mechanical properties of these alloys with those of aluminium and also a number of other metals. The special attractions are the low density and the high specific heat, also the relatively high conductivity of heat and electricity. Magnesium is considerably lighter than aluminium; it is 1.74 as compared with 2.7, whilst the melting points are almost identical—651 deg. C. and 658.7 deg. C. respectively.

Magnesium in the cast state is stronger than aluminium, but an important proposal of Rosenhain and Archbutt to consider the "specific tenacity" obtained by dividing the tensile strength in tons per sq. in. by the weight in pounds per cub. in. gave magnesium a much higher value than aluminium.

Mr. E. Player, of Coventry, recently reviewed at a joint meeting of Metallurgical Societies at Birmingham the properties of magnesium castings. He stated that by pressure die casting these alloys can be produced in fine sections. The strength of castings in magnesium alloys is increased by forging. It is claimed that the physical properties are greatly improved by the addition of calcium. Chill castings thus modified by the process invented by M. G. Michael are said to have lost the characteristic coarse grain and to have assumed a so-called fibrous condition. In this state both thermal and electrical conductivity are said to be enhanced. The metal treated by this process by the Maxium Company is used for pistons with great success

The well-known alloy, elektron, used largely by Germany during the war for aircraft, contained from 5 to 6 per cent. zinc, together with small proportions of copper, aluminium and iron, gave good chill castings, having a tensile strength of 12 to 14 tons per sq. in.; it forged and pressed well, and was capable of heat treatment. Magnesium with 6 per cent. of aluminium is found to be a good useful alloy. Casting and machining magnesium and its alloys are attended with many workshop difficulties; not the least is the inflammability of the turnings and fine cuttings of the metal. Elektron car and trolley wheels are largely used in Germany.

The circumstances connected with the production of die castings are such that the industry never came into the hands of the orthodox foundryman as a part of his regular practice. It may in view of this fact be well to consider for a moment the type of labour engaged.

Die Design.—This work is the most important of all, as engineering draughtsmen of great ingenuity and experience are needed. They must possess imagination as well as knowledge of properties and behaviour of the metals whilst in the fluid and transitional stages to complete solidification. They must be adaptable and have the knack of interpreting the ideas of the customer who sometimes asks for an article which is either impracticable or at least uneconomic.

Next is the *die-maker*, who must be a high-class fitter and machinist, who must be able to make adjustments in difficult conditions, and to anticipate, as well as to overcome, " snags " in production.

Finally the casters. It is a mistake to imagine that tools and machines can be made so fool-proof that any unskilled or casual operator can produce good, sound castings at an economic rate. A capable and experienced caster is a valuable man.

The metallurgist has not been mentioned, but it is worthy of note that the men in charge of all successful die-casting establishments are highly-trained metallurgists with a good knowledge of engineering practice or engineers with a sound knowledge of metallurgy. In such cases a full use and appreciation of the laboratory follows inevitably.

It is with a feeling of great gratification that the author is able to report that his company, Messrs. Fry's, recently acquired a new process in the manufacture of die-castings in yellow metals, which promises to revolutionise this section of the industry. At the moment of writing it is not possible to give intimate details, but it is anticipated that specimens will be shown at the meeting and that particulars of the principle and methods will be available. The improvements and modifications have passed far beyond the experimental stage, and the results in actual manufacturing conditions are overwhelmingly satisfactory.

DISCUSSION.

Mr. A. H. Mundey, in presenting his Paper, took the opportunity, as an old friend and comrade, to congratulate Mr. Lambert upon having attained the position of President of the International Foundrymen's Congress and of the Institute of British Foundrymen, and also upon having been awarded the Oliver Stubbs Medal. It was a very great pleasure, he said, to find old friends and colleagues so honoured by those with whom they had worked, and who were best able to assess their value. Mr. Lambert had attained the respect of his colleagues in very full measure.

Special Steel Pots Used.

Mr. A. J. Shore, commenting on Mr. Mundey's reference to the solubility of aluminium in cast iron, asked whether, in view of that, cast-iron pots were not used for aluminium pressure die casting, or whether special cast-iron pots were used?

Mr. Mundey replied that for pressure die casting he used pots made of steel of a very special character, and not cast iron.

Relative Costs.

Mr. Henry Milner, discussing the pressure machine for die casting of aluminium bronze, said he had tried the use of aluminium bronze gravity-fed die castings for the making of ball race cages, brush holders for electrical machinery, and products of that kind, and had found that sand castings coupled with facilities for cheap machining were cheaper than gravity-fed die castings. The " sand cast " job had not so good a skin nor was it as true to size as the one which had been die cast, but the slow method of production of the latter outweighed these advantages.

He further added that where a job could be sand-cast with a number of patterns mounted on a plate, and the castings afterwards tooled on automatic chucking lathes, the final cost of production was lower than that of gravity-fed die casting.

A New Die-Casting Process.

Mr. Mundey said that at present there were no machines in this country for the making of die castings by the new process referred to in the Paper, but he was awaiting delivery of the first machine. Mr. Pechal and himself had inspected the new process in December, 1928, and had been negotiating ever since; the process had been modified just a little, and his Company had acquired the British Empire rights. It would be before the public in a very short time, and he regretted that he was not yet able to invite those attending the Congress to see the process.

Mechanical Properties of Die Castings.

Mr. W. Cartland referred to the efforts that had been made to improve the mechanical properties of die castings. At first, he said, die castings had a really large sale. The zinc-base alloy die castings produced under pressure had a beautiful finish, but their physical properties were not all that could be desired; they were brittle. Great improvements were effected in the zinc-base alloy die castings, so that they were less brittle, but from the point of view of mechanical properties they were nothing special. A long time had elapsed before the foundry had been able to produce pressure die castings in aluminium, applying the pressure by means of air instead of by plunger, and that represented a great advance; there was a great difference between the properties of the zinc-base and aluminium-base alloy die castings. To obtain castings with higher physical properties, however, it had been necessary to produce the aluminium-bronze or aluminium-brass gravity die castings, which had definitely good physical properties, but with gravity die casting one could not get the precision in finish that was desired. If one were able, by the new process, to produce, under pressure, die castings in alloys of the yellow aluminium-bronze type with high physical properties and first rate finish, it would appear that the foundry had made another great advance.

Another New Process.

The President said he had had the advantage of visiting Germany a few weeks ago, and had seen in operation there a plant for the manufacture of yellow metal die castings, the machine used being, to his mind, unique. A rectangular box, made of special steel, was suspended over the molten brass or yellow metal, the metal being contained in an ordinary plumbago pot. The rectangular box was lowered into the yellow metal and filled itself by gravity. The box was then lifted out by means of a lever arrangement and was swung over and clamped between two plates, one of which formed the orifice into the mould, the other being a blank plate. Air was applied to the rectangular box containing the molten metal, and by that means the metal was forced into the mould. He thought the apparatus was rather novel in its conception. He was given to understand that the contrivance was giving satisfaction, but he was told that there had not been a very great demand up to that time for pressure die castings in yellow metal as compared to the demand for gravity-poured yellow metal die castings.

Mr. Mundey said he had heard of the process described by the President. There had always been a temptation to adopt the vacuum method, by which the mould was exhausted and allowed to fill automatically. It was very difficult, however; the filling must be very good, and must be continuous.

The President suggested that Mr. Mundey might have emphasised a little more than he had done the necessity for constructing the die so that the air was allowed to escape from it. One of the great difficulties in die casting was to get rid of the air in the die, unless the die was properly constructed, but the difficulty had been overcome to a large extent. He mentioned this matter for the information of those who had broken up die castings, and were not enamoured of them because of the presence of one or two holes.

On the motion of the President, seconded by Mr. Simm, a hearty vote of thanks was accorded Mr. Mundey for his Paper.

CRYSTALLINE GRAINS IN CASTINGS.

By Dr. Ing. A. Glazunov

[PRESENTED ON BEHALF OF THE CZECHO-SLOVAKIAN FOUNDRYMEN'S ASSOCIATION.]

According to Tammann, a crystallite is a crystal lacking in crystallographically-oriented boundary-surfaces—that is, without any definite crystallographic shape, the so-called allotriomorphic crystal, or ordinarily polyhedral grains. According to Sauveur, who expresses the American view as to the conception of crystallite, it is a crystalline group or an aggregate of allotriomorphic crystals under the condition, that they represent a definite complex, which may be described as " Dendrite," " Star," " Crystalline Grain," and so on.

As is evident, these two opinions as to the conception of crystallite are totally different. The view of Tammann, identifying the conceptions of crystallite and of allotriomorphic crystal, makes the denomination of crystallite superfluous, and the definition of Sauveur is very indistinct. In Europe Sauveur's definition of crystallite has spread very restrictedly, whereas the opinion of Tammann has asserted itself.

The crystalline grains, of which normally a pure substance, obtained by melting, is constituted, are homogeneous, which fact may be concluded according to the reflection of the light from the polished and etched surface of specimens. Every grain will have its colour—white, black or grey (which is dependent on the direction of its optical axes in comparison with the direction of the optic rays); but the whole grain will always be of one colour.

In Fig. 1 there is shown a microphotograph of pure iron; in Fig. 2, that of pure lead, and in Fig. 3, pure copper. As one may see from these microphotographs, the crystalline grains, of which normally pure metal is constituted, are homogeneous and polyhedral. This had led to the fact that conceptions of "crystallite," "allotriomorphic crystal" and "crystalline grain" have become synonymous so far as metals are concerned. Yet observing the macro as well

Fig. 1.—Microphotograph of Pure Iron. From "Metallographie," by Dr. W. Juertler.

as the microstructures of some metals under special conditions of crystallisation—for instance, the crystallisation of zinc on the surface of iron, as in galvanised sheet (Fig. 4), or the crystallisation on the surface of a pure antimony casting (Fig. 5), there is to be seen a so-called "star-like" structure, in which the metal-grain is not homogeneous, but represents a considerably large quantity (complex) of crystals, grown out from one crystallisation centre. In Figs. 4 and 5 there are clearly shown the physical heterogeneity of the individual star-like grains and the homogeneity of the particular rays.

A similar structure may be also observed in the solidification of pure substances, crystallised in thin layers between two glass-plates, Fig. 6. Here one sees not only a star-like structure, but also a ray-like structure. Such structures are often obtained in the crystallisation of pure substances. If there is a crystallised substance, giving a solid solution, or if a pure substance has been crystallised from some solvent (selective solidification by eutectics), then independently of the conditions of the crystallisation, one may obtain either idiomorphic crystals, or dendrites, or also, as was in the case

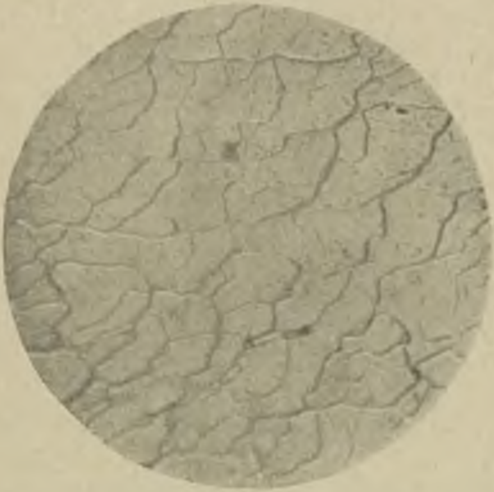

FIG. 2.—MICROPHOTOGRAPH OF PURE LEAD. (INSTITUTE OF THEORETICAL METALLURGY, PRIBRAM SCHOOL OF MINES.)

in the crystallisation of pure substances, star-like grains or allotriomorphic grains.

Elementary Desiderata.

What can one definitely postulate as a crystallite? And to which group should one leave Sauveur's definition of "group of crystals," and where should one make use, according to Tammann, of the classification of "crystallite" and "allotriomorphic crystal" as synonymous terms? Is not the allotriomorphic crystal only one of the possible variants of crystallite? In order to be able to give reasons for one of these views as to the conception of crystallite, it is proposed to study successively the process of the formation of a crystal in the crystallisation of a pure substance, as well as in crystallisation from solutions. Normally, as is well known, the process of solidification takes place under the

FIG. 3.—MICROPHOTOGRAPH OF PURE COPPER. FROM "THE METALLOGRAPHY AND HEAT TREATMENT OF IRON AND STEEL," BY A. SAUVEUR.

influence of two factors, which have their individual values for every substance. These factors are GK and KZ, this is, the linear crystallisation velocity (Kristallisatiosgeschwindigkeit) and the number of crystallisation centres (nuclei) forming in the course of one unit of time in the unit of volume (Kernzahl's nucleus-number).

The crystallisation velocity is ordinarily indicated in millimetres per minute, and the number of formed crystallisation-centres per cm^3 and minute. It is self-evident that for various crystallographic-axes of crystals there also may be various values for KG under the same external conditions. Both these factors KG and KZ are dependent on supercooling and their inter-relationship depends on the size of the crystalline grains, and not on their shape, as will be shown later. It is clear that the fewer the crystallisation centres formed in the course of one minute, and the higher the linear crystallisation velocity, the larger the size of the grains, and inversely. In other words, the size of the final grains is directly proportional to the linear velocity of crystallisation and, contrarily, proportional to the number of crystallisation centres. The relation between the supercooling temperature, between the number of crystallisation centres and the linear crystallisation velocity (according to Tammann) can be expressed as in the diagram (Fig. 7).

Crystallisation of a Pure Substance.

Dependent on the fact how far the supercooling was carried, and on whether the maxima of the crystallisation centres and of the linear crystallisation velocity are lying in the same region, one obtains a fine-grained or a coarse-grained structure, or even glass-like structure. In metals no one has yet succeeded in obtaining this last type of structure. The question of the rationale of crystallisation, after the formation of a crystalline centre of a pure substance, has not yet been definitely solved. Arising from this are the following queries:

(1) Whether the process spreads itself equally, that is, with the formation of spherolite, or whether the action proceeds according to a definite orientation, in accordance with the crystallographic system of the substance; (2) whether the product grown from one crystallisation centre will be physically homogeneous, that is, monocrystalline or physically heterogeneous, or polycrystalline?

In fact, in crystallisation processes there has been observed in a series of substances, in addition to the formation, of well defined crystals (for instance, during the solidification of sulphur after the formation of a crust has taken place on the surface, this crust being broken and the rest of the still liquid sulphur poured out, one finds internally well defined acicular crystals, representing the formation of spherolites), for example in the crystallisation of organic substances, of some minerals, or in the recrystallisation of glass, etc. As to metals, the question of the formation of metal grains remains unsolved.

Tammann explains the formation of these spherolites through the influence of surface tension in the process of crystallisation, that is, through the relation of the surface tension a to the crystallisation forces. The author has translated "Festigkeitskrafte" as "crystallisation forces," because he is of opinion that the literal translation *forces of strength* would not be clear. By this term one would understand *forces maintaining the crystallographic form of the crystal.* If a is higher than f, that is, if the surface tension is higher than the crystallisation forces, spherolites are obtained. On the other hand, if a is lower than f, a crystal is obtained with regularly-defined surfaces. If the number of crystallisation centres is small, and the crystallisation velocity relatively high (immediately below the freezing point) one may obtain the crystallisation of a larger quantity of substance in the form of one crystal. Tammann, in supercooling to 0.1—0.3 deg., definitely obtained. when crystallising organic substances in glass tubes, crystalline cylinders, filling the whole volume and equally orientated in each of their parts, that is, each of them constituted one crystal. Czochralski also obtained in his experiments with the crystallisation of metals large allotriomorphic crystals. All these experiments show that in the crystallisation of pure

Fig. 4.—Macrophotograph of the Surface of Galvanised Iron Sheet. (Institute of Theoretical Metallurgy, Pribram School of Mines.)

substances one may obtain spheroidal, as well as regularly crystallised substances, yet thereby the question is not answered as to how the process is operating in metals practically.

Crystallisation in a Block of Pure Metal.

In the normal process of crystallisation in a metal block, owing to the more rapid cooling of the outer walls, the first nuclei are formed on the face of the block in considerable quantities, almost contiguously. Consequently, the crystals grow inwards, that is to say, at right angles to the walls of the block, and only in a slight degree in a vertical direction in regard to the latter, because the crystals, formed from various nuclei, lying on the same surface, will impede this growth. The result of such a crystallisation will be columnar crystals, schematically represented in Fig. 8.

When this primary period of crystallisation has proceeded so far that the thermal influence of the surrounding space almost disappears, that is, when the temperature of the remaining liquid is everywhere the same, there begins the formation of nuclei regularly disseminated throughout all the liquid phase; the growth of the crystals will continue according to Fig. 9. The crystallisation units formed here are of a polyhedral shape. As a final result of the solidification, taking its course according to this scheme, one obtains a structure constituted of a series of columnal crystals running from the walls and closely touching one another with their long surfaces, with their needle-shaped tops directed towards the interior of the casting, and a large quantity of polyhedral crystalline grains filling the interior of the block. Such a structure is shown in Fig. 10, representing the crystallisation of a block of brass.

It is true that brass is not a pure substance, yet because the block, designed in accordance with its composition is lying within the limits of a solid solution, that one does not see the results of liquidation, one may use this macrograph as a suitable example, because both kinds of crystalline grains—columnar and polyhedral grains—are homogeneous. In this case there is a similar structure, as is normally the case with pure metals, with the exception that the size of the polyhedrons is larger. What is the origin of these homogeneous grains? According to Desch, these grains are produced from the original dendrites, whereby every dendrite grows one grain, and from one nucleus one dendrite is formed. The scheme of producing grains, according to Desch, is shown in Fig. 11.

FIG. 5.—MACROPHOTOGRAPH OF PURE ANTIMONY CASTING. (INSTITUTE OF THEORETICAL METALLURGY, PRIBRAM SCHOOL OF MINES.)

Tschernoff also is of a similar opinion, his views as to the formation of columnar crystalline grains being shown in Fig. 12. Many other authorities have analogous views, Sauveur's, for instance, being set out in Fig. 13.

Rosenhain, Tammann and Oberhoffer, whose opinions, it is thought, are shared by most metallurgists, have outlined the further development of the dendritic theory. They postulate that in the nucleus the elementary crystals are constituted according to their crystallographic axes, that is, in the formation of the grain there is always one properly oriented crystal, whilst its final form may be optional. However, all of the limiting lines will arrange themselves reciprocally according to definite angles as defined by crystallographic laws.

Tammann supposes that crystallisation, proceeding from the nucleus, may continue spherolitically, or by the deposition of crystals according to the crystallographic axes. For metals, on the basis of the homogeneity of the grains, Tammann considers the second process only possible. Under special conditions (for instance, on the surface of a casting) Oberhoffer also admits a dendritic origin of the grains. The scheme for the formation of grains, according to Rosenhain, is shown in Fig. 14, and the grains, constituted in this way (according to Oberhoffer and Tammann), are shown in Fig. 15. Rosenhain and Beilby also state the hypothesis that between the particular grains formed from various nuclei, there is produced a very fine layer of amorphous cement, forming the limiting membrane between the grains. This film is produced on contact, as soon as there is no room for the formation of primary crystals. This hypothesis is shown in Fig. 16.

Co-ordination of Data and Views.

All the established data, as well as differences in opinion, may be summarised into a definite scheme.

Having observed the crystallisation of organic substances in thin layers under the microscope, that is, under the condition that crystallisation takes place practically on the surface (in a two-dimensional space), and that the temperature of the whole sample is the same (this second condition is also present during the crystallisation in the inner part of a large mass of metal), the author found that the structure was always star-shaped. Consequently, crystals grow symmetrically in all directions, that is, with an equal velocity. In other words, the curve, according to which, at every moment during which crystallisation is proceeding (equilibrium curve between the crystalline phase and the liquid phase in which *$F_{liq} \rightleftharpoons F_{cr}$ will be a circle). In the three dimensional space one obtains for $F_{liq} \rightleftharpoons F_{cr}$ a spheric surface, that is a

Fig. 6.—Star-like Structure of Pure Substance crystallised in a Thin Layer. (Institute of Theoretical Metallurgy, Pribram School of Mines.)

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* F_{liq} signifies the liquid phase, and F_{cr} signifies the crystalline phase.

spheroid, the section of which on the surface (in the two-dimensional space) will be a circle. The geometrical centre of this sphere will be the crystallisation centre. Such a rationale, impeded in its evolution by rapid quenching, whereby the remainder of the liquid is quickly crystallised into small grains (with a high KZ), is shown in Fig. 17.

Crystallisation, embodying a group of crystals growing from various nuclei, where a reciprocal impediment to the normal has developed, is shown in the microphotograph (Fig. 6). In comparing the microphotographs Nos. 1, 2, 3, with the microphotograph in Fig. 6, one observes a considerable similarity, as well as the difference between them. The shape of the particular grains in Figs. 1, 2, 3 and 6 is similar. They are made up of polyhedral grains, just as in metal forming the interior of castings, as well as in organic substances crystallised in a thin layer. Yet in metal it is noticed that the particular polyhedral grains are physically homogeneous, whereas in organic substance (Fig. 6), which like metal and according to its composition is

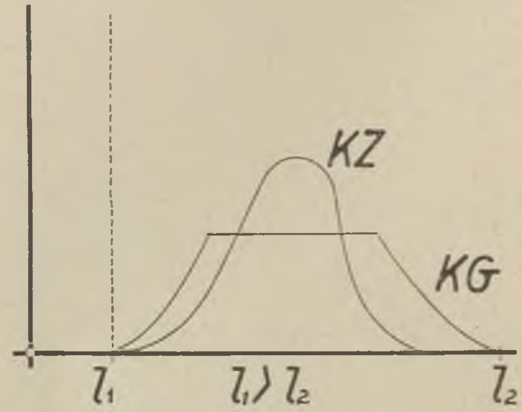


FIG. 7.—RELATION BETWEEN SUPER-COOLING TEMPERATURE KZ—KG.

chemically homogeneous, they will be physically heterogeneous, composed not of one allotriomorphic crystal, but of a series of independent crystals, grown from one nucleus—there is a spheroidal crystallisation instead of a polyhedral one (Tammann).

In comparing the resultant heterogeneous grains with the grains obtained under conditions of crystallisation embodying like conditions, that is in thin layers having practically the same temperature for the whole surface, it is to be noted that in metals one also obtains a star-like structure of the grains constituted from crystals grown from one nucleus and variously orientated. One obtains a heterogeneous, crystalline grain. In Figs. 5 and 6 are shown for the crystallisation in thin layers of zinc, or antimony (on the surface of the casting) in certain grains heterogeneous, star-like shapes.

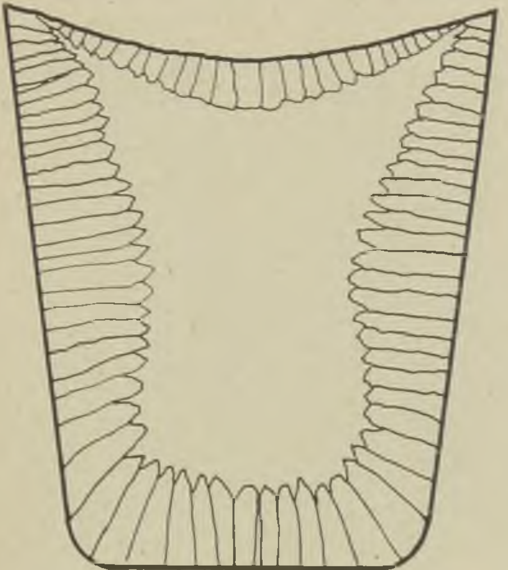


FIG. 8.—GROWTH OF CRYSTALS.

According to Tammann, in spheroidal crystallisation and in polyhedral crystallisation, one obtains other boundaries between the particular grains, and that in the first case there is an uninterrupted curved surface (the section of which will be a curve). In the second case, a plain surface (the section being a straight line), corresponding to the crystallographic qualities of the given substance. As shown by comparing Figs. 1, 2, 3 and Figs. 4, 5, 6, there is not such a difference. In both cases the boundaries are of the same kind, and their sections will be straight lines. Fig. 18 is a micrograph of the boundaries of three polycrystalline grains in spheroidal crystallisation.

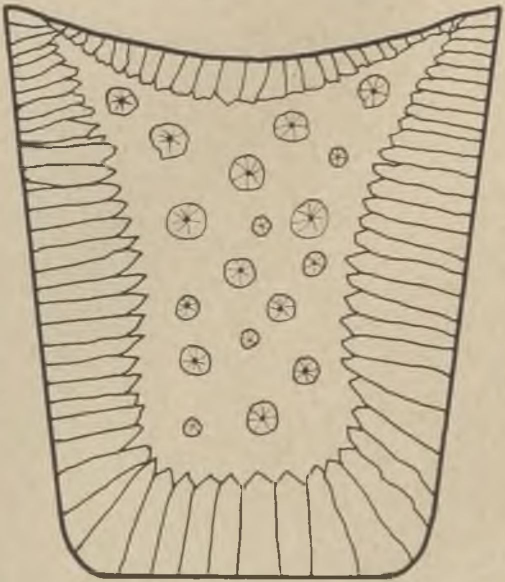


FIG. 9.—COLUMNAR CRYSTALS.

The relation between the crystal-forming energy and the surface tension, that is between f and a, is, in this case, not of any importance for the crystallisation surface, forming the region of the spheroid, as it is composed of the front surfaces of a series of crystals growing from one nucleus. Because the rapidity of the growth, according to equal crystallographic axes, under the same conditions in substances of similar chemical composition is the same, one must obtain in the crystallisation of some series of crystals from one centre, during the growth of the crystals, a spheroid. It is true that some organic substances observed by the author, as well as zinc and antimony, do not belong (as most of metals do) to the cubic system (zinc crystallising, according to the hexagonal system, and antimony to the rhomboidal), to which

Fig. 10.—Crystallisation of a Brass Block. (Institute of Theoretical Metallurgy, Pribram School of Mines.)

adherence is always assumed in explaining dendritic crystallisation, yet this has nothing to do with it. In observing leaded iron-sheet, one can distinguish on its surface star-shaped, crystalline grains (resembling those observed in galvanising iron-sheet), yet normally lead, belonging to the cubic system, gives homogeneous allotriomorphic crystals, as do other metals (see Fig. 2).

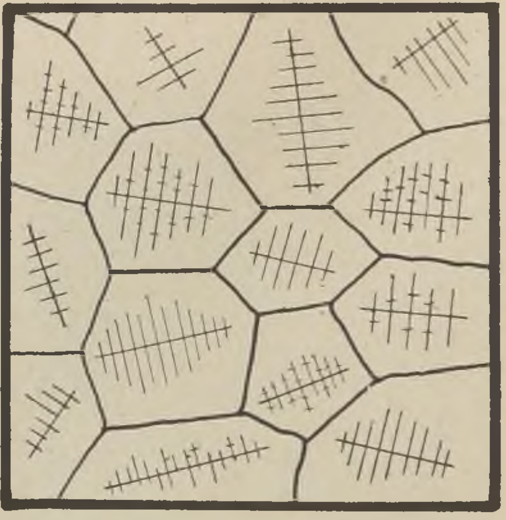


Fig. 11.—Scheme for producing Grains (Desch).

It is not clear why in one case (that is, in the crystallisation of the surface layer), from one nucleus, there should grow a series of crystals in various directions, whilst in a second case (inside a massive casting) only one crystal grows, whilst finally, in the case of the regular system, the growth should only run in three directions, vertical to one another, or why, accepting the hypothesis on the deposition of elementary units, in one case this deposition does not take place, whereas in the other it does.

Therefore the following hypothesis is postulated as to the formation of metal grains (allotriomorphic crystals). From one nucleus there always begins to grow a series of crystals, and that in all possible directions. From the nucleus there is always primarily produced a star-like formation—a physically-heterogeneous grain—and from this, as the first period of the crystallisation of pure substances, there will always be formed a spheroid, composed of a series of crystals growing radially. Further, independently of the conditions under which the crystallisation process is taking place, this heterogeneity of grains remains (entirely or partially) or it disappears. In the latter case from every grain an allotriomorphic crystal is produced.

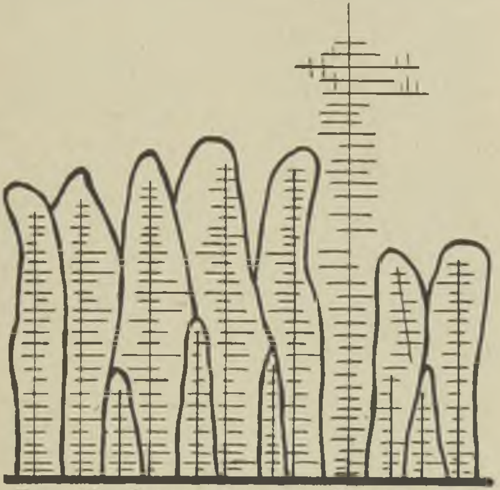


Fig. 12.—Scheme for the Formation of Grain (Tschernoff).

Equalisation of Grain Size in Mass.

If this hypothesis is accepted the rendering homogeneous of crystalline grains would be a secondary process, which, dependent on external factors, would not take its course, or it would do so only partially, or it would continue up to the end—that is, up to the absolute rendering homogeneous of the grain. The essential matter of this secondary process of the rendering of grains homogeneous inside the casting, according to the hypothesis proposed by the author, would be as follows:—(1) The growth from one nucleus of the group of crystals inside the casting takes its course at the melting temperatures of pure metals (or with very little super-cooling), that is, at a relatively high temperature; (2) this process takes its course in a three-dimensional space, so that the shape of the crystallisation surface (where the equilibrium $F_{\text{liq.}} \rightleftarrows F_{\text{cr}}$ is situated) will be spheric and the crystals just formed will be entirely isolated from the other space by means of the crystallisation surface; (3) in consequence of this fact, the cooling influence of the surrounding space can influence only the crystallisation surface: (4) as to the cry-

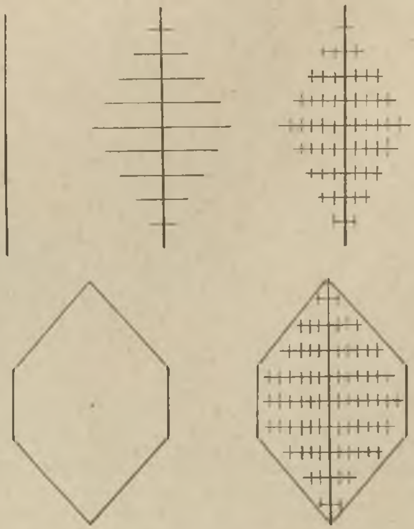


Fig. 13.—Grain Growth (Sauveur).

stals already formed (reference is being made, of course, to the period of the process) from the nucleus up to the crystallisation surface, their temperature remains, during the whole period of the process, constant, and protected from losses (through the influence of the surrounding space) by means of the latent melting temperature, that the crystallisation surface steadily develops; (5) the individual crystals of the growing grain are in close contact with one another through the large crystalline surfaces of the same chemical composition, having amongst themselves

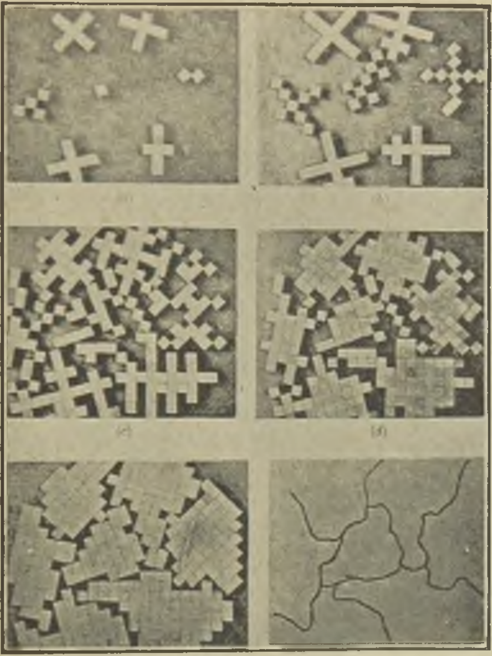


Fig. 14.—Schemes of the Formation of Grains (Rosenhain).

neither amorphous layers, nor even the smallest quantity of whatever the impurities ordinarily contained even in very pure metals, because the remaining liquid will be centrifugally repulsed by the growing crystals, that is in the direction of their growth; (6) these thermal conditions should be very favourable for the fusion of the individual crystals; it is similar to the fact that two drops of mercury will immediately associate when touching one another, of course, under the condition of a pure surface. The difference will be in that the mercury endeavours to decrease the total surface through the forma-

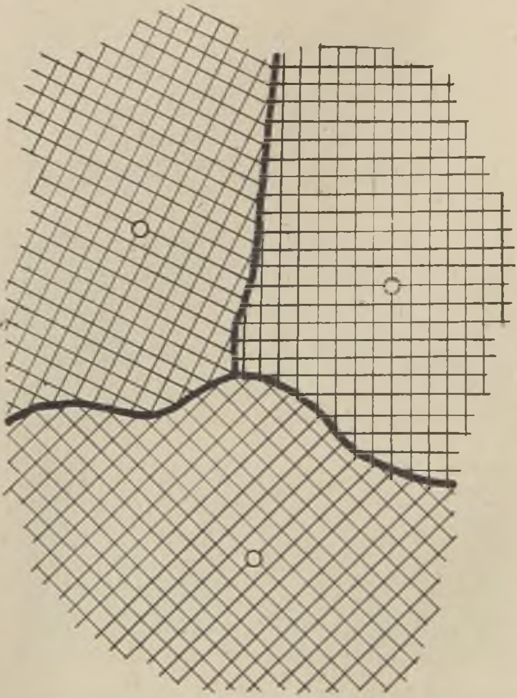


FIG. 15.—FORMATION OF CRYSTAL GRAINS (OBERHOFFER AND TAMMANN).

tion of one spherical drop—that is, it endeavours to obtain a geometrical shape, having a minimal surface, whereas metal during crystallisation only endeavours to increase the crystal, preserving at the same time its shape; (7) this endeavour

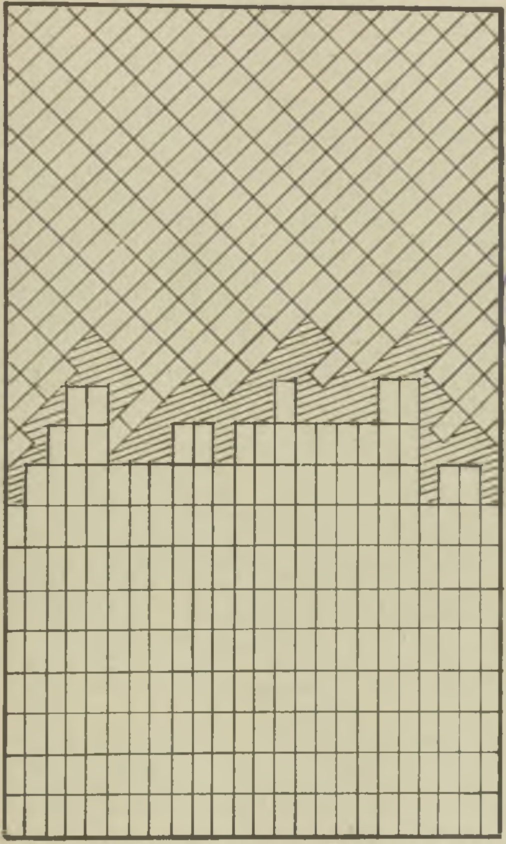


Fig. 16 Scheme of the Formation of Particular Grains according to the Hypothesis of Rosenhain and Bailly.

to fuse together takes place in every system—every system endeavours to obtain maximum stability. It tries to decrease its free energy (in this case, through the decrease of the surface area, to decrease the surface energy), that is, to increase its entropy, and (8) independently of the rapidity of this secondary re-crystallisation process one can obtain such grains, in which the crystallisation units are equally disseminated, or at least that after etching there may be observed the principal re-crystallisation axes (pseudodendrites) whereby sometimes the location of the primary nucleus may be defined, but not always.

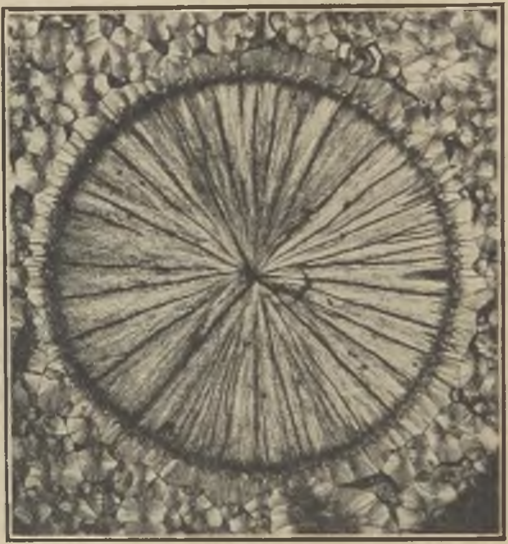


FIG. 17.—INSTITUTE OF THEORETICAL METALLURGY, PRIBRAM SCHOOL OF MINES.

In considering that by heating finished castings for a relatively short time and at a not too high a temperature (sometimes well beneath the melting point), it is possible to obtain re-crystallisation—that is, an increase of grains by the fusing together of the individual polyhedrons—the process having to overcome the re-

FIG. 18.—MICROPHOTOGRAPH OF THREE POLYCRYSTALLINE GRAINS. (INSTITUTE OF THEORETICAL METALLURGY, PRIBRAM SCHOOL OF MINES.)

sistance of the tensioned metallic films between the grains, as well as the impurities accumulated there, whereby the latter become segregated through this process into relatively large accumulations. Obviously at temperatures near the melting point and under the condition that the particular crystals are in mutual contact with pure surfaces, their rapid fusion is very probable.

Table I details the lowest temperatures at which re-crystallisation can still take place (that is, the fusing of various grains, divided from one another by a layer of amorphous cement, or maybe a layer of impurities). This temperature may be a few hundred, and even a thousand degrees below the melting point. The dependence of the speed of grain growth on the temperature is shown in Fig. 19. In temperatures approximating to the melting point, the size of the grains (that is, the fusion of various grains) has increased several times after thirty minutes' treatment.

Table I.—*Approximate Lowest Recrystallisation Temperature (Z. Jeffries and R. S. Archer : " The Science of Metals ").*

Metal.	Melting point.	Approximate lowest re-crystallisation temperature.
Iron	1,528	450
Nickel	1,452	600
Gold	1,064	200
Silver	961	200
Copper	1,084	200
Aluminium	658	150
Platinum	1,753	450
Magnesium	650	150
Tantalum approx.	2,950	1,000
Tungsten approx.	3,350	1,200
Molybdenum	2,620	900
Zinc	419	Room temperature.
Cadmium	321	Room temperature.
Lead	327	Less than room temperature.
Tin	232	Less than room temperature.

As to crystallisation taking place in thin layers, or on the surface of the casting, there is here no longer any protection from the cooling influence of the surrounding space, as the crystallisation equilibrium $F_{liq} \rightleftarrows F_{cr}$ takes place circularly, so that the already formed crystals, contained inside the circle, are of a much lower temperature than is the crystallising part. Owing to the lowered temperature, the re-crystallisation process (rendering homogeneous) does not take such an easy course as it does inside a mass during the crystallisation.

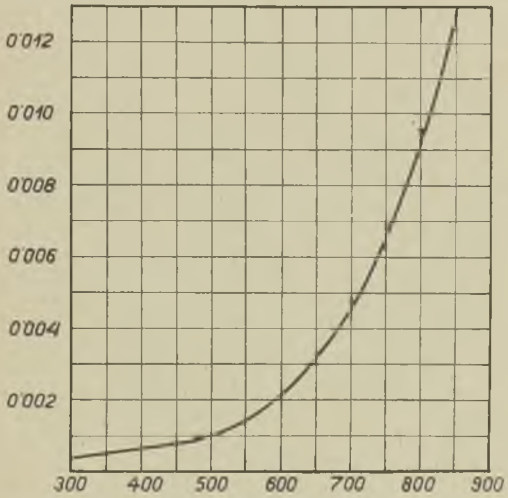


Fig. 19.—Relationship of Grain Growth to Temperature.

Depending upon (1) the absolute temperature at which re-crystallisation takes place, (2) on the capacity of the substance to change at this temperature the orientation of its crystalline units, (3) on the degree of decrease of temperature and (4) from the rapidity with which, under these conditions, the process of rendering the crystals homogeneous takes place, this is total or partial (decrease of the number of rays branches owing to their fusion), or finally none.

The crystallisation process itself, actuating in the thin layers, or on the surface, would take the following course:—(1) From the formed nuclei there begin to grow in different directions star-like crystals with the same rapidity in all directions; (2) depending upon the crystallographic character of the crystal and its definite angles in reference to its axis there are deposited crystalline units. The crystal will also grow in a vertical direction, in reference to its natural radial direction; (3) the rapidity of this process can also be different from the rapidity of the basic axis. KG can be different for every crystallographic axis; (4) this growth will find a mutual obstacle in the growth of the adjacent crystal; (5) if this rapidity resembles (according to the coefficient value) to the speed of the growth of the crystal according to the radial axis, there is obtained a typical, circular, growth; (6) if this speed were much smaller than the speed of the radial growth, one would obtain an acicular structure. Such a structure could be used to explain the formation of sulphur needles from liquid, as previously cited; (7) if the capacity for the rendering homogeneous of the substance, under these conditions, is considerable, there is obtained a partial, or even an absolute, elimination of one sort of crystal by the others—one is obtaining a star-shaped, cruciform, or even a pseudodendritic form; and (8) if this capacity of the substance is low under these conditions, one obtains a typical star-like structure.

This scheme would explain the origin of various types of surface grains. An example of a cruciform structure is shown in Fig. 20. All possible types of crystalline grains of pure substance, as well as their successive transition from one type into the other are represented by the scheme (Table II). A structure, in which, in pure substances, there can be distinguished within the grains a dendritic structure, has been termed by the author "pseudodendritic," in contradistinction to the true dendritic structure (formation of a dendritic skeleton in the course of primary crystallisation), existing in crystallisation from solutions.

The process of the formation of the structure in question always takes its course to the right, as indicated in Table II, and that being so, initially there is formed a star-like structure, which then, independently from the outside factors, either persists, or changes, and that, at such a distance to the right, as is admitted by the crystallisation conditions. Its homogeneity may, under suitable conditions, effect itself so rapidly, that already during the formation of star-like crystals, initially there occurs an absorption of one crystal by the other, so that still early on in the crystallisation process one may obtain a unicrystalline composition of the grain (pseudodendrite in cross-section).

Fig. 20.—A Cross-shaped Structure. From "Das Technische Eisen," by P. Oberhoffer.

If the crystallisation process takes place from a solution, or, similarly, from a molten alloy, one will always have the possibilities shown in Table III. The type of Group III is not dealt with in this Paper, for in a chemically stable combination there will not be any difference according to the crystallisation process of the types of Groups I or II, and in the case of the formation of decomposing chemical combinations—that is, when these are formed in the course of the crystallisation process by a reaction between the precipitated crystals and the liquid—one will obtain, not a primary formation of crystalline grains, but a complicated secondary process, which is extraneous. Equally the type of Group II, 2, B (*a*) is not discussed, because it is also a secondary process.

Fig. 21.—Growth of Binary Alloy.

Fig. 22.—Growth of Ternary Eutectic.

The types of the Groups II, 2, A, and II, 1, are not different from one another in the sense of the crystallisation process. Consequently the types of the Groups I, 1; I, 2; II, 1 and II, 2, B, b, alone remain.

Group I, 1.—The most important case is the type of Group I, 1, that is, the crystallisation of a pure substance from solution. As in this case, also in all of the other cases, in the crystallisation of alloys, except the above-mentioned factors determinating the crystalline process, an important part is played by the concentration of the solution, the change of its concentration during the process of crystallisation and the relation between the rapidity of diffusion in the concentration and the linear crystallisation speed;

TABLE II.

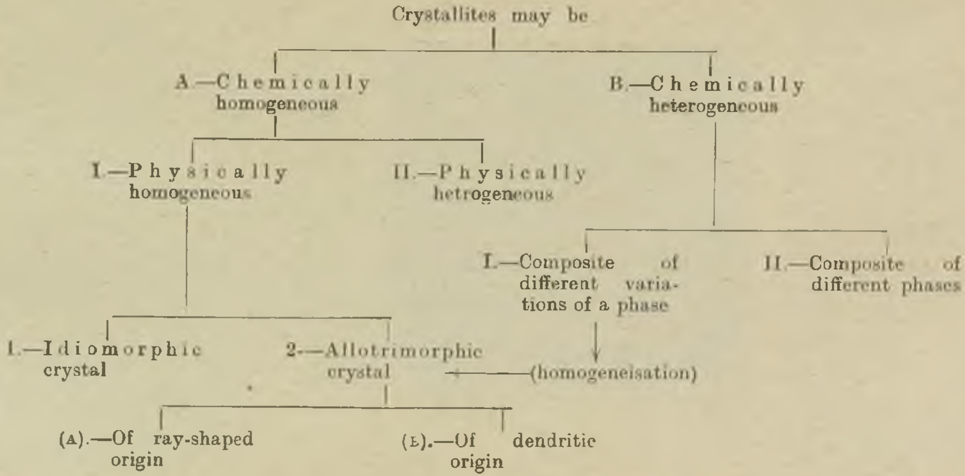
Exterior grains.		Interior grains.		
Without secondary crystallisation (without homogeneisation).	With secondary crystallisation (with homogeneisation).			
	Partial homogeneisation	Complete homogeneisation.		
		Original crystallisation centre still to be observed.	Original nucleus disappeared.	
Star-like grain structure.	Star-shaped grain structure.	Cruciform grain structure.	Pseudodendritic grain structure.	Homogeneous grain.
→	→	→	→	

Table III.

In crystallisation from solution the following cases may occur :—

- I.—Crystallisation of pure substance
  - 1.—The composition of the alloy is indeterminate, except the eutectic composition
  - 2.—The composition of the alloy corresponds to the eutectic composition
- III.—Crystallisation of chemical combination of the dissolved substance from the solvent
- II.—Crystallisation of solid solution
  - 1.—Discontinuous solid solution
  - 2.—Restricted solubility in crystalline state
    - A.—Composition of the alloy lying within the limits of solid solutions
    - B.—Composition of the alloy lying in the intervals between the solid solutions
      - (A).—IV. Roozeboom type
      - (B).—V. Roozeboom type

TABLE IV.


Crystallites may be
A.—Chemically homogeneous
B.—Chemically heterogeneous
I.—Physically homogeneous
II.—Physically hetrogeneous
I.—Composite of different variations of a phase
II.—Composite of different phases
1.—Idiomorphic crystal
2.—Allotrimorphic crystal
(homogeneisation)
(A).—Of ray-shaped origin
(B).—Of dendritic origin

in the case of the crystallisation of a solid solution, the diffusion in the already precipitated crystals also plays an important part.

In case I, 1, when the concentration of solution (under the existing thermal conditions) has attained saturation, the crystals of the pure substance begin to precipitate according to the liquidus curve in definite intervals of temperature, when the temperature will decrease and at a constant temperature in the case of the crystallisation from the solution, when the solvent will gradually disappear.

FIG. 23.—EUTECTIC STRUCTURE—RADIATIFORM STRUCTURE. FROM "LEHRBUCH DER METALLOGRAPHIE," BY J. TAMMANN.

If the crystallisation takes a very slow course, that, is, when the time between the beginning of crystallisation and the final eutectic solidification of the solution is very considerable (the process evidences itself only with a very low supercooling—low KG and low KZ), and chiefly because the absolute value for KG will be low, one obtains large, well-developed, idiomorphic crystals.

Process of the Production of Idiomorphic Crystals.

Equally as in the crystallisation process of the pure substances already outlined, nuclei are formed very sparsely. One may suppose, provided the hypothesis propounded is accepted, that initially, from the nuclei, crystals begin to grow in all directions, yet before they reach any considerable size, equalisation is already taking place and the crystal assumes its innate crystallographic form. Moreover, if KG is low, there constantly will be deposited on this crystal new and fresh layers of crystal; from the saturated solution surrounding it one thus obtains an idiomorphic crystal. If KG is higher than the concentration of the solution, the solution in the immediate vicinity of the surface will be poorer by the dissolved substance; the regularity of the growth will be interfered with and the formation of dendrites started. The crystallising substance will require more material for its growth in other parts of the solution if it is not in the immediate vicinity of the surface. In

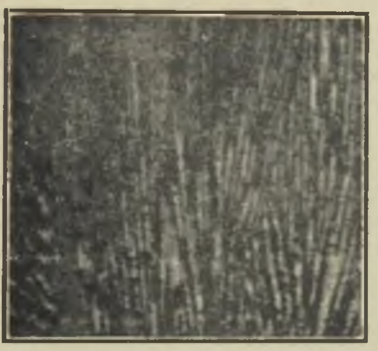


FIG. 24.—EUTECTIC STRUCTURE—FINE-GRAINED STRUCTURE. FROM "LEHRBUCH DER METALLOGRAPHIE," BY J. TAMMANN.

this manner one obtains a true dendritic structure.

The influence of the impoverishment of the solution in the immediate vicinity of the crystallisation surface—owing to a high value for KG—on the precipitating metal may be easily observed in the process of the electrolytic precipitation of metals on the cathode, which follows the same principles as the crystallisation from a molten bath—that is, according to KG and KZ. On the edges of the cathode (supposing it is being worked with a maximum density of current, in which a good cathode deposition may still be obtained there), whereby the density of the current is still higher, branches of a dendritic character begin to form, the precipitating metal requiring more material for the construction of its crystal.

If the crystallisation process reaches finality, the precipitation of the eutectic begins at the eutectic temperature. This surrounds the previously-precipitated crystals, whether dendrites or idiomorphic. Naturally this will occur only if the alloy chosen is of a composition approximating to the eutectic composition, that is if the quantity of eutectic is greater than that of the precipitating primary crystals. On the contrary, *i.e.*, if the quantity of primary crystals is larger than the eutectic, the precipitated crystals will constitute an obstacle to each other as to growth. In the crystallisation of pure substances one obtains a polyhedral structure, whereby the dendritic structure of the polyhedrons are almost always clear. The remaining quantity of liquid solidifies eutectically between the individual polyhedrons.

Formation of Nuclei from Eutectic Alloys.

The type of Group I, 2, represents an alloy of eutectic composition. For clarity it is proposed to treat the most usual case, that is, an alloy composed of an indefinite quantity of constituents, so that this may correspond to whatever eutectics exist. It is immaterial whether this eutectic is mono-, bi-, tri- or " n "-variant.

It is sufficient to have an eutectic, *i.e.*, a composition, in which the liquid will be saturated at the same time with some, or at least two, components. In this case, the precipitation of the smallest particle of one constituent will immediately be followed by the precipitation of the second component. This supersaturation occurs in the *immediate* vicinity of the precipitated particle, so that the precipitation of these other constituents of the eutectic will take place in the immediate vicinity of the precipitated crystal, that is, near the same nucleus. The number of the crystallisation centres will depend on the supercooling. The linear crystallisation speed will assume another value for each of the constituents of the eutectic.

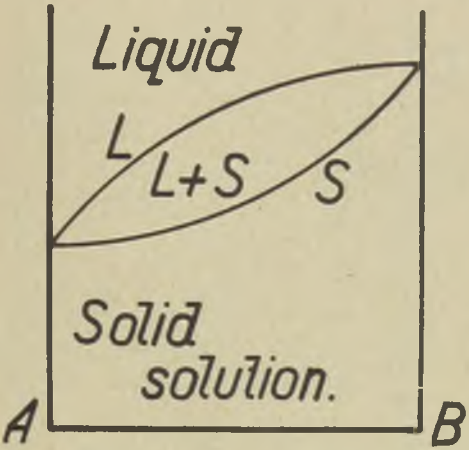


Fig. 25.—Roozeboom's Diagram, Type I.

The process of the crystallisation of the eutectic itself will act in the following manner: For every time-unit, a definite number of nuclei will form, and from these eutectics begin to grow in all directions (spheroidally). These eutectics are constituted of as many constituents as there are in the eutectic. Naturally the crystals in this case growing from one nucleus will have a different chemical composition, so that the adjacent crystals or branches will be of various phases.

In the simplest case, that is, in the case of the binary eutectic, a growth is formed according to the scheme represented in Fig. 21 (the white branches refer to component A, the black ones to component B). In a ternary eutectic (Fig. 22) there are branches of the white component A, of the black component B, and of the grey component C. As a result a star-like structure with a spheroidal growth of the eutectic grains is obtained, constituted not only of crystals orientated in a different way, but also of varying chemical composition. In this case, the fusion of the individual branches is impossible without an absolute overcrystallisation, that is

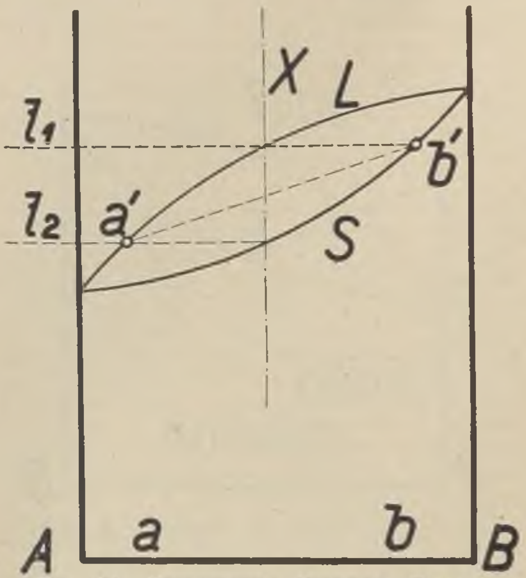


Fig. 26.—Roozeboom's Diagram, Type I.

without the change of the size of the original grains, and crystals of similar chemical composition will be separated from each other through other crystals.

Sometimes, instead of the typical star-like structure, the fine-grained structure of the eutectic is obtained, yet, as is shown in Fig. 23 and Fig. 24, the difference in the structure is dependent on the way in which the surface ot the specimen intersects the eutectic grain. Considering that the eutectic grains can be of very considerable dimensions (for instance, Hargreaves obtained with lead-tin eutectic grains measuring one inch), it is not surprising that the intersection of the individual branches of a crystal give a microstructure similar to small polyhedrons, as shown in Fig. 23.

If a solid solution is formed, that is of the type of the Group II, 1, the process will take its course in a similar way to the crystallisation of pure substance, except that it is a little more complicated. In this case, the formation of one or another sort of crystals will be dependent not only on the factors already mentioned above, but also on the rapidity of diffusion in the liquid, as well as in the crystalline phase, and also on the reciprocal distance at constant temperatures (in the crystallisation interval) of the "solidus" and "liquidus" curves.

Binary Systems.

In the higher systems there will be the same as the binary, except that instead of the "liquidus" and "solidus" curves there will be either surfaces of double curvature or spaces of higher dimensions. In the binary system the process of crystallisation, assuming definite miscibility in the liquid state, as well as in the crystalline one, takes its course according to Fig. 25 (referring only to Type I of Roozeboom, because II and III do not materially differ from it). During the crystallisation process of the alloy of some composition—for instance, of the composition X in Fig. 26.—its temperature will change from t_1 up to t_2, the composition of the liquid phase from *X* to *a* (according to curve *L*), the composition of the crystalline phase from *b* to *X* (according to curve *S*), but the composition of the precipitating crystals every moment will change from *b* to *a*, according to some curve *b-a*, whereby the composition of the first precipitated crystal, in the immediate vicinity of the crystallisation centre, or the composition of the nucleus, will correspond to the point *b*,

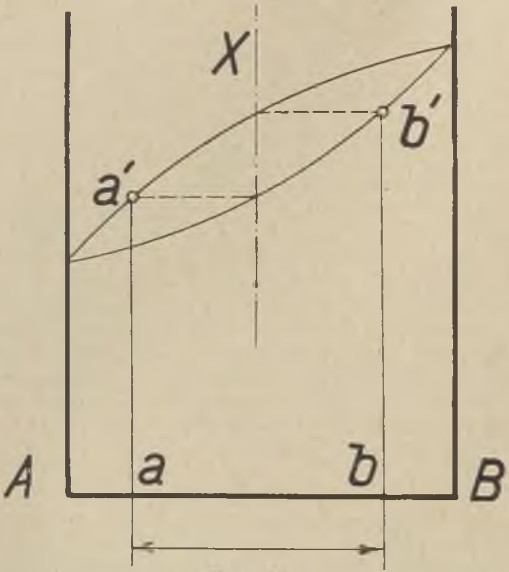


FIG. 27.

and the composition of the last precipitated crystal on the periphery of the grain will correspond to the composition of the point *a*.

It is obvious that the greater the distance of the points lying at the same temperature on the "liquidus" and "solidus" curves, and from the fact that the greater the distance between *a* and *b*, the greater is the difference in the composition of the crystallising substance during the crystallisation process and the greater is the difficulty to obtain homogeneous (also in the chemical sense) crystalline grains.

As shown in Fig. 27 and 28, the difference in chemical composition between first crystalline germ *b* and its part, finally precipitated (*a*) is in the first case (Fig. 27) much less than in the second one (Fig. 28). Varying with the rapidity of cooling, the diffusion in the crystalline state and on the reciprocal distance of the points *a* and *b* one obtains homogeneous or heterogeneous grains. The shape of the grains (either polyhedral or pseudodendritic, etc.) depends on the conditions of crystallisation, exactly as was the case with the solidification of pure substance.

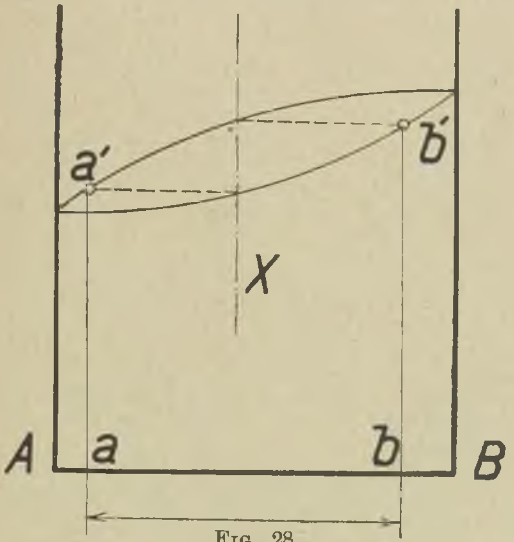


FIG. 28.

In the case of solidification of the system according to Type Group II, 2, *B*, *b*, crystals will be formed according to the mono- or polyvariant process (that is, taking its course in a thermal interval), from nuclei, from which spheroidal star-like crystals will grow. Thus one obtains either a formation of an idiomorphic crystal or of polyhedrons in intervals, between which will be a eutectic or a dendritic structure, whereby the individual polyhedrons or dendrites, independently of the composition of the alloy (on its remoteness from the eutectic composition) will have common limits or will be surrounded by a eutectic. The difference rests only in the fact that the growing grains, spheroidal or dendritic, during their growth of various composition (and one obtains these primary crystals of the same different composition in their various parts) depending on the rapidity of cooling, on the rapidity on the diffusion in crystalline state and on the distance between "solidus" and "liquidus" curves. This process is illustrated in Figs. 29 and 30.

Obviously in the case illustrated in Fig. 29 the chemical equalisation is more difficult than in the case of Fig. 30, primarily due to conditions of cooling. The difference between the chemical composition of the first-precipitated crystal element and the last one (*a*-*b*) is greater in this case. With this case, that is the diagram in which the "solidus" curve is of concave shape, the crystallisation of the primary austenite in the iron-carbon diagram can be associated. The heterogeneity of dendrite in the crystallisation of iron alloys can thus be explained.

This chemical heterogeneity of the individual parts of dendrite makes their physical homogeneisation difficult, that is it renders difficult the formation of homogeneous polyhedrons, through which there is a reason why, in iron alloys, even if they have been worked, primary dendrites may still be observed. The homogeneisation of grains requires initially in this case a chemical homogeneisation, and only afterwards their fusion will be possible, that is, the physical homogeneisation.

Basically, the course of crystallisation remains always the same. There is always formed a nucleus from which crystals grow in various ways, yet always in every direction. Independently of the circumstances whether the system has an absolute crystallisation, a homegeneous or a heterogeneous constitution, there are always obtained grains of various shape (homogeneous or heterogeneous) whereby every grain has been formed from one nucleus.

The author suggests that such a grain, formed from one nucleus, should be called a "crystallite." If this definition is correct, one obtains

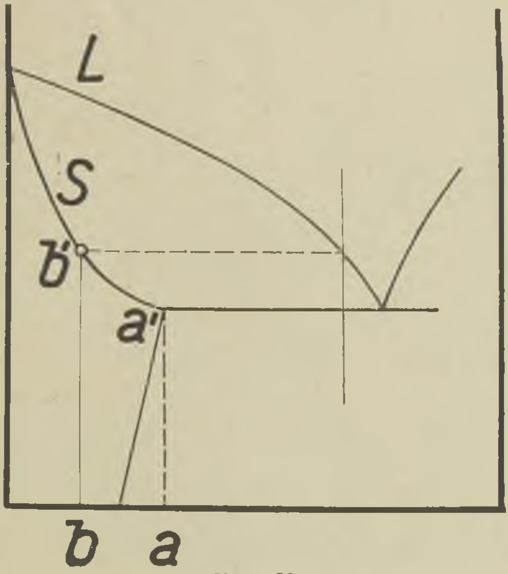


Fig. 29.

thereby a clear conception of a "crystallite," and at the same time there will be no objection to Tammann's and Sauveur's conception of a crystallite. All crystallites could be in this case classified according to the following scheme:—

(A) *Chemically homogeneous*, that is constituted of various crystals belonging to one and the same phase, and possessing an equal chemical composition. This case is obtained in the crystallisation of molten pure substances, in the crystallisation of solid solutions, when the diffusion in crystalline state takes its course rapidly, so that the rapidity of cooling is low and that the distance between *a*-*b* is not too great; equally a chemically-homogeneous crystallite is obtained in the crystallisation of a substance from solution in a composition differing from the eutectic composition. These chemical-homogeneous crystallites may be:—(I) Physically homogeneous, which occurs if the recrystallisation process is rapid during the crystallisation process. Depending upon the fact, whether the pure substance crystallises from its molten bath or from the solution (in the latter case according to whether the composition approximates that of the eutectic or not), one obtains either idiomorphic crystals or

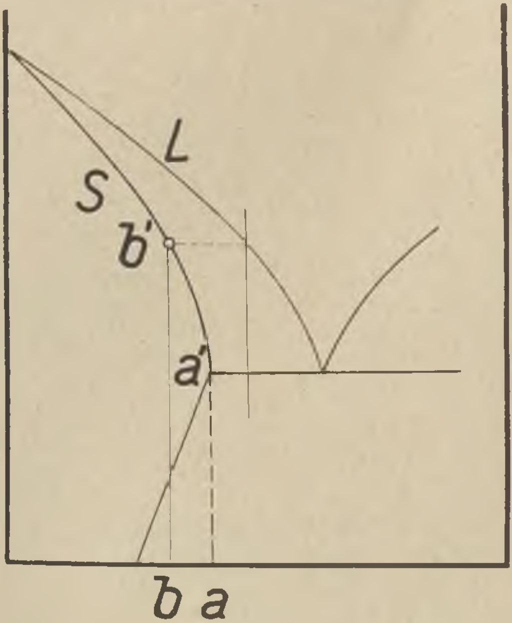


FIG. 30.

allotrimorphic crystals, that is monocrystallic polyhedrons. The latter may arise from dendrites or from branches.

(IIA) The physically-heterogeneous crystallite, that is the polycrystalline crystallite, which constitution one obtains under conditions, in which homogeneisation in the internal part of the crystallite is made impossible by the conditions of the crystallisation process. The structure will be star-like. This structure is chiefly observed on the surface of the casting or in the crystallisation of thin layers.

(B) *Chemically heterogeneous.* This constitution of crystallites is obtained in the crystallisation of solid solutions (under such crystallising conditions which render impossible the equilibrium of the constitution of the precipitated crystals), or in the crystallisation of eutectics. Chemically heterogeneous crystallites may be:—
(1) Constituted of crystals belonging to the same phase, with the exception that the internal part of the crystal will be different (varying with the chemical composition) from the surface, whereby there will be from the internal part up to the surface a continuous transition. This case will be obtained in solid solutions.

(III) Constituted of crystals belonging to various phases—a typical case being the solidification of eutectics. The constitution is normally star-like, and from the same nucleus crystals belonging to various phases grow. The boundaries between the individual crystals of various chemical constitution are very sharp.

This classification of crystals is outlined in Table IV.

Summary.

(*a*) Assuming the metal formation of homogeneous polyhedrons (crystallites), such as grains of metal. They are always star-shaped.

(*b*) These can still, during their growth, become homogeneous, and one obtains either an entirely homogeneous crystallite, or entity in which a dendritic structure may be distinguished as a product of primary homogeneisation.

(*c*) Dendrites in pure metals (pseudodendrites) are of secondary origin—the product of homogeneisation of primary " rays."

(*d*) The trend towards homogeneisation of grains (towards the fusion of the individual crystals) is the tendency of every system to increase its entropy, that is to decrease the free energy. Here the tendency is for the decrease of the surface energy by the decrease of the surface.

(*e*) This process only takes place within the boundaries of one crystallite, because in the fusion of various crystallites it is necessary to overcome the resistance of the intercrystalline cement, as well as finally that of the occasional residual impurities.

(*f*) If the crystallisation process takes its course practically in a bi-dimensional space, it is very probable that a polycrystalline (star-like) crystallite will be obtained.

(*g*) Every crystallite, that is every grain, independently of whether it is homogeneous or heterogeneous, grows from one nucleus.

(*h*) In the crystallisation of pure substances from the bath there is either a spheroidal growth or one according to the crystallographic orientation.

(*i*) The dendritic constitution which is sometimes shown on grains of pure substances is not primary, but it is the product of homogeneisation—and may be termed " pseudodendritic."

(*j*) In the case of selective crystallisation of pure substances from solution, the growth of the crystals may be dependent on the conditions of crystallisation, either according to the crystallographic orientation, or spheroidal or finally dendritic.

(*k*) The same may be observed also in solid solutions.

(*l*) In the case of crystallisation of alloy of eutectic composition, chemically-heterogeneous grains and a chemically-heterogeneous crystallite is obtained. In this case no homogeneisation within the boundaries of one crystallite is possible.

DISCUSSION.

The President (Mr. Wesley Lambert), emphasised that the subject of the crystalline grain structure of castings was of paramount importance. Foundrymen did not like to talk much about the crystalline structure of a metal, because the reference to it always gave the engineer a wrong impression, but all metals which had been melted and founded either in the form of ingots or castings exhibited a decided crystalline structure. Although he had spoken of "crystalline structure," he rather favoured the description "grain structure." Upon examining the fracture of a casting, one was not necessarily looking at crystals, but at grains of a crystalline formation. The question of whether a casting was weak or strong was determined not so much by the size or order of the grain structure as by the inherent properties of the grain, the mechanical dovetailing effect of one grain with another, and the cementing together of individual grains. Included in the inherent properties of the grain was its plasticity—is it likely to deform much under stress, or is it of a brittle character? The crystalline grain structure of metals has less relation to the tensile strength or resistance to fracture under shock than many engineers think it has. One can obtain excellent test results from a metal having a crystalline grain structure of fairly considerable size. There was a good deal of talk, he continued, about metals becoming crystalline through fatigue, but one could not make crystal grains grow by fatigue stresses. Could one imagine anything more ridiculous than to suggest that by stressing a metal one could make the crystal grains grow; surely as the result of repeated stressing the grains would be much more likely to become smaller by attrition. He emphasised the point that the crystal grains found on visual examination of fatigue ruptures pre-existed in the metal; one could not enlarge crystal grains except by thermal treatment, and the fact that the crystal grains were exposed in a fracture was no indication that the metal was necessarily weak. In a manganese bronze having a tensile strength of 40 to 45 tons it was not uncommon to find fairly large crystalline grains. By thermal treatment of a metal with a structure such as that exhibited in Fig. 3 of the Paper, for instance, it was possible to make one grain absorb another. This statement did not mean necessarily that the larger grains will absorb the adjacent smaller grains. He had succeeded in growing some very large grains as a result of thermal treatment.

Star-shaped Crystals and Bearing Metals.

Mr. A. H. Mundey said the author of the Paper had put forward many important points concerning the physical properties of metals, which points ought to be more sympathetically considered and more thoroughly understood by foundrymen than they actually were. There was a great tendency to decide that a material was rotten because it showed a highly crystalline structure, and it was not fully realised that the crystals were always there but were not always visible. Referring to the tests, described by the President, on gun steel, he said that the effect of the final test was practically the effect of a notched bar test, in which the stresses were concentrated and a partial shear was obtained. In that particular case, because the stresses were concentrated at one point, there were no slip bands and there was no movement of the crystals; the fracture occurred in the intercrystalline spaces. It was dependent very largely upon the character of the crystals, their physical properties, and the particular kind of interlocking which existed.

Referring to the star-shaped crystals, he said that in connection with the white metals, metallurgists were careful to arrange that those very crystals, instead of being a source of trouble and anxiety, were enlisted into engineering service, and that provided an interesting example of the manner in which the metallurgist was trying to help the foundryman. In the case of a white bearing metal, consisting of tin, copper and antimony, and maybe a little lead, if there were more than 7 per cent. of antimony present, cuboid crystals of antimony would separate out; these would segregate into groups, unevenly distributed, and if they were very large there was a tendency for them to break around the crystals and exhibit a large crystalline structure. When copper was present in the correct and well-balanced proportion, however, the copper separated out first as a copper-tin crystal, or maybe even as a copper-antimony crystal with a copper-tin crystal encasing it and isomorphous with it, and distributed itself throughout the freezing mass in dendritic crystals—needle-shaped and star-shaped—so that it formed a nice network on which the cuboid crystals, which separated out at a little lower temperature, attached themselves. Thus, if one could obtain a section through some of these white bearing metals as they were freezing, it would look something like a cobweb, on a spring morning, dotted with little diamonds of dew. The attachment of the cuboid crystals of antimony to the copper-tin and copper-antimony network prevented the cuboid crystals becoming segregated. The fibrous structures of which one heard so much did not really exist in metals. The structures consisted of crystals, and the ends which were pulled out and made to look like silky fibres were really the ends of crystals which had smoothed over one another.

False and Real Structure of Wrought Iron.

The PRESIDENT, supplementing his previous remarks and those of Mr. Mundey as to the existence of the crystal grain structure of metals, suggested a simple test which may be carried out on a bar of good wrought iron, of, say, 1 in. diameter. If one nicked round such a bar and struck it sharply with a hammer in such a manner as to jar off the end of the rod, the crystalline grain structure of the material would be observable, although the material was recognised as being good wrought iron. One could then nick the bar a little further along its length and hammer it over until it fractured in such a manner as to show a beautiful silky fibrous fracture.

Continuing, the President recalled a fatal accident which had occurred some years ago as the result of the breaking of a link of a chain. It appeared from the fracture that the metal was very coarsely crystalline. The coroner, at the subsequent inquest, examined the broken link and inquired whether it was considered to be a good iron; the reply was that there was every reason to believe that it was quite normal. The link was tested; full specification test results were obtained from it. A lecturette was then delivered to the coroner on the production of fractures of different appearance from the same bar of metal. The coroner asked whether it would be possible, if he marked one of the links, to reproduce the same fracture as that of the link which had broken. It was pointed out to him that this would be somewhat difficult, but not impossible. After some little trouble it was found possible to break another link of the chain and produce a similar crystalline fracture. He mentioned this experience in order to emphasise that practically all metals were crystalline in structure, and that the appearance of a fracture was dependent upon the manner in which that fracture was effected.

Strength with Grain-Size Reduction.

Mr. T. H. Turner said that in considering the effect of crystallisation in castings, it was well to point out that it was possible in certain cases to reduce the crystal grain size. This had been done especially in the 13 per cent. silicon alloy of aluminium, by an addition of elements causing what was termed "modification." Cast iron was, to a smaller extent, being similarly treated. Foundrymen, therefore, had an important and novel means of decreasing the grain size of their alloys, and the liability to fracture under shock, of the type so ably described by the President, was much decreased when the grain size was reduced. It was probable that the modification of other casting alloys would be everyday practice in the future.

COAL-DUST AS APPLIED TO MOULDING SAND.

By Ben Hird (Member).

This Paper is an attempt to prove, by practical experiments, the action of coal-dust during the pouring of moulds which have been faced with sand containing a percentage of this material, and the changed condition of the sand and coal-dust after use. So far, the author has been unable to find any data of sustained investigations of the action of coal-dust in sand moulds. Practically every foundryman has formed his own ideas as to what actually takes place, the most prevalent idea being that a slight film of gas, or smoke, on the face of the mould, prevents the molten metal fusing the silica grains, giving to the casting a clean blue skin, instead of the rough grey appearance when no coal-dust is used.

Particulars of the ingredients used in these experiments are:—

Sand.—The sand used, throughout, was Stourbridge Red sand, of medium grade, as received from the quarry. The sand was dried and passed through a $\frac{1}{16}$-in. mesh sieve to remove lumps. Coal-dust was well mixed in, and 5 per cent. of water added.

The sand was tested as follows:—

Sieve Tests.—Sieve tests were made on the raw sand as received and on the dried raw sand (dried for one hour at 110 deg. C.) with the following results. The sieves used were the old British standard. This gives an idea of grain size.

—	Red sand as received.	Dried red sand.
Left on 30 mesh ..	0.3	0.3
,, 60 ,, ..	13.8	21.0
,, 90 ,, ..	34.1	37.0
,, 120 ,, ..	27.5	23.5
,, 180 ,, ..	17.2	13.3
Passing 180 ,, ..	6.1	4.2

Permeability Tests.—The permeability of the raw sand rammed to a density of 1.6 in the standard apparatus of the Cast Iron Research Association was 35. This is the time in seconds taken by a gas to penetrate a standard core 8 in. long and 2¼ in. dia. contained in a cylinder. The volume of the cylinder, and hence of its containing core, is 800 c.c., and, therefore, the density of the core is readily obtained by dividing the weight of the sand taken by the volume. In this case the weight was 1,280 gms. Alternatively, a given density can be obtained by weighing out a particular amount of sand, and a little experience soon enables this to be used in just filling the cylinder with a uniform ramming.

Strength Tests.—The strength of the sand taken on a core 1 in. dia., 2 in. long, in the standard compression apparatus of the Cast Iron Research Association, is shown in Fig. 1. This gives the compression strength of the raw sand, both in the unmilled state and after milling for ten minutes. The improvement after milling will be noted. The strength is given for several ramming densities and, of course, the higher the ramming the stronger the sand. The whole of the strength tests were taken on a standard moisture content of 5 per cent.

To eliminate any unknown quantities, used floor sand, *i.e.*, black sand, was discarded.

Coals.

Three coals were ground separately to produce the dust for these experiments:—

		Per cent.
Tirpentwys ..	Volatile	30.6
	Ash	10.4
	Carbon by difference ..	59.0
Treharris ..	Volatile	12.3
	Ash	16.10
	Carbon by difference ..	71.60
Anthracite ..	Volatile	6.6
	Ash	9.70
	Carbon by difference ..	83.70

Each of these coal dusts were divided into three grades, or grists, as follows:—(1) All that passed through a 40 meshes to the linear inch

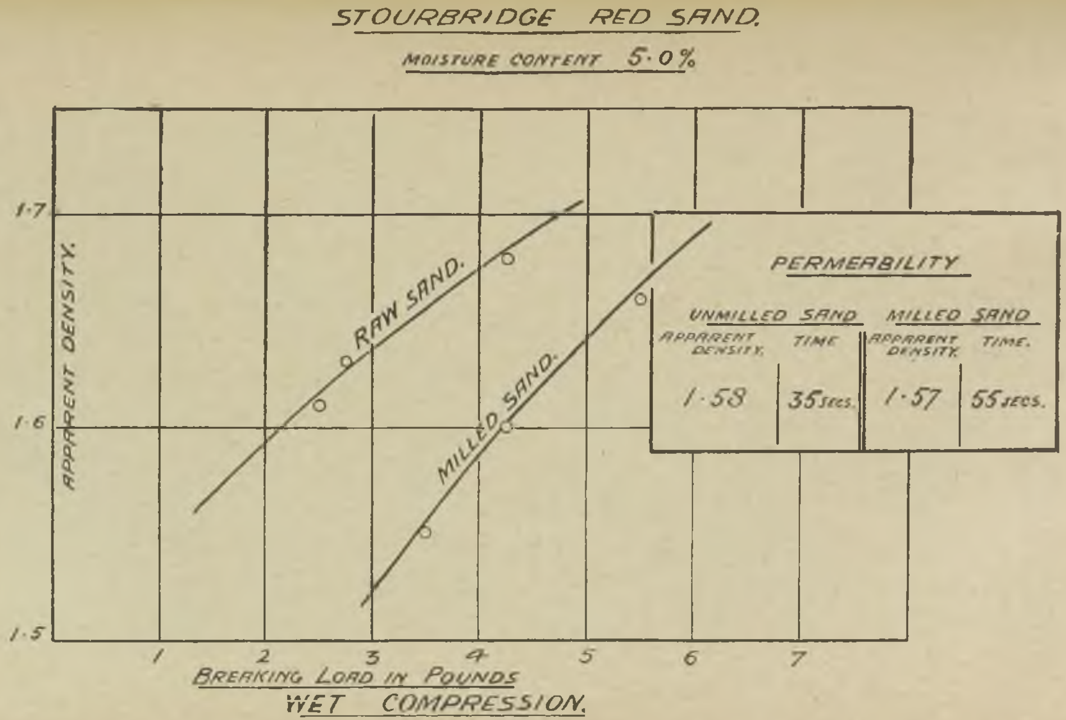

STOURBRIDGE RED SAND.
MOISTURE CONTENT 5·0%
1·7
1·6
1·5
APPARENT DENSITY.
RAW SAND.
MILLED SAND.
1
2
3
4
5
6
7
BREAKING LOAD IN POUNDS
WET COMPRESSION.
PERMEABILITY
UNMILLED SAND
MILLED SAND
APPARENT DENSITY.
TIME
APPARENT DENSITY.
TIME.
1·58
35 SECS.
1·57
55 SECS.

Fig. 1.

sieve; (2) between 40 and 28, and (3) between 28 and 12—that is, fine, medium and coarse grists.

Experiments.

The first experiments were made with small castings, weighing 6 lbs. each, from the pattern of a soleplate 5 in. × 7 in. × $\frac{5}{8}$ in. thick (Figs. 2, 2A and 2B). The facing-sand contained 5, 15 and 30 per cent. of coal-dust, respectively. Three moulds of each grist enumerated above (1, 2 and 3) were made and cast separately.

The results of these tests are set out in detail in Table I. The numbers marked on the soleplates in Fig. 2 refer to the corresponding test numbers in Table I.

To explain as briefly as possible the data given in Table I:—*Tirpentwys Coal* comes within the limits for volatile content for a good coal-dust; *Treharris Coal* has a volatile content considerably below the minimum for a good coal-dust, and *Anthracite*, with its very low volatile content, was only carried through part of the series —two only of these tests are given, as no comparative results were obtained with further tests. Anthracite was used only to prove that the volatile content is one of the essential characteristics of a good coal-dust.

Percentages of coal-dust to red sand were chosen to give low, medium and high mixtures for experimental comparison. The gas given off when a mould was cast was judged by the amount coming away as a blue flame at the box joint. "*Shiny silver-grey*" refers to that very bright silvery appearance of the skin when too much good coal-dust has been used, leaving a carbon-flake deposit on the casting.

The appearance and changed condition of the facing sand, after the casting has been removed from the mould, is very interesting, and merits a detailed description and analysis. The record of the tests shown in Table I prove very conclusively the greater efficiency of the fine grists and the high volatile coal.

Test No. 1, with only 5 per cent. of high-volatile coal-dust added, gave a passable skin, whereas *Test No.* 10, with the same percentage of lower-volatile coal-dust, was very poor. *Test No.* 2 had rather too much coal-dust for a perfect blue skin, whereas the results shown for *Test No.* 3 proved that for coal-dust of this volatile content and fineness the percentage of coal-dust to sand is very excessive. The comparison of the casting skin of the remaining tests is so obvious as to require no emphasis.

Experiments with Heavy Castings.

The experiments just described having been carried out on small castings, weighing only a few pounds, it was decided to carry out similar tests on castings of thicker section, and the following type of casting, and method of testing, was chosen:—A solid cylindrical casting, 11½ in. dia. x 10¾ in. long, was made (see Figs. 3, 4 and 5).

The pattern was faced with four different mixtures of red sand and coal-dust, each covering a quarter of the circumference to the full depth of the mould. This ensured the same mixture and temperature of iron for each set of facing-sand mixtures. The moulds were all bottom-poured, the in-gates being placed about 1½ in. up from the bottom. Four castings were made, one mould (Fig. 3) cast open and three moulds closed. Tirpentwys coal-dust was used in all these tests, varying only in fineness and in percentage mixtures with sand.

The results of these experiments are given in Table II.

Comparing " A " (Fig. 3—mould cast open) with " B " (Fig. 3—mould cast closed), the effect of the coal-dust in each section is more pronounced in the latter than in the former. Is the reason for this due to the fact that smoke (from the coal) burnt in front of the rising metal in the open mould; whereas, in the closed mould, the smoke could not burn owing to the absence of free air, and was able thoroughly to coat the face of the mould with carbon deposit. This would explain why the fins on Section V are deeper and more pronounced than on Section Z (Fig. 3). The castings shown in Figs. 4 and 5 were made in closed moulds. They show clearly the inferior results obtained with coarse grists from the same coal-dust.

A noticeable feature of these two series is the pockmarks and ratching which occur with the addition of 30 per cent. and 15 per cent. coal-dust, and do not occur in the 10 per cent. and 5 per cent. mixtures. This is due to the increased percentage of coal-dust in the mould skin, which, when transformed by the action of the hot metal to coke, swells and creates pressure throughout the mould face. Some of the swelling coke, following the line of least resistance, forces itself into the relatively soft, just-solidifying skin of the casting. With a lower percentage of coal-dust these coking-coal grains have more freedom to expand amongst the sur-

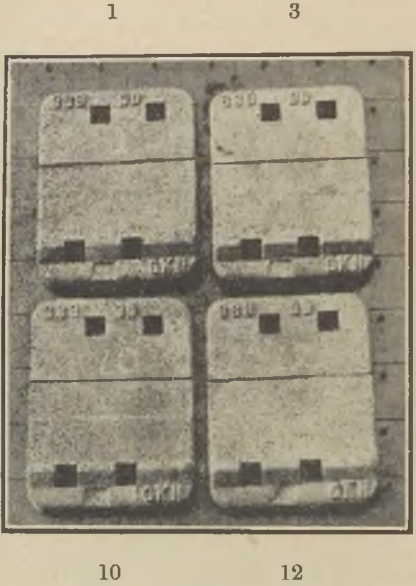


Fig. 2.—Sole-plates.

rounding sand grains, therefore "pockmarks," "ratching" and "mapping" can be accounted for.

Pockmarks.

These unsightly defects on the skin of the casting refer to small pits which can be seen in N and R in the upper half of Figs. 5 and 4 respectively and also on sole-plates Nos. 7, 9, 16 and 18 (Fig. 2). They are directly due to coarse coal-dust. When the molten iron covers these grains of coal, they at once give off their volatile matter, and swell as they become coked. Being comparatively large, this swelling is considerable in the individual grains. A portion expands into the soft, just-solidifying skin of the casting and causes this unsightly indentation, or pockmark.

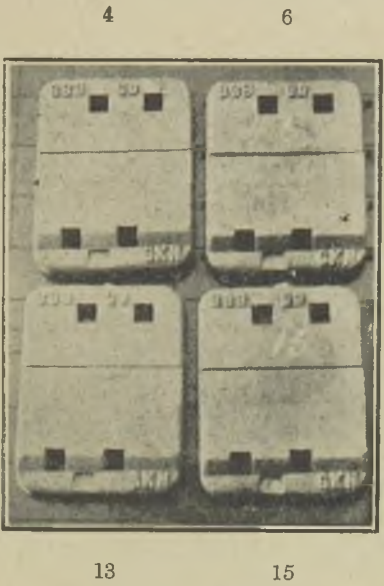


FIG. 2A.—SOLE-PLATES.

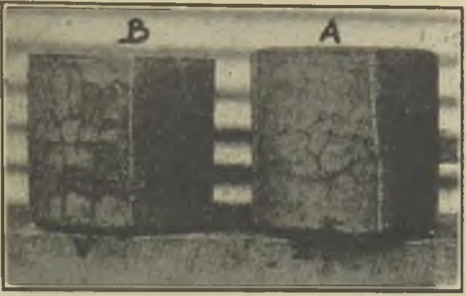
Ratching.

When this swollen piece of coke punctures the thin skin of metal, the liquid metal bleeds through and becomes mixed with the coke, causing those small eruptions on the casting-skin which require filing, or chipping, to remove Examples can be seen in the lower part of N in Fig. 5, and in Table II they are termed "ratching."

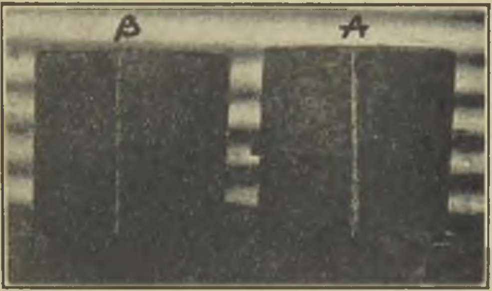
FIG. 2B.—SOLE-PLATES.

Mapping.

Mapping can be clearly seen in sections Z and V of Fig. 3. The direct cause of this defect is due to an excessive amount of fine, high-volatile coal-dust in the facing-sand. When the molten iron is poured into the mould the fine specks of coal, thoroughly intermixed with the grains of sand, give off their volatile-matter and change from specks of coal to small beads of coke. This change, which takes place instantly, causes the specks of coal to swell to more than twice their previous size. This combined action considerably expands the skin of the mould, which buckles inwards, and cracks. The fluid portions of the casting enter into the fissures and form fins on the face of the casting.



Sections V—S and Z—W.



Sections T—U and X—Y.

FIG. 3.—SOLID CYLINDERS.

Experiments with Mica-Window Moulds.

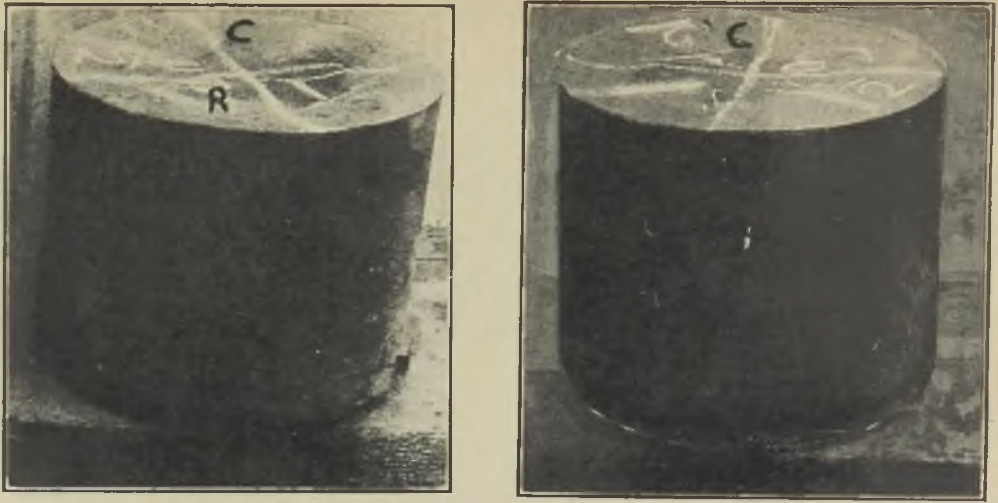
A desire to observe what actually happens inside a closed-mould during casting led to the adoption of a special mould with a mica window.

Details are shown in Fig. 6 and the sketch in Fig. 7. The pattern, with strip of mica, is shown at A. This was rammed up in the usual way in a three-parted box, with the mica in position and opposite the opening in the middle part. Before the pattern was withdrawn the intervening sand between the mica and the slot in the box was cut away, care being taken not to expose the extreme edges of the mica. The in-gate was cut in at the bottom joint, shown in casting at B in Fig. 6. The mould was cast on a low stool to facilitate observation and photographing.

When molten iron was poured into the moulds made with coal-dust facing-sand, smoke immediately began to rise up the sides of the mould. The thickness of this smoke varies with the amount of coal-dust in the sand, and its volatile content. The top of the rising metal has the form of a meniscus, the convex face uppermost as shown in diagram Fig. 8. The metal rises with a rolling action against the sides of the mould, due to the friction of the sand face. There appears to be a clear space, about $\frac{1}{8}$ in. to $\frac{1}{4}$ in. (which follows the shape of the meniscus) between the top of the rising metal and the smoke. This is due to the intense heat of the molten iron. It required very close observation to see the rising metal trap any of the coal gas. It is certain that this action takes place because the coal specks are giving off their volatile gases and continue for some time after the metal has covered them.

Photographs taken through the mica window are shown in Fig. 9. Owing to the exposure required to take photographs, the meniscus and space between the metal and the smoke, referred to, do not show very clearly. A distinct difference in the volume of smoke, due to the quantity and volatile content of coal-dust used, can be seen.

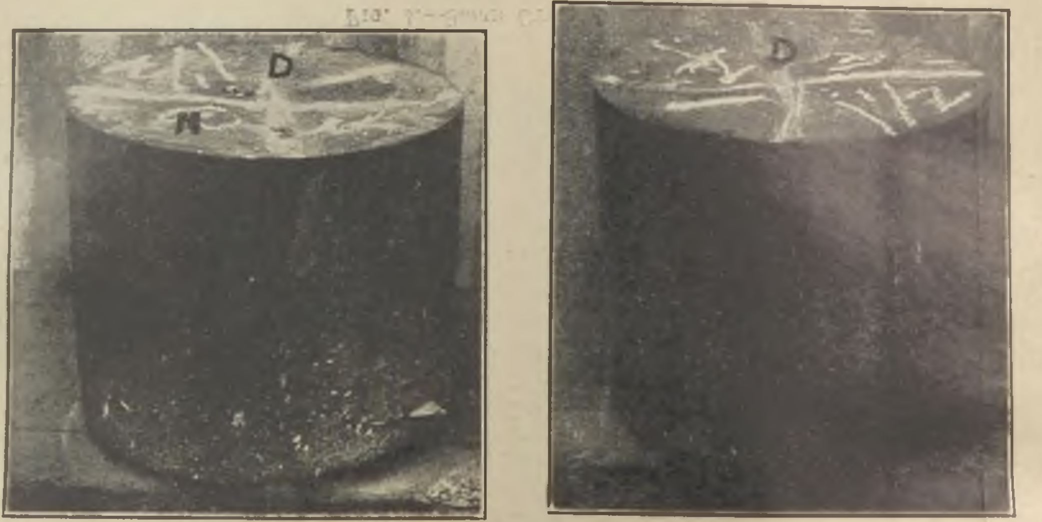
Tests on anthracite coal gave results similar to Fig. 9A. No smoke was visible, and there was no skin on the casting. Further experiments were made to prove this smoking action. Two



Sections R—O.

Sections P—Q.

Fig. 4.—Solid Cylinders.



Sections N—K.

Sections L—M.

FIG. 5.—SOLID CYLINDERS.

moulds as Fig. 7 were made, each having the lower half faced with sand containing 30 per cent. addition of coal-dust, and the upper half, raw red sand, without any coal-dust. The first mould was made as described with a mica

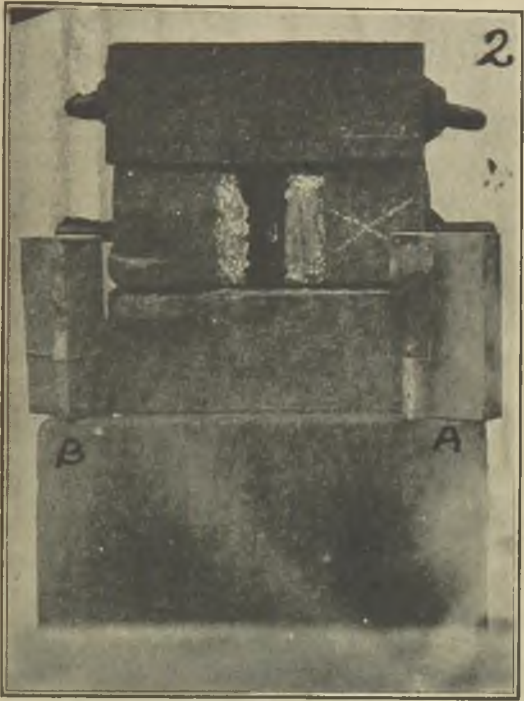
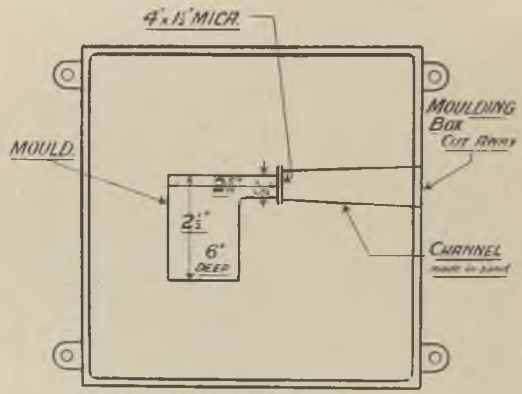


Fig. 6.

window. Iron was poured in, and the smoke could be seen rising up the mould faces. Immediately the metal reached half-way, as judged through the mica window, pouring was stopped, and the top and middle parts of the mould were instantly removed. On examination, the whole of the red-sand face of the upper half had been coated with a layer of black carbon.

The second mould was made in the same way, but without the window, using the same proportion of facing-sand. When the casting, Fig. 10, was removed, the lower half in the coal-dust and sand had a bright and silvery skin. The upper half in raw red sand had a rough grey skin with sand burnt in.

A third mould was made with all raw red-sand facing, having the runner cut in at the bottom face and a riser off the top. In this test, immediately the molten metal entered the mould, a small ball of pitch, about $\frac{3}{8}$ in. dia., was dropped into the rising metal through the riser. Instantly thick black smoke came through the riser. This was stopped with a piece of core, which acted as a cork. Pouring was continued until the mould filled. After removing the casting from the mould, the sand was carefully examined. Most of it consisted of clear silica grains, but the sand from the face of the casting contained about 5 per cent. black-coated silica grains. After cleaning with a wire brush, the casting had a fairly good blue skin. On one



PLAN WITH TOP BOX REMOVED.

FIG. 7.

side, near the bottom, there was an indentation in a patch of silvery skin, with some shiny carbon flakes, where some of the pitch had melted, run to the side and been trapped by the rising metal. This suggests that the deposit of these shiny carbon flakes on the casting and mould-skins are due to the excessive deposition of volatile matter between the two faces.

These experiments seem to prove that the carbon deposit on the skin of the mould, created by the smoke from the coal-dust, has only a preliminary and slight influence on the colour and quality of the casting skin.

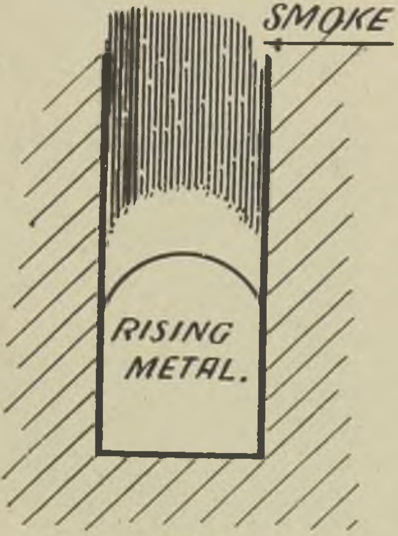


Fig. 8.

As the previous mica-window tests were all made on the vertical faces of the moulds, further experiments were carried out to find the action of coal-dust on the bottom horizontal faces. It was impossible to take photographic records of these tests, because it was necessary to make a lengthy time exposure. The impressions closely observed through the mica window are shown in Fig. 11. "A" represents the mould cavity, B the flowing metal, and C the slight smoke from the coal-dust. The advancing metal forms a very pronounced meniscus, which gives a rolling motion to the flow. Between the advancing metal and the slight coal smoke there appeared to be a clear space, similar to that seen in the "vertical" experiments. Here, again, the trapping of a smoke pad by the advancing metal is not very noticeable.

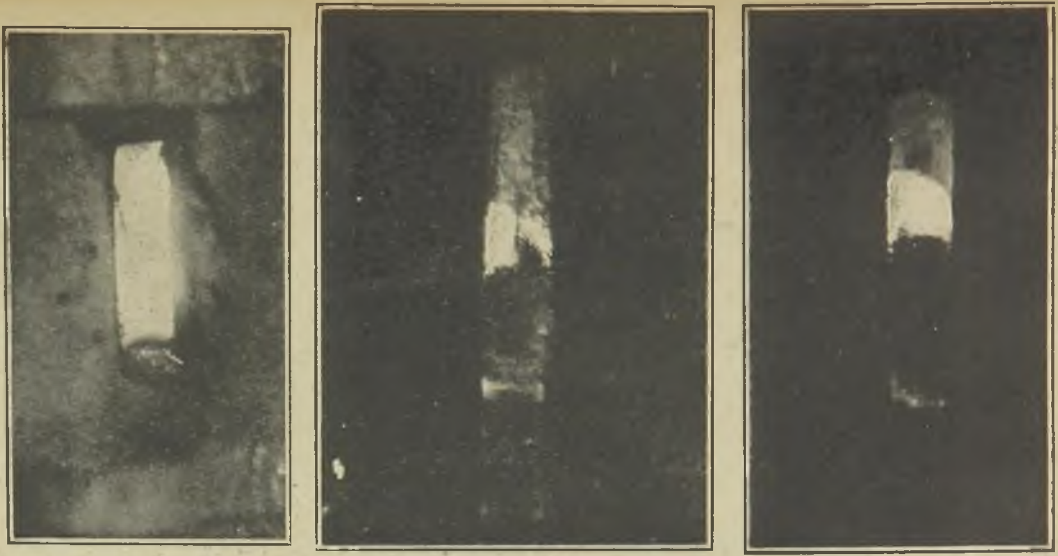
Carbon Absorption.

A test was made on casting Fig. 10 to ascertain if any of the carbon deposit from the coal-dust was absorbed into the casting skin. About $\frac{1}{32}$ in. depth of skin was removed with a file from faces A and B and C and D of Fig. 10. Separate analyses were taken for total carbon, which gave the following results:—A-B (coal-dust and sand skin), total carbon = 2.086 per cent.; and C-D (red-sand skin), total carbon = 1.895 per cent., showing a gain of 0.191 per cent. total carbon, or almost 10 per cent. in that part of the casting made in a facing sand to which 30 per cent. coal-dust had been added. These results suggest that carbon is taken up from the coal gas during the high temperature of the casting, before final solidification has set in. This is probably the reason why coal-dust, added to the sand for facing mild-steel castings, does not operate in the same way as it does with high-carbon steel and grey-iron castings.

The Action of Coal-Dust on the Casting Skin.

The following explanation of the action of coal-dust on the skin of the casting is advanced as a result of these experiments.

The radiant heat immediately preceding the advance of the molten metal causes the coal-dust to give off its volatile matter in the form of smoke. This condenses on the inner surfaces of the mould and coats them with a carbon deposit, thus forming a preliminary protection to the sand grains. As the advancing metal covers



9A.

9B.

9C.

MICA WINDOW PHOTOGRAPHS.

FIG. 9A.—Mould made in all red sand—no coal-dust—no smoke was visible.

FIG. 9B—Red sand, 10; Coal-dust, 3 (30 per cent.). Grade 1 (Grist 40.) Tirpentwys coal. Heavy smoke, casting stripped clean, with a bright silvery skin, covered with carbon flakes.

FIG. 9C.—Red sand, 10; Coal-dust, 1½ (15 per cent.). Grade 1 (Grist 40.) Tirpentwys coal. Conditions very similar to No. 9B.

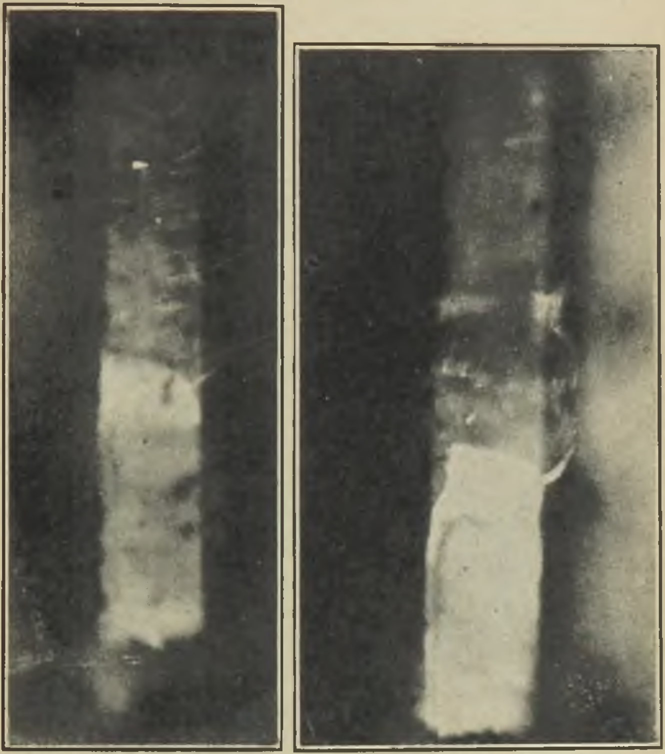
this active coal, the smoke impinges upon the skin of the casting, thus creating a carbon film between the metal and the sand. This reaction of the coal continues throughout the solidification range of the metal.

As the heat penetrates deeper into the face of the mould, more coal-dust is decomposed, evolving more gas. Under pressure of expansion the smoke follows the line of least resistance. The bulk of the smoke percolates through the pores and vents of the mould into the open. Some continues to keep contact with the casting skin, where, due to the high temperature, it is transformed into fixed carbon, which is deposited

9D.—MICA WINDOW PHOTOGRAPH.

FIG. 9D.—Red sand, 10; Coal-dust, 1 (10 per cent.). Grade 1 (Grist 40.) Tirpentwys coal. Smoke slightly less than 9B and 9C. Blue skin. No carbon flakes. Stripped fairly clean.

on to the casting and sand grains of the mould skin when the percentage of fine, high-volatile coal-dust exceeds a certain ratio. A small percentage of carbon is absorbed into the skin of the casting.



9E. 9F.

MICA WINDOW PHOTOGRAPHS.

FIG. 9E.—Red sand, 10; Coal-dust, 3 (30 per cent.). Grade 1 (Grist 40.) Treharris coal. Smoke considerably less than 9D. Dull-blue skin.

FIG. 9F.—Red sand, 10; Coal-dust, 1½ (15 per cent.). Grade 2 (Grist 28.) Treharris coal. Very little smoke. Poor dirty-blue skin.

The Action of Coal-Dust on the Sand.

The sands referred to in this Paper as "skin sand" and "behind skin sand" apply to the sand on the face of the mould, and that immediately behind the face, say, from ¼ to ½ in. thickness. These skin sands, being carbon-coated, will give a fairly good blue skin to a casting when damped down and used again. They are useless as a facing sand by themselves, because, having no bond, the sand swills in front of the metal. Therefore, it must have a certain amount of new sand added to make it usable. The sand behind these two skins still retains most of its bond, and the whole mixed together

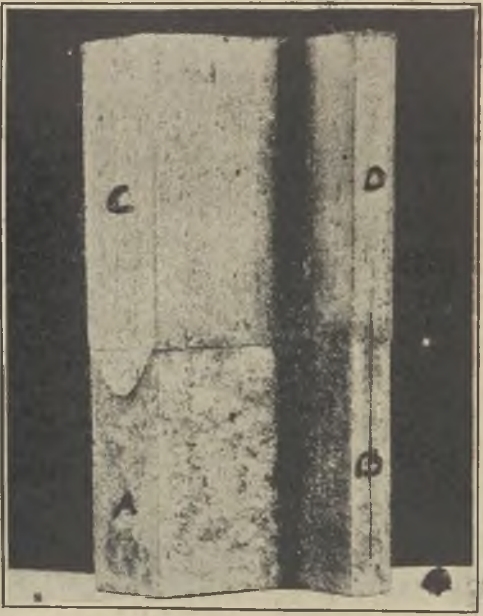


Fig. 10.

TABLE I.—*Coal-Dust Tests on Small Soleplates.*

Stourbridge Red Sand, Unmilled and Dried, used in all Tests. Water added, 5 per cent.

Name of coal.	Analysis.	Grist.	Mixture of facing sand. C.D. to sand.	Test No.	Gas given off when cast.	Colour of casting skin.	Quality of casting skin.	Carbon flake deposit on skin.	Appearance of skin sand from mould.	Appearance immediately behind skin sand.	Amount of top.	Coking bottom.	Appearance of skin sand under magnification.	Appearance of sand immediately behind skin sand, under magnification.
			Per cent.											
TIRPENTWYS	Volatile, 30.6 per cent.	40	5	1	Very slight	Dull blue ..	Fair after wire-brushing	Nil	Slight carbon coating	Loose black grains	Nil	Nil	Slight coating of carbon, shiny black grains	Dull black, slightly matted sand and coal.
			15	2	Slight flame at joint	Blue centre, silver-grey outer edge	Good, very little brushing required	Slight carbon flakes. Bottom face	Silver-grey coked, shiny carbon coated	Grains matted. dull black	$\frac{1}{16}$ in.	$\frac{1}{8}$ in.	Bright silver grains, carbon covered	Shiny grains of dull black.
			30	3	As above ..	Shiny silver-grey	Smooth but slightly mapped	Large amount ..	Coked bright silver grey	Well matted but not coked	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	As above	As above.
	Ash, 10.4 per cent.	28	5	4	Very slight	Dull blue-black	Poor, rough after wire-brushing	Nil	Slight carbon coat, matted grains	Loose dark grains	Nil	Nil	Shiny black grains and small beads of coke	Matted sand and coal grains.
			15	5	As above ..	Dull silvery-grey	Fair, but slightly pockmarked when brushed	Very slight	Silvery-grey	Dark matted grains	$\frac{1}{32}$ in.	$\frac{1}{16}$ in.	Silvery-coated grains of carbon and coke	As above.
			30	6	Moderate flame at joint	Bright silver-grey	Clean, but slightly pockmarked all over	Large amount of carbon flake	Coked bright silver-grey	Well matted, $\frac{1}{2}$ in. thick	$\frac{3}{16}$ in.	$\frac{1}{8}$ in.	Bright silver grains, carbon covered	Heavy masses of matted grains.
	Carbon, by difference, 59.0 per cent.	12	5	7	Very slight	Poor, dull blue-black	Poor, rough, pockmarked after brushing	Nil	Matted grains, carbon coated	Loose dark grains	Nil	Nil	Matted dark grains and coked beads of coal	As above, but less matted.
			15	8	Slight ..	Dull silver-grey	Poor, pockmarked when brushed	Very slight carbon flakes	Silvery-grey	Dark matted grains	$\frac{1}{32}$ in.	$\frac{1}{32}$ in.	Silvery-coated grains of carbon-covered sand	Dull matted grains of sand and coal.
			30	9	Medium flame	Silvery-grey	Badly pockmarked	Slight amount of carbon flakes	Silvery-grey	As above ..	$\frac{3}{32}$ in.	$\frac{3}{32}$ in.	Silver carbon covered grains	Large lumps of sand and coal, all matted.
TREHARRIS	Volatile, 12.3 per cent.	40	5	10	Very slight	Rough grey	Very poor. Sand burnt on	Nil	No carbon coating clear silica grains	No carbon coating, clear silica grains	Nil	Nil	Clear silica grains ..	Clear silica grains.
			15	11	As above ..	Dull blue-black	Fair, after good wire-brushing	Nil	Dark grains slightly matted	Loose dark grains	Nil	Nil	Some grains black smoked, some showing dull red	Same, but more untouched grains dull red.
			30	12	Slight ..	Dull blue ..	Fairly smooth after good brushing	Nil	As above	As above ..	Nil	Nil	Grains of sand are dark smoked	Similar, but some untouched grains.
	Ash, 16.10 per cent.	28	5	13	Nil	Very rough and grey	Slight scab at centre. Very poor. Burnt on	Nil	Grey silica grains, dark specks of burnt coal	Grey silica grains, specks of coal	Nil	Nil	Clear silica grains ..	Clear silica grains.
			15	14	Very very slight	Dull black	Rather poor	Nil	Dark grains, very slightly matted	Loose dark grains	Nil	Nil	Some dark grains, some dull red	Same, but more untouched red grains.
			30	15	Slight ..	Blue-black, sand stuck to casting	Very poor. Rough, covered with small pockmarks	Nil	Shiny black grains, no coking bonding	Dark lumps of matted sand and coal grains, dull black	Nil	Nil	Shiny grains of sand, carbon covered, and small beads of coke	Matted lumps of sand and coal, partly fused.
	Carbon, by difference, 71.60 per cent.	12	5	16	Nil	Very rough and grey	Very bad. Rough and deeply pockmarked	Nil	Grey, with large grey spots due to coal	Same	Nil	Nil	Clear silica grains and half-coked grains of coal	Same.
			15	17	Very very slight	Bad, greyish-blue	As above	Nil	Dull smoky black ..	Dull black grains and dirty red grains	Nil	Nil	Some dark grains matted and some dull red	Same, but more half-smoked red grains.
			30	18	Fair amount	Bad, dirty blue-grey	Extremely bad. Rough, very deep pockmarks	Nil	Rough matted lumps of coked sand and coal slightly metallic	Rough matted dull grains	Nil	Nil	Fine grains have metallic coating	Dark matted lumps of partly coked coal and sand.
ANTHRACITE	Volatile, 6.6 per cent. Ash, 9.70 per cent. Carbon, by difference, 83.7 per cent.	40	5	19	Nil	Rough and grey	Very poor. Sand burnt on	Nil	Grey silica grains specked with grains of coal unchanged	Same	Nil	Nil	Clear transparent silica grains and specks of unchanged coal	Same.
			30	20	Nil	Rough, darker grey	Very poor. Sand and coal burnt in like emery cloth	Nil	Same as above; more coal specks	Same	Nil	Nil	As above: more coal grains	Same.

TABLE II.—*Coal-Dust Tests on Heavy Castings.*

Stourbridge Red Sand, Unmilled and Dried, used in all Tests. Water added, 5 per cent.

Test-piece.	Quarter-section.	Grist.	Percentage of coal-dust in sand.	Colour of skin.	Quality of skin.	Carbon flake deposit on skin.	Appearance of skin sand.	Appearance immediately behind skin sand.	Skin sand magnified.	Behind skin sand magnified.
A Open sand mould	Z	40	30	Bright blue. Top portion slightly silvery	Smooth, mapped. Fins of mapping $\frac{3}{16}$ in. high	Very slight in upper portion of casting	Coked silvery grey, $\frac{3}{8}$ in. deep	Dark grains matted together, $\frac{1}{2}$ to $\frac{3}{4}$ in. deep	Bright silvery grains, carbon coated, well-coked coal grains	Grains of sand, black-carbon coated. Partly-coked coal grains.
	Y	40	15	Deep blue	Smooth good skin, no mapping	Nil ..	Coked bluish-grey, $\frac{3}{16}$ in. deep	Dark grains matted together, $\frac{1}{4}$ to $\frac{5}{8}$ in. deep	As above	As above.
	X	40	10	Dull grey with some dark blue patches	Rough, sand slightly burnt on	Nil ..	No coking. Sand and coal grains matted, $\frac{1}{2}$ in. deep..		Dull black smoked grains of sand and **partly**-coked coal grains.	
	W	40	5	Light grey	Very rough, sand fritted and burnt in. No skin	Nil ..	No coking or matting, sand grains clean white silica, very slight carbon coat on a few grains		Clear silica grains, with very few black grains, comprising coated grains of sand and specks of coke and coal.	
B Closed mould	V	40	30	Silvery, with a few patches of blue	Smooth, very badly mapped, fins of mapping $\frac{1}{8}$ in. high	Considerable in upper half	Coked silvery-grey, about $\frac{3}{8}$ in. deep	Shiny dark grains matted together, $\frac{1}{2}$ to $\frac{3}{4}$ in. deep	Bright silvery grains, carbon coated, and well-coked coal grains	Sand grains with shiny black carbon. Partly-coked coal grains.
	U	40	15	Bright blue	Very good smooth skin. No mapping	Nil ..	Coked bluish-grey, $\frac{3}{16}$ in. deep	Dark grains matted together, $\frac{1}{2}$ to $\frac{5}{8}$ in. deep	As above	As above.
	T	40	10	Dark blue	Fairly good after wire brushing	Nil ..	No coking. Sand and grains of coal slightly matted		All sand grains slightly carbon coated. Coal grains partly coked.	
	S	40	5	Light grey	Very rough, sand burnt in. No skin	Nil ..	Very slight carbon coating on a few skin grains	Clear white silica, with few dark specks of coal. No matting	Clear silica grains, with a few black grains comprising coated grains of sand, and specks of coke and coal, approximately 10 per cent. black.	
C	R	28	30	Dull blue	Poor quality, shallow pockmarks. Slightly ratched bottom	Nil ..	Slight coking, bluish-grey, about $\frac{1}{8}$ in. deep	Shiny dark grains, matted	Mixture of bright silver grains and shiny black. Approx. 50 per cent. of each. Large pieces of coked coal	Black carbon-coated grains, specks of coal and partly-coked coal.
	Q	28	15	Dull blue top portion. Dark dirty grey lower half	Poor. Pockmarks upper part. Slightly ratched bottom half	Nil ..	No coking, very little matting of grains. Dark grey	Dark grains of sand, carbon covered	Mixture of clear silica grains, with black carbon-coated grains. Approx. 25 per cent. of black grains. Large coked grains	As above.
	P	28	10	Dull dirty grey, slightly better skin upper half	Very poor. Sand burnt on lower part. Slightly better skin upper half	Nil ..	No coking. Sand grains matted with partly-coked coal	No coking. Sand grains matted with partly-coked coal	Mostly clear silica grains. Approx. 10 per cent. black grains, and a few coked grains	As above.
	O	28	5	Light grey	Very rough. Sand burnt in. No skin	Nil ..	No coking, or matting. Clean silica grains and some black grains	No coking or matting. Clean silica grains and some black grains	Clean silica grains with very few dark grains, comprising coated grains of sand, specks of coke and coal. Approx. 5 per cent. black.	
D	N	12	30	Dull blue	Very poor. Very deep pockmarks and badly ratched	Nil ..	Very slight coking, $\frac{1}{16}$ in. deep. Bluish-grey large cokes bedded in sand	Coarse grains of coal bedded in carbon-coated sand grains	Few silvery grains, but mostly shiny black, with large pieces of coked coal	Black carbon-coated grains and specks of coal partly coked.
	M	12	15	Dull blue	Fair. Shallow pockmarks and slightly ratched	Nil ..	No coking of sand, slightly matted	Dark grains of sand carbon covered. Slightly matted	Mixture of silica grains and carbon-coated grains with large coked coal. 75 per cent. coated grains	Mixture of silica grains with black carbon grains and partly-coked coal, 75 per cent. coated.
	L	12	10	Dull blue	Fairly good. Best skin on casting. No pockmarks or ratching	Nil ..	No coking or matting. Grey silica sand with a few black specks	As above	Clear silica grains with a few dark grains and large specks of coked coal, 10 per cent. coated	Mixture of silica grains with black carbon grains and partly-coked coal, 50 per cent. coated.
	K	12	5	Grey, but slightly blue on upper half	Very poor. Sand burnt on, but slight sign of skin near top. No pockmarks or ratching	Nil ..	As above	As above	Clear silica grains with a few black grains, comprising coated grains of sand and specks of coke and coal. Approx. 50 per cent. black.	

[To face page 365

is usable for a period, becoming weaker and weaker with each succeeding cast.

"Skin Sand."

The condition and appearance of this sand, which forms the mould face, varies considerably.

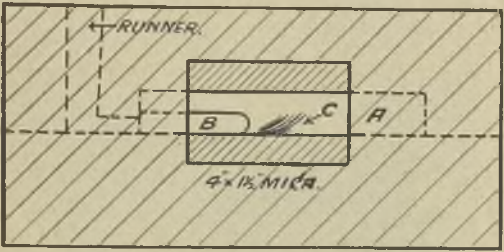


FIG. 11.

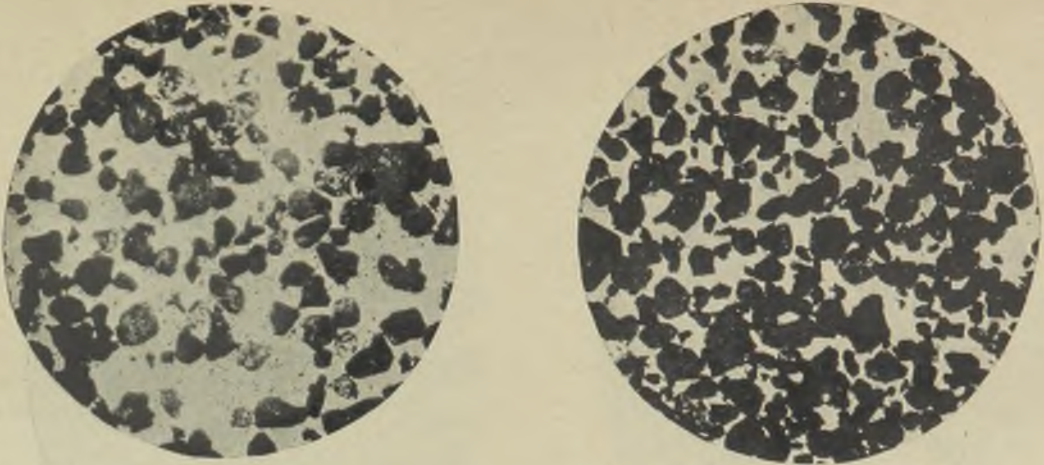
A study of the Tables I and II shows the increased coking effect produced by the fine coal with a high-volatile content. Also, the finer the coal-dust, the more compact this coked skin becomes. Fig. 12 shows two pieces of sand from sole-plate mould No. 3 (Table I and Fig. 2). The depth of the coking can be seen in the section, and the bright silvery appearance in the plan. With Grades 2 and 3, this coking is more coarse, and much weaker in structure. Coking does not occur with the lower volatile coals. There is a very distinct difference of condition and appearance between this skin and the sand immediately behind it, with the exception of some mixtures containing only 5 per cent. additions of coal-dust.

Immediately Behind the Skin Sand.

The exact position of this sand from the face of the casting varies with the depth of the coking or matting (cohering) of the skin sand. In Fig. 12 it is the deep-black central portion in the section. Where coking is present in the "skin" sand, it consists of carbon-coated sand, partly-coked coal, matted together by the tar from the partly-coked coal and that left by the distillation of the smoke from the coked coal in the skin sand, as it filters its way through to the open. With the exception of the 5 per cent. coal-dust additions previously mentioned, these sand grains are always more heavily coated with deep-black carbon than the grains in the skin sand. The photomicrographs, Figs. 13, 14 and 15, show this very clearly. V_A, R_A and Q_A are taken from the "skin sand," V_B, R_B and Q_B from "behind-skin" sand of the castings B and C, Table II and Figs. 3 and 4.

Fig. 12.

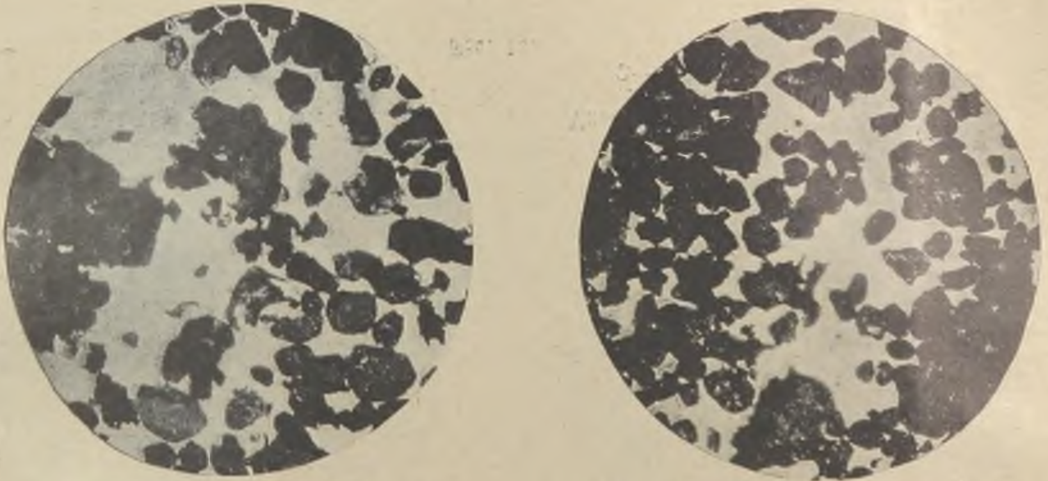
Photomicrograph Fig. 16 of section "O" in Table II shows the exceptions where the "skin" and "behind-skin" sands have the same characteristics. Photomicrograph Fig. 15 represents sand from Section Q, Table II. This shows another peculiarity. The "skin sand" (A) con-



V_A.—Bright Silvery Carbon-coated Grains, Black Carbon-coated Grains and Coked Coal.

V_B.—Black Carbon-coated Grains and some Matted, with Partly-coked Coal Grains.

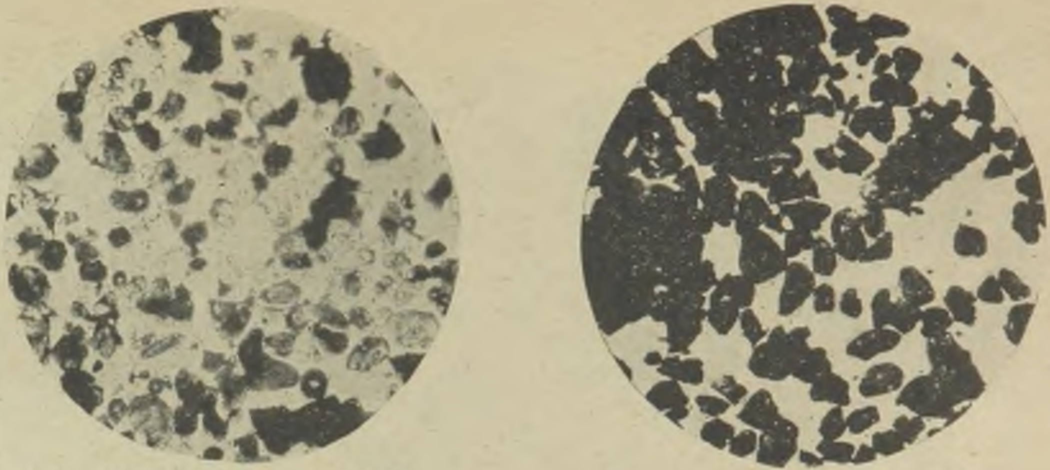
Fig. 13.



RA.—Clear Silica Grains with 50 per cent. Matted Black Carbon-coated Grains.

RB.—Matted Black Carbon-coated Grains.

FIG. 14.



Q_A.—Clear Silica Grains with 10 per cent. Matted Black Carbon-coated Grains.

Q_B.—Matted Black Carbon-coated Grains.

FIG. 15.

sists of a large proportion of clear silica grains. The grains of the "behind-skin" sand (B) are all-black, carbon-coated and matted. Comparing this with No. 5, Table I (containing the same facing-sand mixture) shows a very pronounced difference, which is emphasised by further comparisons on the same lines with other tests in Tables I and II, *i.e.*, S with 1, O with 4, K and M with 7 and 8.

These comparisons support the statement that superfine coal-dust is the most efficient for

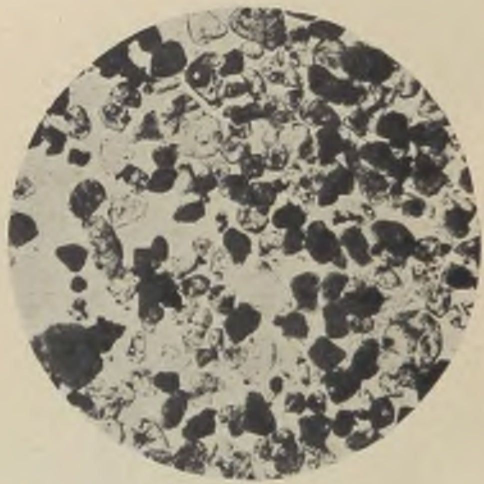


FIG. 16.—SECTION O. CLEAR SILICA GRAINS AND CARBON-COATED GRAINS.

heavy as well as light work; that coarse-graded coal-dust, unless used in large proportions, when they cause other blemishes (such as pock-marks and ratching), are too widely distributed amongst the sand grains to function properly, and leave much of the sand on the mould faces unprotected or so slightly covered that the coating is burnt off by the heat of the metal. Therefore, coal-dust, as its name implies, must be the *dust of coal*, and for all classes of work should be of a "superfine" quality that would pass through a 40-mesh to the linear-inch sieve; also, the volatile content should not be less than 30 per cent., *i.e.*, a bituminous coal. This action of the volatile matter in the coal during the casting of the mould explains the reason why used foundry sand is black, when coal-dust is mixed with the facing sand. This can easily be proved by burning the black "used sand" in air. The carbon film will burn off, leaving a brown or grey silica grain, such as is left on the top of an open sand plate when a thin layer of black sand has been thrown on after casting.

The author desires to thank Mr. W. R. D. Jones, of the Department of Metallurgy, University College, Cardiff, for his assistance and the photomicrographs of the sands; also the British Cast Iron Research Association for the tests of the red sand.

DISCUSSION.

The Origin of Pock-marking.

Mr. F. J. Cook, in a tribute to Mr. Hird, said that those who knew him appreciated the uncanny originality of his methods of approach to any subject; nobody but Mr. Hird would have thought of putting a window in a mould in order to see what happened inside, but by that, as by some of his other unorthodox methods, he had proved many things we did not know hitherto. Referring to the pock-marking of the skins of the castings, he said that this was a great nuisance to those who had to make articles such as stove grates, which had to be used in the condition in which they left the moulds. On one occasion he had been asked to investigate the cause of this trouble, and he had not attributed it to the coal-dust in the sand, but had proved conclusively that it was due to the presence of large grains of raw sand in the facing sand. Often one found that the men engaged in sieving sand on to the face of the pattern were inclined to push the sand through the sieves; he had found that in the particular foundry concerned there was one man whose work was more pock-marked than that of the others, and that this man, not having time to sieve the sand through, was pushing it through; in addition, some of the strands of the sieve were broken. The proprietors of the foundry concerned were not quite convinced that the pock-marking of the castings was due to the presence of large grains of sand. In order to prove the point, he had riddled some sand and had made a mould partly with riddlings and partly with fine sieved sand; when a casting was made in that mould it was found that in the part in which riddlings were used there was pock-marking, whereas in the other part, where the fine sieved sand was used, there was no pock-marking whatever. It was obvious, therefore, that pock-marking was due not only to the use of coarse coal-dust, but also to the presence of large grains of raw red sand. That did not disprove anything that Mr. Hird had said. He considered Mr. Hird was wise in carrying out his experiments with raw red sand only and in avoiding the use of black sand with it, because he had avoided contamination of the sand, and it was wise to introduce as few variables as possible when carrying out research work. If he would give some idea, however, of the additions of black sand permissible in order to obtain the best results, the information would be a useful guide to foundrymen generally.

Coarse Coal-Dust also Pock-marks.

Mr. A. R. Bartlett (London) agreed with Mr. Cook that the pock-marking of the skin of the casting was not due altogether to the use of coarse coal-dust, and said that a far greater degree of pock-marking resulted from a clay-bonded than from a rock-bonded sand of the red-sand type. He used Erith sand, which was clay-bonded, and on castings which were made by men whose practice it was to rub the sand through the sieves there was invariably much deeper pock-marking when a clay-bonded sand was used as compared with a red sand. Naturally, on account of cost, he was anxious to use the local Erith sand as much as possible, and in order to overcome the pock-marking difficulty it was his practice to use the clay-bonded sand mixed with an equal proportion of rock-bonded sand. The use of a coarse coal-dust in the sand also produced pock-marking, of course. At his foundry they ground their own coal-dust, and it was noticed that as soon as the sieves used for grading it became worn, considerable pock-marking of the castings resulted.

Mr. H. B. Hanley (U.S.A.) said he had come into contact with so-called pock-marking in America, and had found that in many cases it was due to the balling up of the binding substance of the moulding sand when the sand was improperly tamped.

Coal-Dust and Venting Properties.

Mr. H. Field, who was anxious to make it clear what was meant by "pock-marking," said he gathered that the appearance of the pock-marks was similar to that of Brinell impressions.

Mr. Hird said that was so.

Mr. Field, continuing, said that he had experienced trouble due to the pock-marking of the surfaces of highly-finished castings, but he did not think it was due to the use of coarse coal-dust, because it was almost impossible to find any coarse particles in the superfine coal-dust used to-day. He did not say this as a contradiction of Mr. Hird's argument, but merely to point out that Mr. Hird's explanation did not appear to fit his own experience. Mr. Hird had stated that in general it was best to use the finest possible coal-dust in order to produce a casting with a good skin. On the other hand, we were told by researchers into sand problems that it was inadvisable to use sand mixtures containing sands of varying grain size, because the fine grains would fill up the cavities between the coarser grains, and less efficient venting would result. He asked whether, if a fine coal-dust were used, the fine grains of coal would fill the cavities between the sand grains, and, if so, why better venting properties were obtained with a fine coal-dust than with a coarse coal-dust.

Volatiles in Coal-Dust and Skin Effects.

Mr. H. B. Hanley (U.S.A.), in expressing appreciation of Mr. Hird's valuable contribution to our knowledge of coal-dust as applied to moulding sands, said the ground was covered more thoroughly by this Paper than by any previous contribution he had seen. The use of coal-dust, he continued, was a matter of considerable importance in the foundry. It was very easy to introduce difficulties by the use of an excessive amount of it, and also by the selection of the wrong grade or particle size. He was particularly interested to note Mr. Hird's remarks concerning the occurrence of pock-marks, and his own experience was in accordance with that of Mr. Hird. It was also quite a common experience to find manifestations of pin-holes in castings when coarsely-ground coal was used in fine moulding sand. Mr. Hird's method of procedure in studying the behaviour of coal-dust was very illuminating, and the work had been carried out in a painstaking and comprehensive manner. His theory relative to the function of coal-dust and its effect upon the surface of the castings was also interesting. There had always been difference of opinion amongst foundrymen as to whether the residual carbon contained in the sand was responsible for the production of cleaner castings, or whether the volatile carbon generated under the action of heat was the beneficial agent. For the want of more information, he had regarded the latter reaction as of first importance. Further, he believed that the chemistry of the reaction between the bonding substance and the volatile gases under the action of heat was very much responsible for the peeling phenomenon observed in many sands. One had only to note the colour of the changed mass after the casting was made to recognise the influence of the carbonaceous material upon the ingredients of the facing. It appeared quite clearly that a chemical change of considerable importance occurred in the reducing atmosphere.

Referring to the grade of coal to be used in practice, he said that Mr. Hird leaned towards the use of finely-ground coal. One advantage of the use of finely-ground coal—by which he meant coal ground so finely that 90 per cent. or so would pass through a 100-mesh sieve—was that less of it was used to do the work than would be used if it were more coarsely ground, but, on the other hand, it was well known that the finer coal acted as a filler in the facing, and consequently lowered the permeability. Measurements had shown that finely-ground coal in green-sand practice contributed a slight increase in bond and a desirable smoothness to the sand. The opinion had been expressed from time to time that ground coal increased the permeability of facing sand. No doubt the coke produced by the incomplete combustion of the coal increased the voids, but it was hardly possible to conceive of an increase in permeability. The amount of gas generated when ground coal was present rendered good permeability of the sand more necessary than ever. The more coarsely-ground coals were used as a rule only for the making of medium and heavy castings. In America five or more grades of sea coal were used in the foundry. The analysis conformed generally to the following composition:—Moisture (as received), 1.30; volatile matter, 33.96; fixed carbon, 55.46; ash, 9.28; and sulphur, 1.27 per cent. The percentage of volatile carbon seemed to be a little higher in those coals than in the coals he had seen in Mr. Hird's collection at the Foundry Exhibition. The average fineness numbers of the American coals referred to were 128, 142, 189 and 272, and there was a still finer grade called "air-floated" material. The coarser grades were always used by the manufacturers of heavy castings in grey iron; the medium and fine grades were used extensively in the medium grey iron and malleable shops. The finely-ground (but not air-floated) material was being used more and more, and that was in accordance with Mr. Hird's recommendation.

There were, of course, a number of natural sands in America whose bond content was so very low that the use of ground coal with them was not called for. On the other hand, some of the American sands, carrying a sticky bond, would not produce clean castings in green-sand practice without the addition of one part of ground coal to ten or twelve parts of sand. In malleable foundries cleaner castings were produced when ground coal was used than when it was not used; the greater temperature of the iron made necessary the use of sea coal.

The producers of sea-coal facing—as it was called in America—marketed their grades under standard specifications, and generally the product could be relied upon as regards uniformity of grade and chemical composition.

Finally, Mr. Hanley expressed the hope that Mr. Hird could continue his investigations, in order that we might appreciate fully the rôle played by powdered coal in its various applications to foundry practice. Mr. Hird's work was of high calibre and of great value to the industry.

Cushioning Effect of Coal-Dust.

Mr. J. G. A. Skerl (British Cast Iron Research Association), in congratulating Mr. Hird upon his work, carried out more or less in his spare time, said that the industry could do with the help of many more men of his temperament and ability, to carry out experiments which might be thought to be quite simple, but which were necessary to the advancement of foundry technique. The technical literature of the foundry industry lacked Papers concerning the addition of materials to facing mixtures. The work of the Research Association would be confined practically to laboratory work, because the Association had no foundry of its own, unless members and others in the industry carried out experimental work in connection with sands, and such co-operation was welcomed by the Association.

Stourbridge red sand had been used by Mr. Hird for the purpose of his experiments, and it was to be expected, of course, that when casting into virgin Stourbridge red sand—which was a good and strong sand—one would obtain a bad casting in the first place: the metal would not lie on this strong sand, and the skin of the casting would be rough. If coal-dust were used with the sand, undoubtedly the metal would lie on the mould, by reason of the cushioning effect produced by the coal-dust. Mr. Hird had the honour of being the first to have published the results of some permeability and strength tests carried out by methods put forward by the British Cast Iron Research Association. Those methods would be published shortly.

Grading Difficulties.

Discussing the fineness of grinding, and sieving, he said Mr. Hird had used a fine, a medium and a coarse grist. It would appear, however, that his fine grist was equivalent to the medium grist of most coal-dust producers; the superfine grist produced by the big firms was very much finer than the fine material used by Mr. Hird. With regard to the ratching effect referred to in the Paper, he suggested that this might be due to a large extent to the fact that the sand was too strong, and, being green sand, the action of the metal would cause the sand to shrink, so that cracks were formed, into which the metal could penetrate.

Relative Carbon Absorption by Steel and Cast Iron.

In the section of the Paper dealing with carbon absorption, Mr. Hird had proved satisfactorily that a certain amount of the carbon was taken up by the skin of the metal from the coal gas. Then he had stated: "This is probably the reason why coal-dust, added to the sand for facing mild-steel castings, does not operate in the same way as it does with high-carbon steel and grey-iron castings." Mr. Skerl asked for a more detailed explanation of this statement, because he believed that a mild steel would take up more carbon, inasmuch as it contained less in its original state. The probable reason for the non-absorption of carbon in mild steel was that its freezing range was shorter than the metals containing higher carbon percentage.

Dealing further with the question of grain size, he recalled the claim of research workers—already mentioned by Mr. Field—that the size of the particles of coal-dust used should be practically the same as that of the sand grains, and said that Mr. Hird's results had confirmed that, because the grading of his superfine or fine coal-dust was very similar to the grading of most moulding sands.

The Tarry Constituent of Black Sands.

A point which Mr. Hird had not emphasised particularly was that much of the black material in black sand was mainly tarry matter, and not carbon. He (Mr. Skerl) had proved that quite 50 per cent. of the black material in a moulding sand which had been used was definitely tarry material; it was soluble in various reagents, whereas carbon was not. He urged Mr. Hird to continue experiments on dry-sand moulds, because it seemed to him that in the experiments so far carried out no account had been taken of the effect of moisture. Judging from the contents of Mr. Hird's Paper, one would expect the same things to happen in a dry-sand mould as in the others, but one knew from practice that that would not be the case. The effect of moisture in this connection would have to be considered sooner or later.

Coal-Dust in Green-Sand Castings.

The Paper did not settle the question as to whether or not the use of coal-dust was advisable in green-sand mixtures. Varying opinions were held in this country with regard to this matter. Some five years ago he (Mr. Skerl) had read a

Paper before the Sheffield Branch of the Institute of British Foundrymen, in which he had discussed the effect of coal-dust, horse manure and other things on facing mixtures, and had pointed out that there was no real reason for the addition of these materials to a properly-prepared sand. Since then he had become more certain than ever that coal-dust, horse manure and such materials were not so necessary in foundries to-day as we were inclined to think they were. He had visited foundries in which green-sand castings weighing up to 2 tons were made without the addition of coal-dust to the sand, but it was interesting to note that the mixtures in which these castings were made were always weak, as compared with the ordinary green-sand mixtures used in most foundries. Most foundrymen would consider such weak mixtures unsuitable for the class of work for which they were used, but there were some who held the view—which he believed was held also by some of the American visitors to the Congress—that most of the ordinary green-sand mixtures used in this country were very much on the strong side, having in view the work for which they were used. Some time ago an opportunity had arisen to test the argument that coal-dust was not necessary in green-sand moulds. As part of the routine of the Association, it was the practice to test the surfaces of castings as affected by the moulding sands by making fairly large castings, weighing up to nearly 1 cwt., and 1, 2 and 3 inches thick, in the virgin sands. Erith sand was one of the sands tested. There were five grades of Erith sand—mild, very weak, yellow (weak), medium-strong grade and extra-strong grade. The mild and yellow sands would not be accepted by any ironfounder because of their lack of bond. The castings made in the very weak sand had as good a skin as one could wish for, but those made in the progressively stronger sands were badly marked. When coal-dust was added to the sands in varying proportions, the skins of the castings were not so good as that obtained with the weak sand alone, so that there was some basis for the view that coal-dust was not definitely necessary in moulding sands, and that the treatment of a moulding sand had a far greater effect on the surface of the castings than we had believed hitherto. A properly-prepared sand, without coal-dust, would produce as good a casting as, and often better than, a sand containing coal-dust.

Mr. Skerl hoped that many members would experiment with their green-sand mixtures by varying the percentage of new and old sand and with varying percentages of various grades of coal-dust, and contrasting the results obtained. It was only in this way that they could get the best out of Mr. Hird's Paper.

Coal-Dust Deemed to be Unnecessary.

Mr. J. M. Primrose, discussing generally the practice of adding coal-dust to moulding sands, pointed out that gas in a mould was a source of great trouble and danger, yet the foundryman added to the sand something that would produce more gas; further permeability was very desirable in a mould, yet the foundryman added something to the sand which helped to block up the vents; bond was an important factor, yet the foundryman added something which was deleterious; economy was necessary in the foundry—all castings were said to be 10s. per ton dearer than they ought to be, no matter how cheap they were—(laughter)—and yet we added something which would increase the cost of the castings. For generations foundrymen had been adding coal-dust to moulding sands, not because there was any sense or reason in it, but because their grandfathers had done so, and he was quite positive that, so far as his business of producing light castings was concerned, coal-dust was not required. One saw people preparing sand in automatic mixing machines for the making of light castings in moulding machines, and one saw them adding coal-dust and blacking, but he did not think they knew why they were adding those substances; he had made light castings for years without the use of either coal-dust or blacking. He might be asked "Where is the blue skin?" but his reply was that he was producing grey-iron castings, not blue ones. (Laughter.) If we were going to add blacking in order to produce a wonderful blue skin, why not go the whole hog and produce castings with yellow, green, red and other coloured skins? (Laughter.) At the same time, Mr. Hird's Paper was valuable, because in it a practical man had given reasons why he considered coal-dust was necessary in moulding sand, but he would like another practical man to write a Paper and to state the reasons why coal-dust was not required, because he believed that ultimately sands would be properly prepared and coal-dust would then not be required at all.

An Inverse Action.

Mr. S. H. Russell (Past President), whilst agreeing that the investigation carried out by Mr. Hird was of extreme value, joined issue with him on what seemed to be one of his fundamental points. Mr. Hird had failed to convince him that it was the coking of the coal particles that caused the phenomenon to which he had referred. For instance, he could not agree that the mapping, which had occurred when using a mixture containing three parts of coal-dust and ten of red sand, was due to the expansion of the coke formed in the sand. In this case there was a sphere or cylinder of molten metal in a closed mould with a head of molten metal on it, and there was therefore fluid pressure. In the sand surrounding the molten metal there was merely the pressure generated by the gases; the sand was more or less self-venting and the pressure amounted to only a few pounds, and it was obviously very much lower than the great pressure exerted by the molten metal. It seemed to him that probably the mixture of three parts of coal-dust and ten parts of sand was, from a foundryman's point of view, a ridiculous mixture. There was too much coal-dust. Was it not conceivable that, instead of the coke expanding and cracking the mould, the opposite action occurred, *i.e.*, that the molten metal rapidly attacked the large surfaces of coal, penetrated between them and pushed the sand before it, so that the action was outwards and not inwards; that the metal forced its way through the bonded sand, breaking it up, burning the coal out, and then forcing its way farther. In another case, even when using what was called a superfine coal-dust, Mr. Hird's theory was that this coal-dust was converted into coke near the skin, but he (Mr. Russell) was not so sure that that was so. It was somewhat difficult to criticise, because the Paper contained no definition of "superfine coal-dust," and he did not think that Mr. Hird and himself would quite agree as to what was a superfine coal-dust; what he himself called a "superfine" coal-dust was one so fine that one could not retain it in the palm of the hand in a strong draught. Mr. Hird has stated that superfine coal-dust was the most efficient for heavy as well as for light work, and that coarse-graded coal-dust was not satisfactory, but if he (Mr. Russell) used his superfine coal-dust in the moulds for making castings weighing two tons he could not turn them out at all; it was not used for castings weighing more than a few pounds.

Instantaneous Combustion of Coal-Dust.

He visualised that the process in the mould was somewhat similar to the process in the burning of powdered fuel, *i.e.*, that the combustion was almost instantaneous; he suggested that the particles of coal in the mould were so minute that they had not time to coke, that they were converted almost entirely into gas on the surface of the mould, and only a very small proportion of ash remained, and he could not conceive that the coal-dust could give rise to the pock-marks after the mould had filled. In his view the pock-marks were due to the presence in the facing of coarse pieces of sand which had been rubbed through the sieves, which coarse pieces, he believed, contained a very large percentage of clay bond; the action of the metal on the clay bond was to produce a small bubble, which was retained there from the moment the metal had flowed over it, and could not get away owing to the large quantity of clay there and the consequent lack of permeability. It seemed inconceivable that sufficient pressure could be produced in the sand to force anything from the sand into the casting and produce the pock-marks.

Mr. Russell also joined issue with Mr. Hird with regard to the refractoriness of black sand. Mr. Hird seemed to have suggested that it became more refractory because it had been coated with deposits from coal-dust, but he himself believed that any refractoriness in black sand was due entirely to the enormous amount of actual coal-dust in it. Anybody using moulding machines, particularly of the hand-rammed or push-off variety, would notice the tendency for the men to use an excess of facing sand because it contained a bond and the moulders more easily obtained a good lift.

Standardisation of Size Chaotic.

MR. H. WINTERTON expressed gratitude to Mr. Hird for having studied the action of coal-dust in moulding sands so thoroughly and for having arrived at conclusions which were likely to lead somewhere. He recalled that in a Paper he had presented to the Birmingham Branch of the British Foundrymen's Association twenty years ago he had stated that a reasonable percentage of volatile matter in the coal-dust was about 30, and he was pleased that Mr. Hird had confirmed that. With regard to the grists adopted by Mr. Hird, he suggested that they were somewhat weird, and were certainly very much coarser than those which he (Mr. Winterton)—as a manufacturer on a large scale—had been endeavouring for many years to make standard. The chemist at his Chesterfield laboratory had stated that the tests showed definitely that all the superfine coal-dust they produced would pass through a 90-mesh sieve, and 90 per cent. would pass through a 110-mesh sieve, so that it was much finer than the superfine coal-dust referred to by Mr. Hird There should be a standard to work to and an insistence that coal-dust, no matter by whom it was supplied, should conform to that standard. He believed that the sea-coal facing in this country was of better quality, considering the requirements of the foundry, than that obtainable in America. The grists supplied in this country to-day were more regular than the American, judging by the specimens he had seen there. The more we could co-operate in these matters, the better for all concerned, and he emphasised that it was the desire of all the suppliers of these materials to meet the requirements of the users fully, and not to foist upon them anything which might add to the already too numerous troubles of the foundry. He hoped sincerely that, as a result of Mr. Hird's further investigations, coupled with those which were being carried out from day to day in the laboratories of the manufacturers, we should arrive at a satisfactory basis in the not far distant future.

Mr. F. J. Cook, discussing the phenomenon of mapping, said he did not think a true explanation of it had been put forward either by Mr. Russell or Mr. Hird. It could be seen better, perhaps, in a dry-sand mould than in any other. If one made a dry-sand mould—such moulds were usually made with very strong sands—and baked it rapidly, the surface of the mould would exhibit the mapping which was exhibited on the casting referred to by Mr. Hird and unless it were filled up with blacking, the casting made in that mould would have a similar marking. It was due to the contraction of the sand under the influence of heat, and he believed that was the true explanation in moulds other than dry-sand moulds also.

AUTHOR'S REPLY.

Mr. Hird, replying to the discussion, said he had endeavoured to record conscientiously the experiments he had made, and his conclusions were his summing up of the results obtained. He admitted he had only touched the surface of this subject, and hoped that others would carry out further experiments with coal-dust facing sands, and give their findings of its effect on the casting skin and the sand. They might prove, or disprove, some of his statements, but it would all add to the general knowledge. He would be pleased to collaborate as far as he could with anyone who took up the subject. Specimens of his experiments were exhibited in the Science Section of the Exhibition, and he would like to meet there anyone who was interested and discuss the results. With regard to the grists, the three grades used were adopted for experimental purposes, and suited the sieves at his disposal. His Paper represented an ordinary foundryman's attempt to deal with one of the many troubles encountered in the foundry, and he sincerely hoped that others with better facilities at their disposal would carry further the investigations he had begun.

Pock-marks due to Coal-Dust.

Replying to Mr. Russell's criticism about the cause of pock-mark, he maintained his statements in the Paper and indicated that he would be pleased to meet Mr. Russell at the Exhibition to examine the specimens exhibited there (subsequent examination of one of the pock-marked castings convinced Mr. Russell that the author's statements were correct, as under low magnification a speck of coal transformed to coke could be seen embedded in a pock-mark).

Dealing with the remarks of Mr. Primrose, he agreed that coal-dust created more gas, and therefore it must tax the permeability of the sand to a greater extent. The addition of coal-dust to sand coated many of the sand grains with carbon, which destroyed the alumina bond.

He did not agree with Mr. Skerl's remarks with regard to Stourbridge red sand. The grade used in the tests under discussion had been used in his (Mr. Hird's) foundry for many years—it was of medium fineness of grain and bond, and very seldom milled. Trouble on a certain job, where the liquid shrinkage caused a drawhole owing to the unequal section of the casting, had been almost eliminated by facing the heavy section with raw red sand. His theory was that the coal-dust in the sand helped to maintain the heat of the metal, and therefore in comparison the raw red sand acted as an incipient chill. With regard to ratching, the trouble was usually found on that part of the casting formed by the bottom and lower parts of the mould. He had carefully removed some of the ratching and examined it under a low-power microscope, which revealed specks of coked-coal with all the pores filled with metal, and on this he based his conclusions. The theory of carbon-absorption by the casting from the coal-dust in the sand developed in his mind when thinking over a statement made to him by Mr. W. B. Lake, of Braintree, to the effect that coal-dust in the sand gave no results on mild-steel castings, but Mr. Lake had found it operated in helping to skin and strip castings made of special high-carbon steel. The author had only made the one experiment given in his Paper, and he would appreciate it if someone with better facilities than he had would carry out similar experiments to check this theory. Also if someone would define more clearly the difference of the three distinct carbon deposits left in the mould by the decomposition of the coal, viz.:—(*a*) The free bright silvery carbon flakes on the face of the casting, (*b*) the silvery carbon coating the sand grains in the coked portion of the skin sand, and (*c*) the dull-black tarry deposit on the sand grains behind this part. This would materially help the foundryman to understand the composition of his black sand, which composed the bulk of the sand used in most foundries. With regard to the amount of coal-dust left in the black sand, he had had an analysis made for free coal-dust, taken from a sample off the foundry floor: the result showed that there was only 0.5 per cent. free coal-dust left in the sand, although in appearance it was quite black.

Commenting on Mr. Field's suggestion that pock-marking was due to something other than coal-dust, he said that in his experiments he had not discovered anything other than coal-dust to account for the pock-marking. The red sand was carefully dried and sieved through the same fine-mesh sieve for all experiments, and, with the exception of water, nothing other than coal-dust was added, and the latter was the only variant. The results he had obtained fully supported his theory, and he suggested that Mr. Field and he might, with advantage, study together the specimens being shown at the Exhibition.

With regard to the venting, or increased porosity of the sand, due to the addition of coal-dust, he thought this was a subject for further research. In his opinion the idea of adding coal-dust to sand to increase the porosity was wrong. The addition of very fine coal-dust, such as he advocated, must block some of the pore spaces formed by the sand grains, and the gases given off would also add extra duty to the pore spaces. Again, the swelling of the specks of coal, when suddenly changed to coke, tended to pack the sand grains closer together (as instanced in the case of mapping). Further, these beads of coke, when crushed to fine particles by the working of the sand, form fine silt (or dust). On the other hand, the specks of coke remaining whole would have a far greater porosity than the grains of quartz sand. Yet, despite the above points against very fine, high-volatile coal-dust, in the whole of the tests made on soleplates, only Nos. 13 and 16 showed any sign of scabs. These were made with 5-per-cent. additions of coarse grist, low-volatile coal-dust.

Replying to Mr. Bartlett, he agreed with him that the coarse coal-dust would produce more pronounced pock-marks in the casting when a tough clay-bonded sand was used. The strong sand would offer greater resistance to the sudden swelling of the coal grain as it changed to coke, causing it to swell outwards from the mould face, and press deeped into the skin of the casting.

Replying to Mr. Hanley, he did not encounter this balling up of the bonding clays in strong facing-sand, but nevertheless could not see how this would cause the same type of pock-marks which he had obtained with coarse coal-dust.

Concluding, Mr. Hird said he could not find words to express adequately his thanks for the very kind appreciation which the members—particularly Mr. Hanley—had given to his Paper, and it made him feel recompensed for all the work he had put into it. Finally, Mr. Hird paid a tribute to Mr. Cook, and said that it was due to his intuition that this Paper was presented to the Congress. He (Mr. Hird) had intended to present the Paper to a Branch meeting, but Mr. Cook had urged that, in view of the importance of the subject matter, it ought to be presented to the Congress. He wished publicly to acknowledge the help he had received from Mr. Cook in connection with his experiments.

On the motion of the CHAIRMAN, a hearty vote of thanks was accorded Mr. Hird for his Paper.

THE PROBLEM OF FOUNDRY MOULDING SAND.

By H. Van Aarst

[PRESENTED ON BEHALF OF THE DUTCH FOUNDRY TECHNICAL ASSOCIATION.]

For several years the author has made many experiments with moulding-sand, and as a result prefers synthetic moulding-sand, as all natural sands, both as regards grain-size and the clay content, are very irregular.† From the beginning of 1928 the author has prepared loam, moulding-sand and core-sand, using only river-sand, sea-sand, dune-sand and clay. The composition of these sands are outlined in Table I.

TABLE I.

——	SiO_2	H_2O	Al_2O_3	Fe_2O_3	CaO
River-sand ..	94.00	3.70	1.10	1.00	trs.
Sea-sand	98.01	3.86	2.04	0.46	4.50
Dune-sand ..	90.60	5.39	2.44	trs.	1.40
Clay‡	65.00	20.99	10.26	2.92	0.78

‡ This shows many variations and consequently it must be regularly controlled.

The loam consists of fine river-sand, which is mixed up with undried clay, to which flax-waste and fine coal is added. Figs. 1 and 2 show two castings, made without a pattern, and cast in this loam. Fig. 1 is the half of a centrifugal pump (principal dimensions: length 4,250 mm., width 1,600 mm., height 2,750 mm., diameter of delivery tube 1,400 mm., weight 9,000 kg.; time required for casting, 45 sec.). The other casting is a stern tube for a motorship, which was cast vertically (time required for casting, 3½ min.; length 6,600 mm., weight 11,000 kg.).

Moulding-sand for dry moulds is made of fine river-sand, clay, flax-waste and fine coal, mixed dry. In this sand both locomotive cylinders

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† "De Gieterei," 1927, pp. 30-36.

and the heaviest type of foundation-plates are cast. It is also used for lighter castings, but it is then made up of a finer grain and without flax.

For core-making sea- or dune-sand is almost exclusively used, but for very large cores fine river-sand is prepared. The sand is dried until quite free from water. Linseed-oil is mainly used as a binding-material.

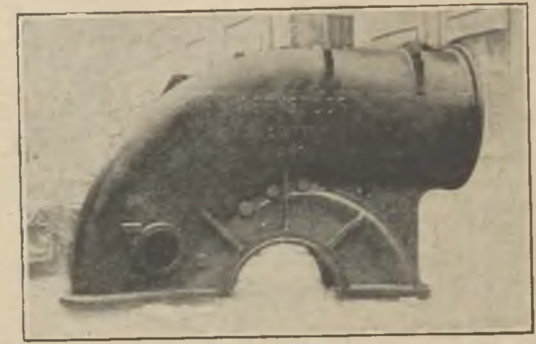

FIG. 1.

FIG. 2.

Routine Testing of Sand.

The sand is tested daily for controlling the grain-size. All the various mixtures of loam or sand are controlled to conform to fixed dimensions, and, according to their ultimate use, suitable samples are dried at the same temperature as the moulds. The temperature of the stoves is registered automatically on a "Cambridge-Thermograph." The drying-stoves are heated with coke-breeze in a "Herrmann" furnace. With some few exceptions, the temperature of sand- and loam-moulds is not higher than 400 deg. C., whilst for the cores 225 deg. C. is not exceeded.

The author has designed an apparatus for testing the density of sand which resembles that of Shaw (see Fig. 3). After opening the cock B the compressed air streams through the coil A and through the cake of sand under test. The nozzle, placed on the cake, has a rubber ring at the lower side. Round the coil, above the nozzle, a piece of lead is attached, so that the rubber rings completely shut off the sand. On the scale D the resistance in mm. can be read which is imposed on the air in passing through the sand. In Table II some differences in pressure are stated for loam, clay and core-sands. In the second column all figures are the same. Possibly in reality these figures are higher, but higher figures cannot be measured with the apparatus.

In the FOUNDRY TRADE JOURNAL of December 6, 1928, Mr. C. Presswood deals with the various contradictory opinions regarding the porosity of moulding-sand. The following explanation may commend itself: the blackened skin of the mould almost entirely prevents the gases from exhausting through the sand to the open space of the mould, so these gases have to find their way chiefly through the vents; further, they press on the mould and consequently partly prevent the gases behind the blackened skin (the gases which have developed there) from exhausting to the inside of the mould or through the liquid iron.

Thus such a mould can be compared with a chill mould, in which steel is cast, or with a permanent mould. The sand behind the

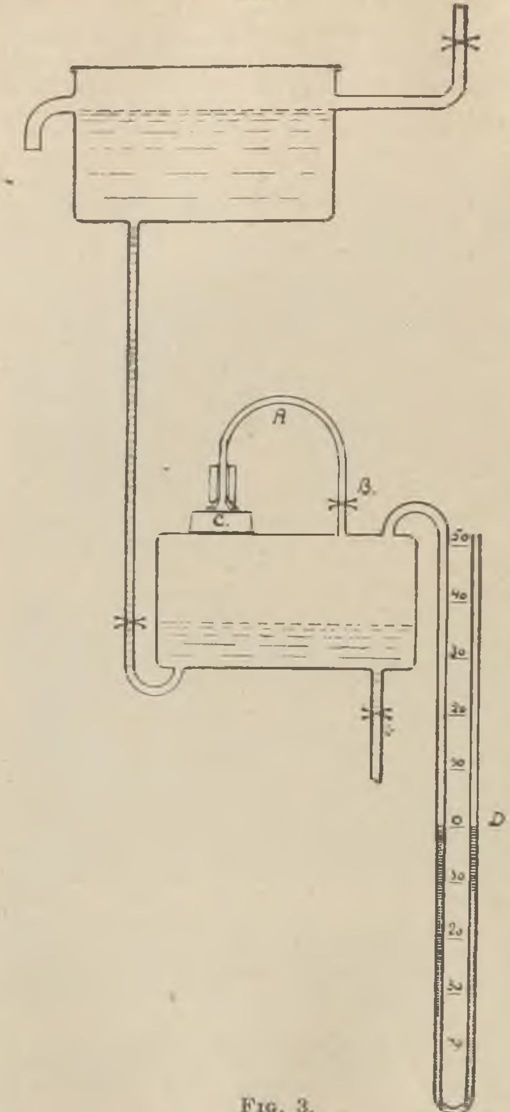

FIG. 3.

blackened skin cannot be too porous. This is best seen when pouring a casting of some importance, moulded in the floor. The gases exhausting from the coke-bed very often have such a velocity that they escape from the exhaust-tubes whistling. When these gases encounter obstructions one may count on having a faulty casting. Table II, therefore, is of much importance.

TABLE II.

——	Untreated	Black washed.
Loam	370	950
Loam for hot melted iron ..	460	950
Sand for dried moulds ..	300	950
Core-sand for large moulds ..	60	950
Core-sand for light moulds ..	110	950
Core-sand for hot melted iron	450	950

Fig. 4 shows the Doty apparatus for controlling the strength of the moulding-sand. This test takes place before the moulds are dried in the stove. The samples have the following dimensions: 30 × 30 mm. sq. and 250 mm. long, weight of B: 750 grams. The value of A (being the point at which the bar will break) depends more or less on the oil content and on the fineness of the sand. For instance, 300 litres of sand, with 5, 6½, 8 and 9½ litres of linseed oil, the test-pieces broke, and when made of river-sand, 73, 95, 103, 122 mm., and when made of

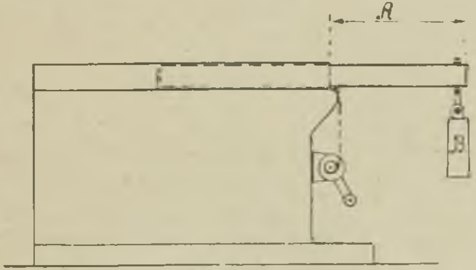

FIG. 4.

sea-sand, 95, 118, 143, 147 mm. respectively. Room temperature also has an important influence.

Fig. 5 is an ordinary transverse apparatus. The distance between the supports is 200 mm., whilst the test-pieces have a section of 30 × 30 mm., and in the middle of the sample a small bucket is suspended into which water is poured until the sample breaks, and then the quantity of water is weighed. The test-pieces are dried at a temperature between 150 and 175 deg. C. The following results have been obtained: 300 litres of sand with 5, 6½, 8, 9½ and 11 litres of linseed oil broke with 13,500, 20,000, 25,700, 27,800 and 32,400 grams of water respectively.

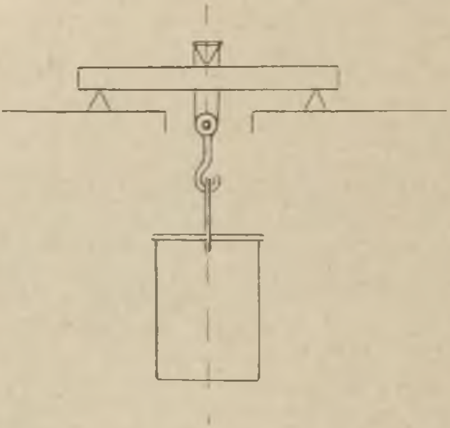

Fig. 5.

WRITTEN CONTRIBUTIONS.

Mr. F. Hudson wrote: This Paper contained interesting work relative to the effect of blackwashing mould-surfaces upon permeability, and a contention as to the theory of permeability. Unfortunately the figures shown by Mr. Van Aarst in Table II are not of general application. To exemplify this fact, he would particularly like to draw attention to the appended table of permeability test figures as found by himself during a study of a similar question. It will be noticed that the large differences in permeability found on the same core before and after blacking by Mr. Van Aarst do not exist when tested in a different manner. The test results shown in Table III were obtained by drawing 600 c.cs. of air through a 1-in. dia. core as shown in Fig. 6. They show that the thickness of the black-wash coating, together with the composition of the black-wash used, will vary the permeability figure, but at the same time little variation is probable if these two factors are controlled.

In regard to the use of synthetic sands for loam moulding, this has been more or less standard practice on the Clyde for many years. A coarse river-bottom sand, not unlike gravel, is heavily milled with or without slight fireclay addition, no sawdust, cow-hair, coke-dust or horse-manure being added whatsoever. Approximately 17 per cent. of water is required to obtain the condition for strickling or working. Such a mixture gives a transverse test of 151 ozs. per sq. in. with a permeability of 3,142 seconds. On the other hand, the practice on the Tyne is to use a mixture of Erith loam, black sand, horse-manure, sawdust, etc., milled with about 25 per cent. water and giving a transverse test of 511 ozs. per sq. in., with a permeability figure of 1,230 seconds. So far as test results go the Tyne mixture is certainly the better, although in practice excellent results are obtained from each.

The Clyde sand is nearly 2½ times more dense than the Tyne practice, but the increased permeability of the Tyne sand is offset by the extra amount of gas generated on casting through decomposition of the organic matter added.

It would appear that the degree of permeability required in moulding-sands is determined by the amount of gas generated at casting, together with the ease of removing displaced air

TABLE III.—*Effect of Blacking on Cores.* (*Permeability.*)

Type of core.	Coating.	Thickness of coating in Ins.	Perm. in secs.
3 per cent. linseed oil and sea sand.	None	—	38
	None	—	37
	None	—	38
	Blacking (clay wash bond) ..	$\frac{1}{32}$ approx.	45
	,, (clay wash bond) ..	$\frac{1}{32}$,,	45
	,, (core gum bond) ..	$\frac{1}{32}$,,	75
	,, ,, ,, ...	$\frac{1}{16}$,,	106
Glenfield & Kennedy oil core sand.	None	—	47
8 parts sea sand.	None	—	44
1 ,, Wormit Red.			
2½ per cent. compound S.S.	Blacking (clay wash bond) ..	$\frac{1}{64}$ approx.	47
2½ ,, ,, 444.	,, (core gum bond) ..	$\frac{1}{64}$,,	47
Drysand cores.	None	—	205
	None	—	263
	Blacking (clay wash bond) ..	$\frac{1}{64}$ to $\frac{1}{32}$ approx.	207
	,, ,, ,, ..	$\frac{1}{64}$ to $\frac{1}{32}$ approx.	300
Loam.	None	—	3,324
(Irvine river bottom sand milled for	None	—	2,960
½ hour.)	Blacking (clay wash bond) ..	$\frac{1}{32}$ approx.	3,616
	,, ,, ,, ..	$\frac{1}{32}$,,	2,426

from the mould. If no gas is generated and the displaced air has easy means of escape, then permeability in a moulding-sand is a very minor consideration indeed. In closing, he thanked Mr. Van Aarst for drawing attention to a foundry point which is often overlooked in the study of moulding-sands.

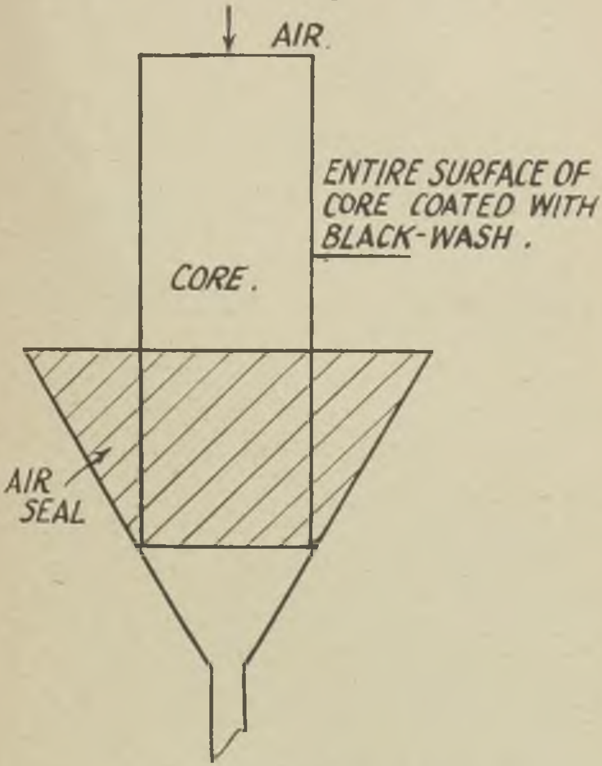

Fig. 6.

Mr. J. G. A. Skerl (British Cast Iron Research Association) wrote that this short but interesting Paper raised the important issue of testing methods. The author of the Paper had taken test methods from various sources, methods which in the countries of their origin have not received the unqualified support of the committees dealing with the question of sand testing. Is it too much to ask that from this international gathering that some attempt be made to form some international committee to discuss this problem? The need for such a committee may not be apparent to many foundrymen at the present time, but in the near future the issue will have to be faced. For example, in the steel industry of this country the development of synthetic sand mixtures is coming to the fore, but until sand-testing methods are internationalised we will not be able to make the fullest use of the published results of American and German workers on these synthetic sands.

THE APPLICATION OF PULVERISED FUEL TO METALLURGICAL FURNACES.

By H. W. Hollands, B.Sc., A.M.I. Mech. E. and
E. C. Lowndes, F. Inst. F.

The authors present this Paper with a certain amount of diffidence, since it deals principally with the application of pulverised coal to steel furnaces. A large amount of research and experimenting has been done in this country with regard to iron processes, but difficulty has been experienced in obtaining information, whilst it has not been found possible to obtain permission to publish any of the results. It is, therefore, fortunate that work has been carried out on the Continent, and much available information with regard to melting and annealing of malleable iron has been obtained from France and America. Before dealing with specific applications, it would perhaps be as well to give some details of the basic principles essential to the successful application of powdered fuel to metallurgical processes.

There are two main divisions in the type of plant that can be installed, namely, the "bin-and-feeder" system or the "direct-fired." Both have their advantages and disadvantages, and it is entirely a question of local conditions which method is utilised. Obviously, in the case of one or two small furnaces, there is little or nothing to be said for the central system, whilst equally, on a plant having, say, twelve or more furnaces, it is difficult to justify the unit system.

Advantages of the Bin-and-Feeder Method.

With regard to the systems themselves, the direct-fired system has nothing to commend it when compared with the central-station arrangement. The essence of the successful application of pulverised coal to metallurgical furnaces is fine pulverisation, and this is difficult, if not impossible, to obtain with unit pulverisers for reasons which will be explained later. Briefly, the advantages of "bin-and-feeder" system are as follows:—(1) Coal can be accurately dried (using the modern form of rotary drier, the cost of drying varies between 18 to 30 lbs. of coke per ton of coal, depending on the initial moisture content); (2) the fineness of pulverisation remains constant throughout the life of the rolls and can accurately be adjusted to suit the particular conditions obtaining; (3) the mills, whatever their type, are of the slow-speed variety and the maintenance cost, therefore, is lower than with unit mills; (4) pulverised coal is stored in small bunkers over each furnace and is deaerated before storing. This results in an accurate degree of coal and air mixture and, at the same time, gives a measure of reliability, inasmuch as failure of the pulverising plant does not necessarily shut down one or more furnaces; (5) inasmuch as supply of pulverised coal is always available, unusual or peak loads can be met instantly; (6) lower power consumption, due largely to the much lower speed at which the mills operate.

Disadvantages of the Unit System.

Alternatively, the disadvantages of the unit system are:—(1) Failure of the mill or motor means that the furnace in question is definitely out of action; (2) pulverisation rapidly deteriorates from the first moment that the mill is put into operation; (3) moisture has a serious effect not only on the fineness of the pulverisation but upon the mill maintenance and power costs; (4) any attempt to meet an unusual or peak load usually results in stalling the mill or motor: and (5) the plant is incapable of supplying a mixture of coal and air as accurate as that obtained with the central system.

With regard to the degree of pulverisation required, the finer the coal can be ground the better from the combustion point of view, but, obviously, there must be a point beyond which, on account of economical questions, it is not possible to go, and it may be perhaps convenient to define the degree of pulverisation required as follows: The coal must be ground to such a point that combustion is practically instantaneous; the minimum amount of unconsumed carbon must be left in the ash, whilst it must be possible to obtain maximum amount of CO_2 in the flue gases at the conclusion of the operations. In one experiment which has come under the authors' view the coal was ground so that 95 per cent. would pass through a 300-mesh. Whilst this is ideal from the combustion point of view, it was obviously obtained at a very high cost which would eliminate the other savings to be obtained from the use of pulverised coal.

Importance of Dry Fuel.

Generally speaking, the coal needed for heating and melting furnaces should be dried to less than 1 per cent. and pulverised so that 98 per cent. passes through 100-mesh screen. It is not the percentage through 300- or 200-mesh that gives efficient operation in this work but the lack of cobble-stones left on the 100-mesh screen. At the same time all through a 100-mesh would not be commercial. The ash-content and the nature of the ash is a further serious consideration for the designers of the furnaces. In operations such as puddling or any process where the metal is in a molten state, it is nearly always possible to flux the ash which necessarily settles on the metal, and this can be tapped off with the furnace cinder. Obviously, with processes such as billet- or plate-heating, no such arrangement is possible, and very careful consideration must be given to where and in what form the ash will be deposited and the effect, if any, it will have upon the metal treated and upon the brickwork.

In one particular case, which the authors will describe later in the Paper, very serious trouble was caused through the melting of the furnace bottom, through the action of the acid ash on the basic bottom. After very much trouble and expense a bottom made of chrome-brick was put in, and no further trouble has been experienced. Here, again, no definite laws can be enunciated, but each application must be considered on its own merits, and in no case should it be impossible to design plant in such a way that the ash will give no serious trouble or result in high maintenance charges. Obviously, however, the better policy is to buy coal with as low an ash content as possible, having due regard to the B.T.U.s per penny.

Advantages of Pulverised Fuel.

Before describing in detail actual applications, it would, perhaps, be as well to set out the theoretical advantages to be obtained from the use of pulverised coal. These are as follows :—

(1) The ability to utilise efficiently a cheaper grade of fuel. This does not necessarily mean a poorer grade, but inasmuch as it is possible to use a very small slack, the price is invariably lower than that obtaining for furnace coal. The difference in price obviously depends upon the locality, but it may be taken that reduction in price will not be less than between 7s. and 10s. per ton of coal.

(2) *Flexibility*: Coal, if pulverised sufficiently finely, is as flexible as oil or gas, and whilst this point is not so important on furnaces as it is on boilers, it is certainly one worthy of consideration.

(3) The time required for heating the particular metal under consideration is usually reduced, the reduction amounting to probably 20 per cent.

(4) Banking, starting up and stopping losses materially reduced.

(5) In view of the perfect combustion which can be obtained, actual quantity of coal per ton of metal consumed is reduced to the extent of from 25 to 50 per cent. below that obtaining with hand-fired furnaces.

Against these advantages it is necessary, of course, to bear in mind that pulverisation and maintenance account for a certain amount of money, the actual figure depending upon the type of plant installed, the nature of the coal to be pulverised and other local conditions, but a figure varying between 2s. 6d. and 5s. could reasonably be taken and would, with one exception, cover every case which has had the attention of the authors. Coming to actual applications, which would probably be of more interest than mere theorising, the authors have had experience in the application of pulverised coal to furnaces for skelping, billet and plate heating, malleable-iron annealing and puddling, and, to a much lesser extent, with open-hearth furnaces.

Examples from Practice.

With regard to skelping furnaces, an existing furnace at the works of Messrs. Edward Smith, Limited, Wednesbury, was put into operation approximately five years ago, and has, within reasonable limits, proved extremely satisfactory. The directors of this concern very kindly put their furnace at the disposal of the authors, who posed fourteen questions as follows:—(1) How long has the furnace been in operation? (2) output per hour of finished material? (3) Coal consumption? (4) Temperature required? (5) Is heating uniform? (6) Coal consumption when hand fired? (7) Has output increased? (8) How does the present cost of coal per hour compare with hand firing? (9) How has installation of pulverised coal affected: (A) labour charges and (B) quality of material? (10) H.P. consumed by pulveriser motor? (11) Maintenance costs on furnace and pulveriser? (12) Has ash affected the operation materially, and has moisture affected the operation materially? (13) Has the application of pulverised coal materially affected the life of the furnace? (14) Are you satisfied that, in installing this equipment, you came to the right decision?

To these several questions the answers are given below:—(1) Approximately five years. (2) 35 cwts. per hour. It will be observed that the actual time for heating the material is but part of the period occupied from the time of charging until it is withdrawn from the furnace.

(3) Four and a-half cwts. per hour, or 2.56 cwts. per ton. This consumption during the actual period of working is 6 cwts. per hour, or 3.4 cwts. per ton. This is the average consumption charged to working hours, but includes fuel used getting furnace up to working temperature before 6 a.m. This furnace is in operation for two shifts a day, and the firm is convinced that, if it was able to work for three shifts a day, both of the above coal-consumption figures would be materially reduced. (4) 1,200 to 1,400 deg. C. (5) Subject to waste gas ports being clear and adjusted properly, combined with suitable adjusting of deflection valve, a good uniform heat is obtained. (6) (A) 5 cwts. and (B) 7¼ cwts. (7) Approximately 5 to 6 per cent. (8) Fuel now used costs 14s. 6d. per ton, against what would be present cost of previous fuel 22s. 6d. per ton. (9) (A) Additional labour charges owing to dry fuel being necessary and for cleaning of furnace more frequently, and (B) less oxidation of material, saving approximately 1 per cent. of weight.

(10) Approximately 10 h.p.

(11) Including cost of renewals and spares, labour, bricks and bricklayers time, it is estimated to be 2s. 8d. per ton of fuel pulverised. This may appear to be rather high, but as an explanation it should be recorded that renewals have cost £30 per annum since the machine was purchased, and, in addition to this, there has been purchased a spare rotor shaft (not included in these figures). We find that the fitter's and bricklayers' time has been heavier than estimated by suppliers of the machine and furnace.

(12) (A) Yes. All ports have to be daily cleaned and working bed of the furnace scraped; also the combustion chamber has to be cleaned weekly; (B) if fuel contains over 6 per cent. moisture, the temperature and the effective working of the furnace is interrupted.

(13) Nothing appreciable.

(14) Yes; the firm is satisfied with its decision, but it would like to add that it has been found by experience that a low-grade fuel with high

ash content will not do the work or permit the furnace to be heated to proper working temperature, and dust would be a serious hindrance to carrying on.

The authors have many times inspected this furnace in operation. The material to be welded consists of strip steel or wrought iron which, after leaving the furnace, is bent and subsequently welded to form a welded tube. Obviously, the question of ash is important, since extensive deposit would not only materially affect the life of the mandrels, but also it would affect the strength of the weld. Neither of these troubles have been experienced at Messrs. Edward Smith, Limited, and tubes produced from the powdered-coal furnace are equal to the usual high standard which is always maintained at these works.

It will be observed from the answers to the questions that the principal saving is from the lower price of coal. Saving from weight of coal consumed is probably offset by the wear and tear of the pulveriser and maintenance of the furnace. It is, however, certain that, in the light of modern experience, the furnace could be so designed that the troubles that they have had through ash deposit can be materially reduced. Fig. 1 shows several views of Messrs. Edward Smith's furnace, which is fired on the unit system.

A Billet Furnace.

The same set of questions was submitted to Messrs. F. R. Simpson & Company, Limited, who seven years ago put into operation a pulverised-coal-fired continuous re-heating furnace for billets. Their answers to these questions are as follow:—

(1) Powdered-fuel-fired furnace has been in operation about seven years.

(2) Maximum possible output, 6 tons per hr. This furnace supplies a 9-in. merchant mill rolling a great variety of finished product, necessitating frequent roll changes, and bringing down average throughput to about 2½ tons per

hr., and the coal consumption naturally varies according to size of finished product.

(3) The mill is working five days per week, 16 hrs. per day, and the furnace has to be kept in the other eight hours. Including heating up

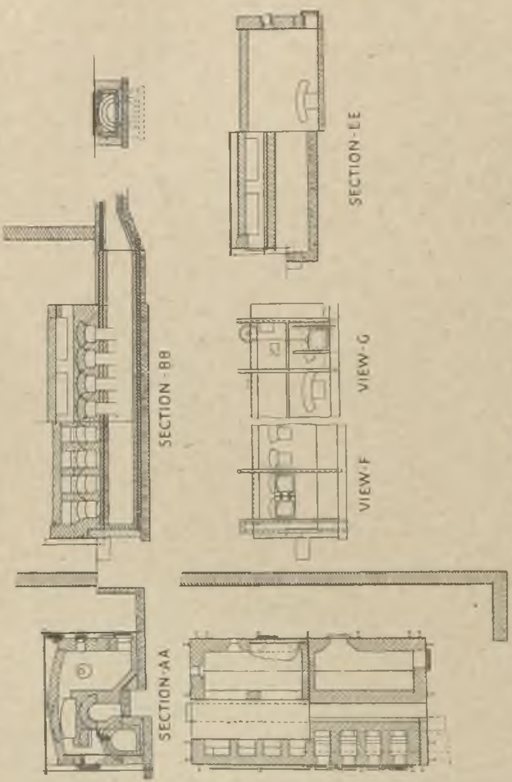

Fig. 1.—A Reheating Furnace Fired by Pulverised Fuel, Installed at the Works of Messrs. Edward Smith, Limited.

the furnace and keeping in during the idle shift, the coal consumption is 2.93 cwts. per ton of steel heated. Less the fuel used in keeping in the furnace during the idle shift, the consumption is 2.55 cwts. per ton of steel heated. Less the fuel used in heating up and keeping in, *i.e.*.

actual working hours, the consumption is 2.16 cwts. per ton heated. These figures are the average for six months' working, with an average throughput of 2.57 tons per hour. With a throughput of 4 tons per hour, there is a coal consumption of 1.6 cwts. per ton of steel heated, and 6 tons per hour, 1.3 cwts. per ton.

(4) The temperature attained about 1,300 deg. C., whilst the combustion chamber temperature reaches 1,600 deg. C.

(5) The billets are uniformly heated and well soaked.

(6) The coal consumption before installing pulverising coal, about 4¼ cwts. of coal per ton.

(7) Output has increased slightly.

(8) Coal costs have decreased.

(9) (A) Labour charges about the same; and (B) little or no difference in quality of material compared with that from gas-fired furnace billets uniformly heated and well soaked. The waste is the same.

(10) The power consumed by the pulveriser is approximately 19 units per hr., *i.e.*, 7.6 pence per ton.

(11) *Repair Costs.*—On installation repair costs were great owing to severe refractory troubles, due principally to furnace design. By using suitable refractories, suitable furnace design and suitable pulverising and blowing equipment, this trouble has been very much lessened. The repair costs are:—Material, 7s. 9d. per ton of coal, less undetermined credit for stocks of materials and labour, 11d. per ton of coal.

(12) (A) No ill-effects from dust are experienced, although this depends upon the quality of the fuel used. Using a good-quality fuel, screened beans with an ash content of 5 per cent. or 6 per cent., yet fusible, most of the ash is extracted in a fused condition from the combustion chamber. Trouble has arisen when using inferior fuel with 20 per cent. ash, of an infusible character, when the dust more or less chokes up the furnace and insulates the billets. (B) Moisture.—No ill-effects experienced. The

fuel as purchased contains about 9 per cent. moisture, dried by flue gases to about 4 per cent. before entering pulveriser.

(13) *Life of Furnace.*—This is quite satisfactory, but it is necessary to do a little patching to the refractories in the combustion chamber, say every six months.

(14) Satisfied.

Considerable trouble has been experienced by Messrs. F. R. Simpson, due to failure of the furnace bottom, but by plating the furnace with chrome bricks they appear to have overcome this trouble, and, as will be seen from the answer to question (13) very little work is now necessary to keep the furnace in working condition. The furnace in question is about 30 ft. long by 5 ft. 6 in. wide, and has end charging side discharging. In view of the fact that, before equipping with pulverised coal, the furnace was gas-fired, the saving shown is considerable, since it is usually difficult to show any appreciable saving in favour of pulverised coal when compared with gas-producers. Here, again, this furnace is direct-fired with unit pulveriser.

Coming to a subject which is probably of greater interest to founders, namely, application of pulverised coal for annealing malleable cast iron, it is with regret that the authors are unable to publish any figures obtained from British practice, but the plant described below is actually in operation in France, and, subject to making due allowance for the difference in the quality of the coal obtainable in France and this country, it is thought that the description will be of interest.

Fig. 2 shows the furnace and type of equipment in operation. Before applying pulverised coal, the details of the operation were as follows:—*Width of oven*, 12 ft.; *length of oven*, 10 ft. 6 in.; *height from floor to curve of arch*, 6 ft. The ovens are lit, the doors sealed-up, brought up to heat and kept at a constant heat for 120 hours. Each oven holds 5 tons of castings. *Total actual consumption for* 120 *hours*, say, 7 tons of coal, costing 29s. per ton delivered.

The cans endured two heats only on account of the fact that, at one stage in the process, there was heavily reducing atmosphere, whilst later on there was a heavily oxidising atmosphere. Draught was regulated by the operation of the damper at the base of the chimney. First of all, the chimney was removed, and two lateral furnaces were used in order to arrange two gas-discharge ducts to take the gas to a main flue connecting up the various furnaces in the battery and leading to a brick chimney

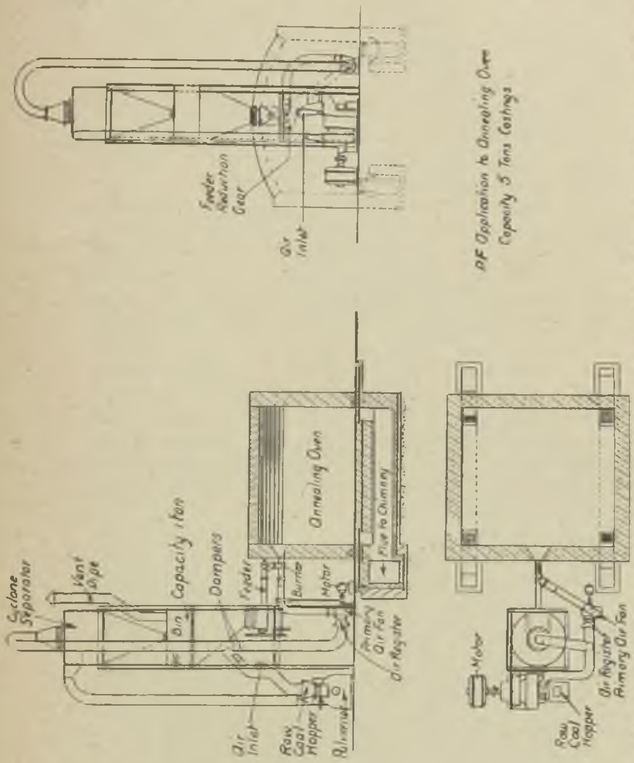

Fig. 2.—Malleable Castings Annealing Furnace Fired with Pulverised Fuel.

situated outside the building. A damper, which could be operated from the outside of the furnace, was fitted at each end of the flues above indicated, and this allowed the flow of the gases in the furnace to be correctly regulated.

A burner, similar to the one shown in Fig. 2, was fitted to the front of each of the furnaces, at such a distance from the hearth that the flame just passed well over the boxes containing the castings to be treated. The coal is brought to the burner by a screw-feeder and air by a pipe, fitted with a valve, which allows combustion to be regulated.

In the case of malleable cast iron, the reheating operation is divided into three phases.

(1) *Raising the temperature.*—The approximate duration of this is 36 hrs., at the end of which time a temperature of 870 to 880 deg. should be registered. It will be obvious that the amount of coal to be consumed will vary according to the design of the furnace, radiation losses, tonnage of the castings to be treated, and also the weight of the cast-iron annealing boxes. The dampers are so regulated that the furnace is well filled by the gases. In the case under discussion, the coal-feeder fed 60 to 66 lbs. of coal per hour to the burner.

(2) *Maintenance of the temperature.*—The duration of this period is 120 hrs., at a temperature fluctuating between 870 and 880 deg. C. The amount of coal consumed during this period depends above all upon a judicious handling of the dampers, so as to reduce to a minimum losses through the chimney and those due to radiation conditions in the walls of the furnace. In the case under discussion, the feeder supplied coal to the burner at the rate of about 20 to 22 lbs. of coal per hour.

(3) *Cooling.*—The duration of this stage is about 48 hrs. Cooling is split up into two phases, which depend mainly upon the conditions of manufacture. This cooling is carried out with the burners shut off, and can be dismissed from the question. Its underlying principles

are as follows:—(1) The rate of cooling is 5 to 6 deg. per hr. to about 650 deg. when the dampers of the furnace are shut; (2) cooling is then made more rapid by opening the dampers, until the completion of the operation.

Results Obtained.

The weight of the castings to be treated is about 5 tons, and associated with this is a coal consumption of about 15 cwts. per ton of metal treated, these results being obtained with good-quality coal of calorific value of about 7,500 calories.

The boxes in which castings are stacked stand up much better, there being a difference of at least 5 to 1, whilst cases are reported where boxes have showed no signs of stress even after having been 15 times through the pulverised coal furnace, as compared with two or the maximum three times when the furnaces were hand fired.

It is highly important, however, that:—

(1) Very fine coal be used.

(2) Very efficient regulating dampers are supplied, so as to obtain exact regulation.

(3) The charging boxes be piled up very regularly on the hearth, and enough space left between them to ensure being well enveloped by the gases.

The results obtained require very close attention to firing operations, especially in regard to co-ordinating the rate of combustion with the operation of the gas-discharge registers, and it is apparent that the best way is to determine by experiment such rate of combustion as follows:—

(1) Temperature to be raised by about 20 deg. per hour using a minimum amount of fuel and the furnace remaining under slight pressure.

(2) Temperature to be maintained under the same pressure conditions with a minimum amount of fuel.

(3) Strict observation of the fineness and moisture conditions of the pulverised coal used.

In malleable melting furnaces the coal requires drying down to about three-quarters of 1 per cent. moisture to prevent agglomeration of the particles as they go to the burners, as the addition of carbon and sulphur have been prevented by its proper drying.

In malleable annealing, with coal properly dried and pulverised to fineness as above, ratios of 4 to 5 to 1 are being secured, and the increased life of boxes is not the least saving.

Plate Heating Furnace.

Messrs. Thomas Piggott & Company, Limited, of Birmingham, have applied pulverised fuel to two plate-heating furnaces, but, beyond the fact that the installations are both satisfactory, the authors have little or no knowledge of this plant. It is known, however, that they have found it necessary to use particularly dry fuel pulverised as fine as machines will permit.

Steel Melting Plants.

Open-hearth plants using pulverised coal are unknown in this country, but a number of them are in successful operation in America, and at this time the subject is being given marked consideration.

Owing to early difficulties with checkers and high furnace maintenance, in addition to the fact that open-hearth furnaces have been long ago brought to a high standard of efficiency, for gas and oil, there has been very little progress as to the number of plants changed to pulverised coal from other fuels. However, most of the early troubles have been overcome, and, whilst one plant has been in operation for six years, a large number of plants have been in operation for shorter periods of time. The elimination of expensive checkers and the ability to use low-grade, high-sulphur, high-ash coals in pulverised form, added to the increased tonnage possible, due to more uniform operation of furnaces, will make the change in fuel well worth while in many cases.

Frequently the difference in price between high-grade coal used for gas-producing operation and the screenings possible to use in pulverised form shows savings sufficient to pay for the installation in one year. Savings per gross ton of ingots produced in some cases run as high as 7s. 6d.

When pulverised coal was first used in open-hearth furnaces, it was found that the checkers were rapidly filling up with ash. It was believed at that time that this could not be prevented, and, therefore, arches were substituted for the checkers because of the greater space. The arches are placed about 18 in. apart, in rows, one above the other, with about 3 ft. between the rows. Slag pockets are equipped with removable structural steel boxes, which fill up in about 15 days. The time ordinarily required to pull two boxes and to get fuel in the furnace again is about 5 hrs.

The average analysis desired for coal suitable for pulverisation for open-hearth furnaces is about:—Volatile, 36 per cent.; fixed carbon, 52 per cent.; moisture, 1.25 per cent.; ash, 6 to 8 per cent.; and sulphur, under 1.25 per cent.

The operation of the open hearth does not present more difficulty than with producer gas, although it is not so simple as with oil.

Economies Effected.

A cold charge is used, and the time for charging is about 4 hrs., whilst a heat takes about 12 hrs.

The life of a furnace roof is about 200 heats, although the use of a flat suspended arch would probably increase this materially.

There is a milling plant on the central-station system, consisting of a battery of Raymond mills, coal being delivered to the furnace by means of a shooting tank, situated 450 ft. from the furnace. The coal required runs as low as 500 lbs. and as high as 600 lbs. per ton of ingots.

The wide variation is partly due to the grade of coal, partly to the charge, to the analysis required in the product, and a little to the age of the furnace, although the time from tap to tap varies less than was formerly thought possible.

The temperature maintained in the furnaces is essentially the same as that with producer gas.

Other applications of pulverised fuel which have had successful results are soaking pits, spelter furnaces and, in fact, almost any metallurgical process, particularly in the ferrous trade.

Puddling Furnaces.

The application of pulverised fuel to puddling furnaces is an excellent illustration of the advantages to be gained by this method of firing applied to metallurgical furnaces. The puddling process consists of the conversion of pig or cast iron into wrought or malleable iron, and the temperatures required on the furnace hearth vary from about 500 deg. C. up to 1,500 deg. C., and, further, these temperature fluctuations are required with extreme rapidity.

In 1923, when the authors first applied pulverised fuel to puddling furnaces, the standard or accepted method of burning pulverised coal was employed, that is to say, a very large and deep combustion chamber of cathedral-like dimensions was erected, displacing the fire grate of the previously hand-fired furnaces. Into that massive edifice the pulverised coal was introduced with the whole of the air necessary for complete combustion, and the furnace hearth itself containing the metallic burden was heated by the products of combustion drawn over a fire bridge into the furnace proper. The temperature in the combustion chamber was obviously higher than that obtaining over the furnace hearth, because combustion was being actually completed before the furnace hearth was reached. The temperature, in fact, in the combustion chamber rose to such a point as to melt out completely the refractory lining of the combustion chamber. The unit therefore suffered from two obvious disadvantages, one of which was entirely disastrous. First of all, the life of the combustion chamber was limited to a few hours, and secondly, the development of the temperature was taking place at a point other than that where it was required. Various means of cooling the refractories of the combustion chamber were tried in hope of curing the major trouble, but obviously on such a small unit as a puddling furnace, which has an output of only about 3 cwts. of metal per hour, any frills in the design of the combustion chamber were commercially impossible owing to the capital cost of construction. It was necessary, therefore, completely to abandon all accepted practice in the firing of reverberatory furnaces with pulverised fuel, and to start afresh with a view to arranging the unit in such fashion that the combustion chamber should be at a low temperature, and that the maximum heat should be obtained over the working hearth of the furnace. This was eventually effected by reducing the combustion chamber in cubical content to a point not only less than that of the pulverised fuel-fired furnace, but considerably less even than that obtaining on the furnace as arranged for hand firing.

The whole combustion end of the furnace was, therefore, re-designed on the principle that, although the space required for the complete combustion of pulverised fuel is relatively large, nevertheless, if the pulverised coal was first gasified and the producer gas arising from that operation was burnt over the furnace hearth, such producer gas could be completely burnt over the hearth of the furnace, and in such burning the highest temperature could be developed at the point where it was required, namely, in contact with the metallic burden of the furnace.

To put the matter briefly, if the pulverised coal could first be gasified, it was obvious that no separate combustion chamber at all was required, but that the hearth of the furnace itself would serve as a combustion chamber for the development of the highest temperature. However, the gasification of pulverised coal is a very different proposition from that of solid or lump coal, which can be gasified in any commercial type of gas producer, whereas in the case of pulverised coal where the coal is introduced into the furnace at a more or less high rate of travel, an obvious difficulty that arose was the retention of the pulverised coal in the gasifying zone for an interval of time sufficient to turn it into producer gas. Such operation would require a long length of travel, and a chamber of considerable dimensions, but by experiment this disadvantage was overcome, as it was discovered that if the pulverised coal was introduced into a comparatively small chamber in such fashion that the stream of coal and primary air struck a bridge wall and recoiled into the oncoming stream, then a violent agitation or turbulent effect was set up in the gasifying zone, enabling the minute particles of coal to be retained in suspension therein, in contact with the deficiency of air for an interval of time sufficient to enable the whole of the coal to be turned into producer gas, the producer gas passing over the fire bridge and there coming into contact with a supply of secondary air (preferably pre-heated), sufficient to effect complete combustion of the gas over the working hearth of the furnace.

It is also found by observation that another great advantage has been obtained, inasmuch as the pulverised ash content of the coal was largely dropped in the gasifying chamber through the agitation taking place therein, and that only a very small percentage of the ash contained in the coal passed over the fire bridge into the furnace itself. These discoveries cured many troubles. First of all, the overall dimensions of the furnace were considerably reduced for the same output. Secondly, the life of the combustion chamber was prolonged indefinitely, owing to the fact that the temperature therein did not rise above 800 deg. C. The ash was collected before it reached the metal burden, and radiation losses were largely eliminated by reason of the very restricted dimensions of the primary chamber. In short, a revolution has been effected in the method of applying pulverised coal to a metallurgical furnace.

It is essential in this method of applying pulverised coal that the coal should be pulverised finely and uniformly, because if there are coarse particles of coal in the stream, these fall to the foot of the gas-producing chamber. It is true that these can then be gasified by the introduction of steam and air, but this means further capital cost and consumption of steam, both serious points on a small metallurgical furnace. The authors consider, therefore, that the coal preparation for metallurgical furnaces should, if possible, be effected in central mills rather than in unit mills, where there is a rather rapid deterioration in the fineness of pulverisation.

Pulverised Fuel Marketed.

Apart from this feature, the power and maintenance costs on central mills are very much lower than on unit mills, but, on the other hand, the comparatively small coal-user is unable to employ central mills as his coal demand is insufficient to warrant their installation. This difficulty is already overcome in certain foreign countries by organisations marketing coal in already pulverised form.

It has been suggested that in the firing of metallurgical reverberatory furnaces with pulverised fuel, no external combustion chamber at all need be employed; in fact, experiments have been made with a view to discharging the powdered coal directly on to the working hearth of the furnace. Theoretically, such application has merit, inasmuch as radiation losses are reduced owing to the elimination of the primary chamber. It has, however, been found that two disadvantages arise: first of all a cold zone exists in the furnace chamber immediately in front of the pulverised-fuel burner, owing to space being required for the development of the flame; and secondly, the ash content of the coal is distributed over the metal in the furnace.

The authors have shown the disadvantages of firing in a large combustion chamber on the one hand, and on the other hand, of firing directly on to a furnace hearth.

The gasification system just described eliminates the troubles and commercial drawbacks of both those methods. It has a further great advantage, that scaling losses of the metals are greatly reduced, owing to the fact that excess air is practically eliminated, and a slightly reducing atmosphere can be maintained over the hearth of the furnace.

DISCUSSION.

Differences in British and Foreign Fuel.

Mr. F. J. Cook said that pulverised-coal firing would be applied more widely in the foundry in the very near future, for the claims that could be put forward and proved with regard to it were such that no foundryman could ignore. He asked the authors to augment the Paper by stating what they considered the tendency would be in regard to the application of pulverised-coal firing to melting and annealing. Most of the applications of pulverised-fuel firing to foundry work had been applied in other countries than our own, and he had heard it stated that there was a considerable difference in the results obtained with some foreign coals and with British coals. He believed that the moisture content of British coals was a source of trouble, and if the authors had any data available as to the results obtained with coals from the various coalfields of this country in pulverised form, it would be of great help to foundrymen. Pulverised-fuel firing was being used very successfully in at least one instance in this country for melting and annealing. At first the application of the system had appeared to be almost hopeless, but he believed that was due largely to the difference in the nature of the coal used here as compared with that used abroad in a similar installation.

Difficulties in Slag Removal.

With regard to slag trouble, he said that that was one of the first snags in connection with steam generation; he believed that the first boiler which was fired with pulverised fuel had become one mass of rock in the course of about six weeks, and had had to be blasted and pulled down. We had got far beyond that stage, but he believed that trouble was likely to arise with the slag if pulverised fuel were used in a cupola; the fuel used would have a comparatively high sulphur-content, and he asked whether the sulphur would not so contaminate the slag that, when the metal fell through it, there would be considerable sulphur pick-up. He was not afraid of sulphur in quite large amounts, but there was a limit beyond which one could not go in this direction.

Powdered Fuel for Receivers.

Mr. B. Hird asked if pulverised-fuel firing could be used in a foundry for the purpose of maintaining the temperature of a quantity of metal in a receiver or for raising the temperature of the metal from that at which it was poured into the receiver to a higher temperature for use continuously on a casting plant. He also asked how far the fuel could be carried successfully from an existing plant to operate in a receiver such as he had referred to.

Feeding of Pulverisers.

Mr. B. Winterton asked for further information with regard to the pulverisers. In Fig. 2 the pulveriser seemed to be so small as to represent an almost negligible part of the total outlay. Reference was made in the Paper to pulverising coal so that 98 per cent. would pass through a 100-mesh screen, and to an output of 4½ cwt. per hr. Presumably, if the process were to be economical, it would be necessary to have a hopper arrangement for feeding the coal in, because it would appear that if one had to feed a pulveriser by hand at the rate of 4½ cwts. per hr., the cost would be high. He also asked what type of pulveriser was referred to, and whether it worked at slow speed or high speed; if the latter, he suggested it would be necessary to pass the coal through a magnetic separator before pulverising, because no one received coal which did not contain tramp iron, and if it were not removed it would have a serious effect upon the pulveriser.

Powdered Fuel for Annealing Furnaces.

Mr. J. W. Gardom said it was surprising, and somewhat disconcerting, to hear the authors state that the greatest factor of economy, when pulverised-fuel firing was adopted, was the difference between the price of high-grade coal and of the screenings which could be used in pulverised form. That might have been so a few years ago, but even metallurgists were getting sufficient commercialism knocked into them to recognise that as soon as there was a demand for anything the price of it would increase, and at the present time the difference in price is not great. In those circumstances, he suggested that the use of a pulverised-coal fired system would not be economical. He was interested particularly in the application of pulverised-coal firing to the annealing furnace. It must be remembered that when the furnace was fired with ordinary coal the fireman could leave it quite safely for a couple of hours or so, but it seemed to him that if it were fired with pulverised coal the mechanic would not be able to leave it for a moment; the fact that shifts could not be broken increases the number of pay-hours per day, and there is also the increased wage-rate between a fireman and a mechanic. There must be added to that extra cost another 2s. 6d. per ton of coal for pulverising. He did not agree with the authors' figures representing the costs of annealing in an ordinary coal-fired furnace. It was stated that 7 tons of coal were used to anneal 5 tons of malleable iron, but he himself—using the same times and figures as the authors—was able to anneal in one furnace with only 0.75 ton of coal per ton of castings. He need hardly say that that result was obtained with forced-draught, and that system had many advantages over pulverised-fuel firing. With regard to the two main types of pulverised-fuel systems, he disagreed with the authors' remarks as to the disadvantages of the unit system. It had the great advantage that its cost was lower than that of the bin-and-feeder system, and it was more flexible and could be changed from one furnace to another. The authors had mentioned as one of its disadvantages that the failure of the mill or motor would result in the furnace in which it was used becoming definitely out of action. He believed, however, that the present-day electric motor was very reliable. This being established leaves the suggestion by the authors that the mill breaks down, and he asked for confirmation of that.

Air-Separation and Drying Systems.

As to the statement that, with the unit system, pulverisation rapidly deteriorated from the first moment the mill was put into operation, he said he saw no reason why that should be so, if one used a fairly good pulveriser provided with an air-separation system. Again, it was stated that moisture had a serious effect; but that was so in both systems. There were many pulverisers on the market which would deal with coal containing up to 8 or 10 per cent. of moisture, and it was quite easy to reduce the moisture content to that extent by simple air-drying. Another disadvantage of the unit system, according to the authors, was that the plant was incapable of supplying a mixture of coal and air as accurately as that obtained with the central system. He pointed out, however, that the conveyance of the coal from the pulveriser was effected by means of primary air, and then secondary air was added, and he saw no reason why it should not be capable of adjustment at any time. With regard to the lay-out of the annealing furnace, he said that although the authors had given their reasons for not using a fire-box, he believed they were wrong. They had stated that the heat in the fire-box was so intense that it had melted away; yet they were going to put the burner straight into the furnace and burn the annealing boxes and pierce the work by the intense heat. He considered it better to have a fire-box, to place the burner in the fire-box and burn the coal there, and to adjust the dampers in order to draw the heat into the furnace. By such means one could obtain a more even annealing temperature throughout the whole of the oven.

AUTHORS' REPLIES.

In reply to Mr. Cook, the application of pulverised coal to iron-melting cupolas has not so far, within the knowledge of the authors, been attempted, though a certain amount of experimental work has been carried out on blast furnaces in Germany, the results of which the authors are not familiar with. Pulverised fuel is highly successful when applied to melting and annealing furnaces, a fairly full description of the latter being contained in the Paper.

Effect of Different Coals.

There are very noticeable differences between foreign and British coals; even though the analyses appear the same, it is possible to have two coals of practically identical analyses, the one being " bright " coal and the other " dull " coal. These physical differences depend largely upon whether the main constituents of the coal are fusian, vitrain, clarian or durain. With the exception of lignite and one or two coals from Prussia, American and European coals are generally more friable than British coals, the result being lower power costs, cheaper maintenance and greater output from mills of supposedly similar capacity.

Slag and ash do present certain difficulties, and it never pays to buy coal purely on price without due regard to the calorific value, and therefore to the ash content. An excess of sulphur will contaminate liquid metal, and the sulphur content should therefore be kept down to under 1.25 per cent.

Referring to the points raised by Mr. Hird, no difficulty would be experienced in applying pulverised coal to metal mixers, and in the event of such an application being made, the powdered coal could be used either to maintain a certain fixed temperature or to raise the temperature as and when required. In this connection the pulverised coal could be carried about a thousand feet. If it were desired to convey the coal further it would be necessary to introduce a booster at this point, when the coal could be conveyed another thousand feet.

Coal Handling Cost.

The application of pulverised coal certainly does not increase coal handling costs. On a large installation it would be possible to justify automatic coal handling plant, whilst on a small job employing one pulveriser, the hopper above the pulveriser could be made to hold, say, an hour's supply. It is customary to use magnetic separators, but these are not strictly necessary on unit mills, most of which are equipped with automatic separators working on the gravity and air suction principles.

Referring to Mr. Gardom's remarks, whilst it is true that there is no longer such a gap in price between lump coal and slack, there is still a difference sufficiently big to justify the use of pulverised coal. It is still possible in this country to buy coal as low as 11d. per ton at the pit head. The calorific value of the particular coal in question is 7,000 B.T.U.'s, and its economic value from a metallurgical process point of view is doubtful. On the other hand, no difficulty should be experienced in buying a slack at a price which would save at least 10s. per ton over the price of lump coal. Mr. Gardom also raised the question of a man standing by, and, as pointed out above, this is not necessary if the coal hopper is made of a sufficiently large capacity.

Bin-and-Feeder System.

The authors are unable to agree with Mr. Gardom's remarks on the subject of the unit system, and still adhere to the point of view that unless one is considering one furnace or boiler only, the bin and feeder system is the better proposition, and they offer the following reasons against the unit system for this decision:—

(1) The power consumption is equal to that required to drive the unit at no load plus a variable factor increasing with the output; (2) the capacity is affected by the character of the fuel and its moisture content; (3) the pulverised product varies in fineness with the output, the greater the output the coarser the product; (4) all have a maximum output beyond which, if the rate of feed is increased, the unit chokes and ceases to function; (5) all are subject to wear which, as it continues, results in a decrease of maximum capacity and in a coarser product at any given output, and (6) all have the characteristic, inherent in high-speed machines subjected to severe service, of being subject to breakdown without notice.

Combustion in the pulverised-fuel furnace is essentially an instantaneous process, so nearly so that for any momentary variation in the ratio of fuel to air entering the furnace there can be no compensation. Uniformity of air supply through the unit is easily obtained. Corresponding uniformity of coal feed, however, is most difficult, in fact well-nigh impossible, owing to variation in size and the effect of moisture content. To the extent that a variation in coal feed takes place, a loss in efficiency results. The loss due to unburned carbon in the flue dust increases with the rate of combustion in the furnace, a condition which is aggravated in the direct-fired system by the fact that the pulverisers are operating at their maximum output under such conditions, and therefore supply coal of the maximum coarseness. This result is further aggravated as the pulverising elements become worn.

In the discussion the point was raised that in foundry operations, presumably annealing operations, a firebox was necessary, otherwise the temperature would be too high in the furnace. The authors entirely agree as to the necéssity, or at all events the desirability of a firebox, though for rather different reasons.

The point is dealt with at some length commencing with the section " Puddling Furnaces," p. 414. In fact the remainder of the Paper is indirectly an argument in favour of the firebox. The object of those pages being to describe the revolution which the authors have effected in the method of burning pulverised fuel for metallurgical operations.

Burning of Producer Gas.

The authors desire briefly to reiterate that the hitherto accepted practice of heating by means of pulverised fuel has been to heat the metal-carrying-furnace by means of the burnt gases arising from the complete combustion of pulverised coal in a combustion-chamber. Under the authors' system the metal burden is heated not by radiation from the burnt gas passing over or through the burden, but by the actual burning in the furnace of producer gas generated in a small primary chamber attached to and forming part of the structure of the furnace proper. It is well known that the range of temperature in a furnace employing producer gas can be made pretty well anything that is desired. In fact the authors specially refer to this aspect of the matter on page 414, that is to say, the paragraph commencing " The application of pulverised fuel to puddling furnaces."

The authors' method is to employ the furnace proper as the combustion chamber, burning producer gas generated from pulverised fuel, and the standard method is to employ a separate and voluminous combustion chamber, where the pulverised fuel is completely burnt, and the burnt gases are subsequently employed to heat the metallic burden in the furnace.

Obviously of the two methods the authors' is much more economical, because by their method the heat value of the coal is employed in heating metal, and not brickwork.

THE CRITICAL EXAMINATION OF STEEL CASTINGS.

By G. F. Gillott, B. Met.

(Communication from the Research Dept., Woolwich.)

The last few years have been marked by decidedly increased demands on the quality and service expected of the products of the steel foundry. With the tendency towards higher stresses, higher temperatures and reduced weight in the zealous quest after higher thermal and mechanical efficiency, the engineer's requirements have, on the one hand, become extremely exacting. On the other hand, the competition of old rivals of steel castings has become more keen. The ancient art of cast-iron founding has at last been put on a more scientific basis under precise metallurgical control, whilst the smith's art has progressed until quite large and intricate forgings of lower cost and superior characteristics have been made possible by recent developments in drop-stamping and machine-forgings. The new problems can only be met by basing advances in steel foundry practice on existing knowledge and on the results of special investigations interpreted in the light of such information as is available from a critical examination of steel castings. The long-standing practice of breaking up an occasional casting and examining the fracture gives a limited amount of information; but the recent developments of radiology enable an equal or greater amount of information about the presence and distribution of defects to be obtained without the necessity of destroying the casting.† By interposing the casting to be examined between a piece of photographic film and a very powerful X-ray tube, a shadow picture is obtained which shows on the

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† V. E. Pullin, Proceedings Inst. British Foundrymen. Vol XXII.

positive print less-dense patches corresponding to the defects, which offer less resistance to the passage of the rays than sound metal. To yield the "hard," short wavelength X-rays necessary to penetrate such a dense substance as steel, a very powerful hot-kathode tube is used with an applied potential of 200 to 400 kilovolts. With the maximum power available it is possible to penetrate about 4½ in. of solid steel and to detect in this a flaw equivalent to 3 per cent. of the thickness of the section. Typical radiographs are shown in Figs. 1, 2, 3 and 4, in which various defects are denoted by light areas.

Fig. 1.—Radiograph, showing Cavity and Chaplet.

Of still more importance than knowing the presence of a defect is learning the source of its origin. In many cases this is not revealed with certainty by X-ray examination and detailed examination of sectioned castings is essential to arrive at a solution of the problem of eliminating the defects. Steel ingots have been intensively studied for many years and the results applied with great advantage to the production of sound ingots showing a minimum of segregation. The question of soundness in steel castings is a different and, in many respects, a more difficult problem, but methods which have profitably been employed for the examination of ingots are applicable with suitable modification to castings also.

Briefly, the methods employed in studying sectioned-ingots have been macroscopical and microscopical examination, chemical analysis and hardness testing. The application of the first two of these to steel castings will be considered.

Macroscopical Examination.

The machined-surface of the section is ground, or ground and polished, with fine emery and is

Fig. 2.—Radiograph, showing Transverse Cracks in Cylinder.

then ready for the further treatment. This consists, in the first place, of sulphur-printing. Gaslight photographic-paper, soaked in 5 per cent. solution of sulphuric acid, is laid face downwards on the specimen, and close contact preserved for about two minutes. On removal from the specimen, the print shows brown coloration of silver sulphide at positions where the emulsion has been in contact with sulphide in the specimen. The record is permanent after fixing with "hypo." and washing in the usual way. The sulphur-print gives a graphic representation of the degree of heterogeneity, based on an unequal distribution of sulphide. It is known that sulphur, carbon and phosphorus segregate together and, therefore, the sulphur print indicates the general heterogeneity of the steel. Typical sulphur-prints are shown in Figs. 5, 6 and 7. Fig. 5 indicates the tendency of segregation to occur in the thicker section at the junction of four walls. Figs. 6 and 7 show V-segregations of sulphide, which on a larger scale are a common feature of steel ingots.

FIG. 3.—RADIOGRAPH, SHOWING CIRCUMFERENTIAL CRACKS IN CYLINDER.

Fig. 7 shows an interesting type of heterogeneity which is common in steel castings, consisting of a surface layer of material differing from the rest of the casting. All these types of heterogeneity are also shown by other methods of examination and discussion of their meaning is, therefore, deferred until later.

The surface of the section after sulphur-printing is usually etched with some suitable etching-medium. This may be :— (*a*) 10-per-cent. solution of nitric acid in alcohol; (*b*) Heyn's reagent, consisting of 8- to 10-per-cent. solution of copper-ammonium-chloride in water; and (*c*)

Humfrey's modification of Heyn's reagent, starting with the neutral reagent and following with Heyn's reagent containing progressively increasing percentages of hydrochloric acid, up to 5 to 10 per cent. by volume of concentrated acid.

Of these reagents, nitric acid, depending for its action on the carbon segregation, fails to show up the primary crystal structure if the casting has received an efficient annealing resulting in uniform distribution of the carbide. Humfrey's reagent, however, depends on characteristics which are less affected by annealing and has the advantage that the surface need not be so carefully prepared. It is very suitable for deep etching of fairly coarse structures. Since the selective action of this reagent depends on the distribution of phosphorus and possibly also of oxygen, both of which exist as solid-solutions in cast steel, a more continuous record of the primary structure is revealed than by sulphur, which is present chiefly in isolated globules of sulphide. The result of etching is, therefore, to show not only the general heterogeneity but also the dendritic structure of the primary-

Fig. 4.—Radiograph, showing Cracks at Base of Brackets.

austenite crystals. The reagent first attacks the purer material in the cores of the primary dendrites, so that if the dendrites are very small, they are obliterated by deep etching, owing to the interdendritic material being dissolved away by outward attack from the core. Equiaxial crystals show only as indefinite dots. Fig. 8 shows a photograph of a section etched by this method. An advantage of this process is that the structure stands out in relief and direct-contact prints can be obtained on "glazed art"

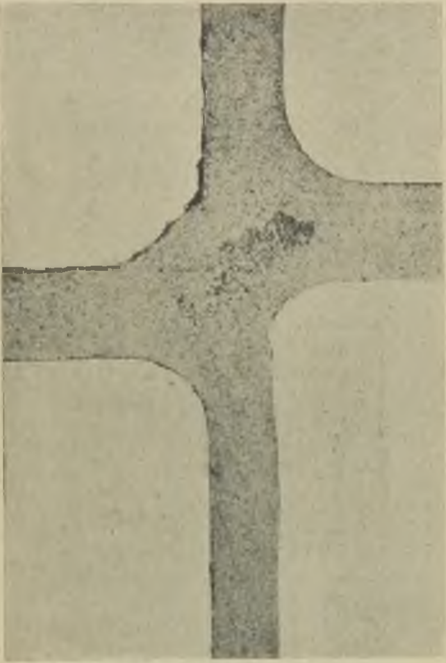

FIG. 5.—SULPHUR PRINT, SHOWING SEGREGATION AT THE JUNCTION OF FOUR WALLS.

Fig. 6.—Sulphur Print, showing V-Segregation.

paper by means of printer's ink, as illustrated by Figs. 9, 10 and 11, which are photographs of such prints. The segregates stand out in relief on the etched surface and, after rubbing with fine emery paper, appear light. In the ink-print, the segregates are represented by the dark areas, as in the sulphur prints.

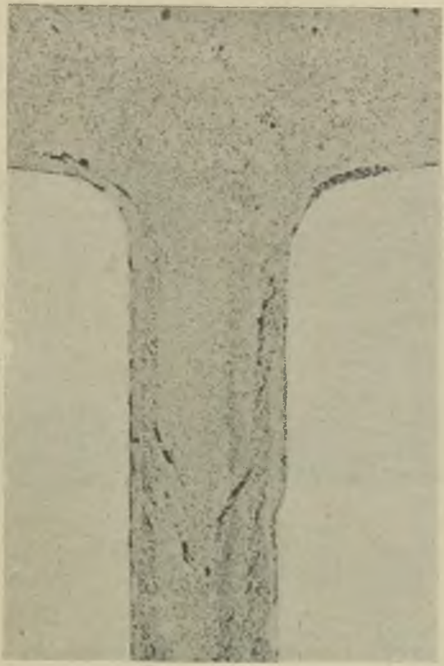

FIG. 7.—SULPHUR PRINT, SHOWING V-SEGREGATION AND "CHILL" EFFECT.

Macroscopical examination frequently indicates the regions which may profitably be examined more minutely by means of the microscope.

Microscopical Examination.

Certain features of the general structure of a casting are revealed by microscopical examination of specimens taken from any convenient position in the casting, for example, from the cast-on test-bars. The most important indications of microscopical examination applied as a routine test have reference to the efficiency of the annealing received. The structure of the cast steel before annealing consists of large grains of pearlite in which angular fragments of ferrite have separated along the cleavage planes, giving a coarse "lattice" type of structure possessing poor mechanical properties. The object of annealing is twofold: (1) To cause a recrystallisation and refinement of the large grain size, and (2) to relieve internal stress. The former necessitates heating for a considerable time above the upper limit of the critical range; the latter is effected at a much lower temperature and is almost complete at about 550 deg. C. The danger of insufficient annealing lies not so much in persistence of internal stress as in the inferior mechanical properties of the

Fig. 8.—Illustration showing Macro-structure, including Cavities, Cracks and Segregates.

steel, shown particularly in a low true-elastic-limit and poor impact figure. The incompletely-annealed structure shown in Fig. 12 was associ-

FIG. 9.—INK MACROPRINT, SHOWING V-SEGREGATION.

ated with slight but unimportant stress, but the limit of proportionality and impact figure were both low and were restored by a more efficient annealing. The actual test-figures before re-annealing were: Limit of proportionality, 7 tons per sq. in.; Izod impact-figure, 5½ ft.-lbs. After re-annealing these improved to 11 tons per sq. in. and 18 ft.-lbs. The yield-point and elongation were also improved, whilst the tensile strength only increased slightly. The structure after re-annealing is shown in Fig. 13. The

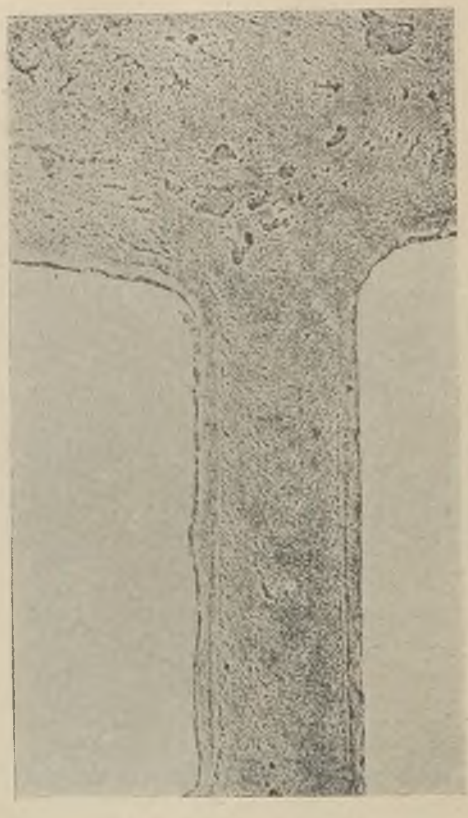

Fig. 10.– Ink Macroprint, showing V-Segregation and "Chill" Effect.

"as-cast" structure of another casting is shown in Fig. 14, whilst Fig. 15 shows the refined structure resulting from an efficient annealing. A further effect of annealing is the partial balling-up of sulphide films which may form initially round ferrite and pearlite grains, and which in that position are very detrimental to the mechanical properties. Such films, some practically continuous and some partially balled-up, appear in the ferrite bands in Fig. 16.

FIG. 11.—INK MACROPRINT, SHOWING "CHILL" EFFECT AND DENDRITIC STRUCTURES.

The annealed casting may show two distinct types of microstructure, one which may be termed the normal structure of pearlite grains embedded in a ground mass of ferrite (Figs. 13 and 15), and the other a pearlite network surrounding the aggregates of small ferrite grains (Figs. 17 and 18). Piwowarsky* attributes the network structure to the influence of aluminium or some other element such as vanadium, added to the molten steel as a deoxidiser, and the present author has only observed this network structure well developed in electric-furnace steels to which aluminium has probably been added in all cases. Fig. 17 also shows extensive decarburisation round blowholes caused by steam from a green-sand mould which blew through the plastic metal. The blowholes appear as dark

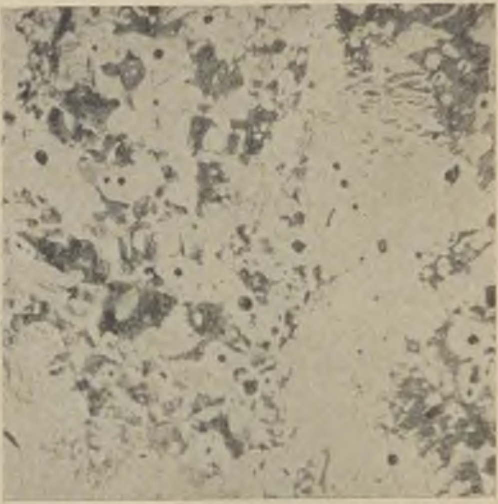

Fig. 12.—Microstructure of an Incompletely Annealed Steel Casting. × 100.

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* Stahl und Eisen, 1928, *48*, 1665.

areas in the decarburised region. The reverse effect is shown in Fig. 19, which illustrates surface-carburisation of a steel casting occurring when the very hot metal lay in contact with a carbonaceous mould-dressing. Rather deep surface decarbonisation has later occurred, probably owing to the access of air to the annealing furnace. Such decarburisation by mould "washes" may conceivably be one cause of difficulty in machining the surface skin of a casting.

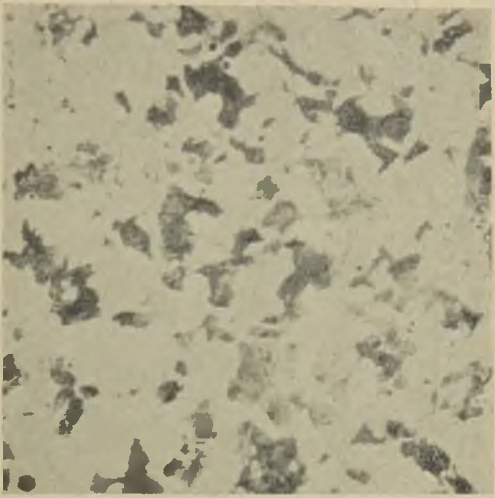

FIG. 13.—MICROSTRUCTURE OF EFFICIENTLY ANNEALED CASTING. × 100.

The use of microscopical examination as a routine test and the keeping of systematic records of the miscrostructure of the test-bars, along with the analytical and mechanical data they provide, will tend to throw light on such points as have been mentioned and lead to greater uniformity and improved quality of the product.

For purposes of investigation it is usual to complete a macroscopical examination before selecting small specimens for polishing, etching and microscopical examination from the positions which show promise of giving most information. In illustrating some of the structures so encountered, it will be convenient to revert to the explanation of the indications of the radiographs and of the macrosections.

FIG. 14.—MICROSTRUCTURE OF STEEL CASTING, "AS CAST." × 15.

The Occurrence of V-segregates.

During the last stages of freezing of an ingot, as sinking of the liquid steel occurs to compensate for contraction, the segregates in the adjacent viscous material are drawn down with it, and the sagging effect gives rise to the V-shaped segregates characteristic of the axial region of an ingot. In a casting the metal rising steadily in the mould begins to solidify at the mould surfaces, forming dendritic crystals, which grow at right-angles to the surface of the mould. As the dendritic growth proceeds, the temperature of the metal continues to fall until the conditions are such that free growth of crystals can take place from nuclei formed in the remaining liquid. The solidification of this liquid will not be complete until after the mould has been filled, and will be accompanied by a considerable movement to compensate for contraction. The V-segregates indicate movement of the solidifying metal towards the portion of the casting where solidification is first completed. Such V-segregates are shown in the sulphur prints, Figs. 6 and 7, and in the macroprints, Figs. 9 and 10. In other words, feeding occurs in the direction of the point of the V, and any cavities present below the V indicate that feeding from this direction cannot be adequate, and that it is desirable to provide additional feeding at another position.

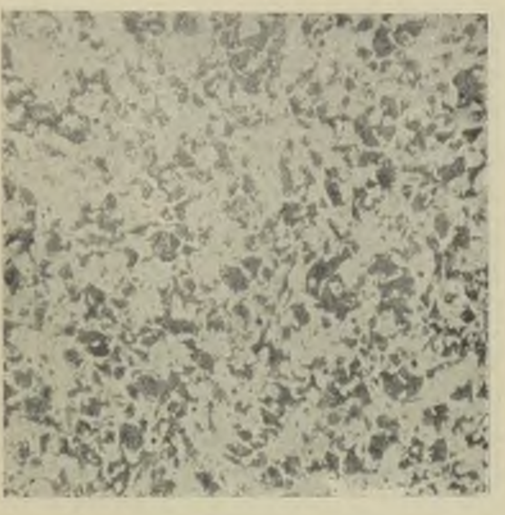

FIG. 15.—MICROSTRUCTURE OF STEEL CASTING, AFTER ANNEALING. × 25.

Contraction Cavities and Blowholes.

Although the word "blowhole" is frequently used as a general term to include all kinds of cavities in steel castings, such use is quite unjustified. Voids are of two kinds at least. Blowholes, excepting the small pinholes seen in oxidised metal, are rarely due to the evolution of gases from the metal, since the steel supplied for foundry purposes is usually well deoxidised. Blowholes due to gases evolved by the metal are usually bright on their inner surface. The more usual cause of blowholes is steam, air and organic gases given off by the sand of the mould or core in contact with the hot metal, and unable to get away through the sand, either owing to inefficient venting or to unforeseen trapping by some intricate part of the casting. Patching

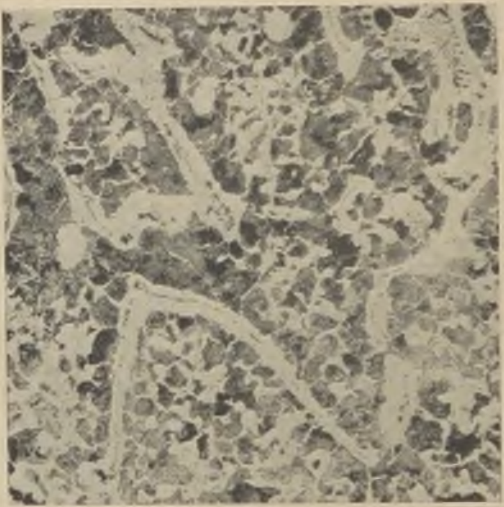

FIG. 16.—MICROSTRUCTURE OF STEEL CASTING, SHOWING SULPHIDE FILMS. × 100.

of the mould with damp sand just before casting is another cause of this type of blowhole. Such blowholes usually exhibit an oxidised scaly inner surface, as the gases involved are of an oxidising character. This type of defect may be accompanied by the decarburisation already mentioned in connection with Fig. 17.

More serious than blowholes, and usually more difficult to avoid, are contraction cavities. These arise from the same causes as piping in steel ingots, namely, the liquid shrinkage of the metal, together with the large contraction on freezing. Since these cavities occur generally in the portions of the casting which solidify last, they are frequently associated with the low melting-point segregates of the steel, and the surrounding segregated area is frequently porous. Such a contraction cavity in an acid

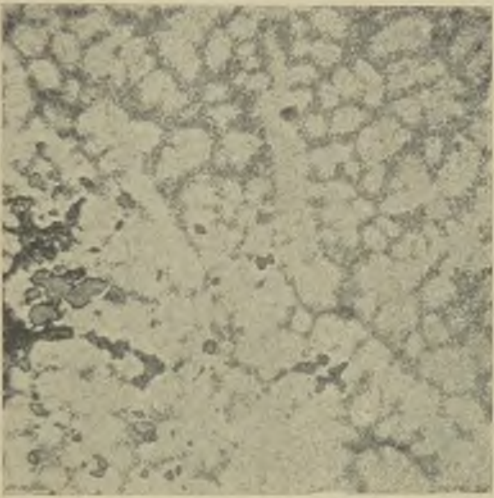

FIG. 17.—MICROSTRUCTURE OF CASTING, SHOWING DECARBONISATION, BLOWHOLES AND NETWORK STRUCTURE. × 25.

open-hearth casting is illustrated by the radiograph Fig. 1. On cutting into this cavity the whole of the inner surface was bright with the exception of a few adhering particles of greenish slag. The upper surface was fairly smooth, but the lower surface, being covered until a later stage of cooling with a pool of still-liquid metal, allowed free growth of the dendrites to proceed until the liquid was exhausted. The photograph (Fig. 20) of the floor of the cavity shows the dendrites in relief. On the bottom of the cavity were also several small shots of lower melting-point material squeezed out from between the growing dendrites by contractional movements. The macrosection (Fig. 8) was cut from the wall of a long hydraulic-cylinder cast in a horizontal position. Near one end, three shrinkage-cavities appear, partly filled in their lower part with

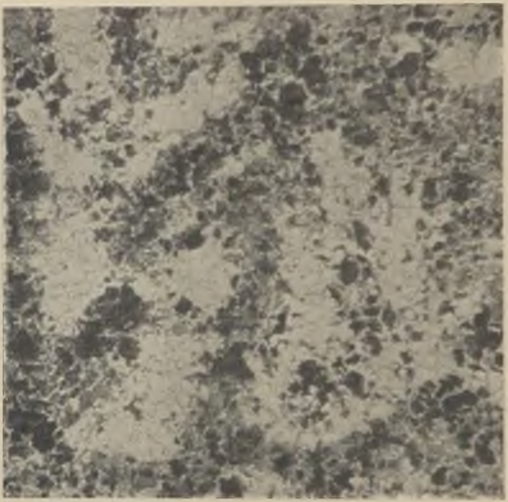

FIG. 18.—PHOTOMICROGRAPH, SHOWING PEARLITE NETWORK. ×100.

segregates which form a horizontal row along the middle of the section.

The characteristics of these contraction cavities indicate the desirability of casting where possible with the heavier sections uppermost and of providing large feeding-heads over such sections.

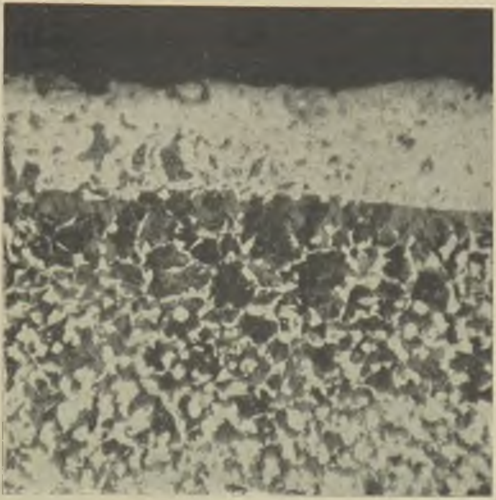

FIG. 19. PHOTOMICROGRAPH, SHOWING SURFACE CARBURISATION AND DECARBURISED LAYER. × 25.

Interdendritic Weakness.

Cracks such as are revealed by X-ray examination (Figs. 2 and 3) and shown in the macrosection (Fig. 8) are frequently localised in the interdendritic segregation. These regions would remain fluid and plastic longer than the surrounding materials and would form surfaces of weakness at high temperatures, along which cracking would be likely to occur under the influence of tensile stresses set up by the resistance of the sand to the contracting casting and by unequal sections in the casting itself. Fig. 21 is a photomicrograph of the region round one of these cracks, polished and etched with Stead's copper-reagent. It will be seen that the copper has not deposited on the material immediately round the crack, indicating that this contains segregated impurities which are extremely weak at high temperatures. That actual interdendritic separation may be present in the casting is shown by the fracture of the tensile test-piece (Fig. 22), in which a flaw showed the contours of the dendritic surfaces. In this way arises the serious defect known as "hot-tear" or "pull." The recent work of Körber and Schitzkowski* has confirmed that these cracks occur during cooling down of the casting after freezing, in the region of 1,350 deg C. If the stresses which

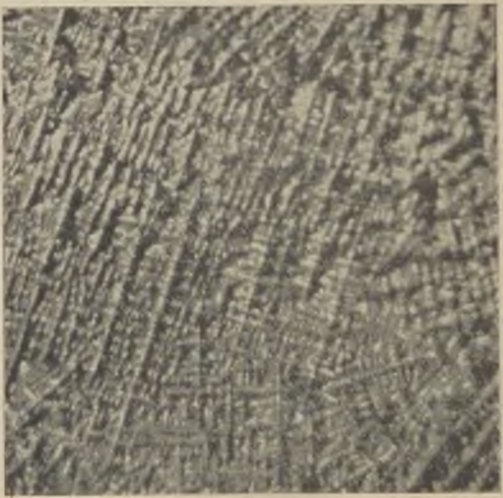

Fig. 20.—Photograph, showing Dendrites in Relief on Surface of Cavity. × 10.

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* Stahl und Eisen, 1928, *48*, 129 and 172; F.T.J., 1928, *39*, 47.

give rise to hot-tearing are to be minimised, the sand of the mould must be loosened before the casting has cooled to this range, that is, within 3 to 5 minutes of the finish of casting. Since the hot-tears arise in the segregated material, considerable improvement is obtained by using a purer metal. This explains the relative freedom from such cracks of electric-furnace refined-steel as compared with converter metal. In particular, the steel should be as free as possible from sulphur, phosphorus, and oxygen, which are the chief offenders.

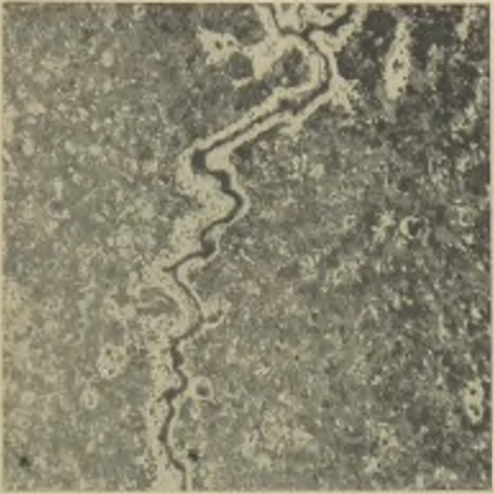

Fig. 21.—Photomicrograph of Copper-Etched Specimen, with Crack in Segregated Region.

Further Explanations of the Radiographs.

Reverting to Fig 1, the cavity has already been considered. The edges of a long chaplet are outlined by faint horizontal parallel lines of less density, indicating slight discontinuity. The two stems of the chaplet are outlined by rough dark circles, caused by the coating on the chaplet of some heavy metal (probably tin or lead-zinc) which is more opaque to X-rays than steel. The scattered dark spots along the chaplet probably arise from the same cause. The dark shadow at one end is due to a heavier section of the casting. The white spots are small voids, possibly blowholes, and the black square marked with the letter " C " is a lead index-mark attached to the casting for identification purposes. The radiograph (Fig. 2) shows a network of fine transverse cracks, which caused copious leakage from the walls of a hydraulic cylinder, although the defects were not noticeable on a superficial inspection. Fig. 3 shows circumferential cracks or hot-tears near a change of section in the same casting. Fig. 4 is a radiograph illustrating a possible danger in the use of temporary brackets or fins to strengthen a change of section with the object of avoiding " pulls." This has had the effect of localising cracking at the end of the brackets, which were ended-off too abruptly. A similar type of crack can be caused by a heavy chill, applied with the object of improving the soundness of thicker sections, if the chill is not tapered off sufficiently at the edges. Fig. 8 shows a macro-section through the transverse cracks similar to those shown in the radiograph, Fig. 3, and just to the right of the crack can be seen several bright

FIG. 22.—FRACTURED TENSILE TEST PIECE, WITH FLAW SHOWING OUTLINE OF DENDRITES.

streaky segregates which form likely paths for the formation of cracks at high temperatures.

The "Chill" Effect.

A peculiar surface effect is often noticed in sections of steel castings, illustrated in the sulphur-print, Fig. 7, and in the ink-prints, Figs. 10 and 11, as a layer of material differing in macrostructure from the interior of the casting. This layer is often separated from the interior by a layer of purer material, shown in the ink-macroprints as a white line. In Fig. 10 this line separates the V-segregated interior region from the surface layer. In Fig. 11 the line is crossed by columnar dendrites. Although this "layer" effect is probably connected with the slight chilling-action of the sand-mould, no complete explanation has yet been offered to account for it.

Conclusion.

Some features of the structure of steel castings have been discussed, but it is not considered to be within the scope of this Paper to indicate or suggest radical modifications of the methods of casting designed to overcome some of the defects which have been illustrated. Although steel-founders have devoted much time and study to investigating the problem of securing the best-possible castings, it remains an ever unsolved problem in view of the continually more exacting demands of the engineer. The only hope of continuing to meet these demands is by intelligent application of the results of critical examination carried out on lines such as those suggested in the present Paper, coupled with practical observations made in the foundry.

DISCUSSION.

The President expressed regret that so little time was left for the discussion on this Paper, and he asked those who desired to discuss the Paper to communicate their comments in writing. He said that he sincerely hoped that this course would be followed, because the efforts of authors who prepared Papers were greatly appreciated and this subject in particular was of special importance.

Unfortunately, in the complete examination of steel castings one had generally to wait until the casting was scrapped. If some means could be devised which would enable a casting to be thoroughly examined before despatch, it would be an extremely useful thing. Such means may be within the scope of X-ray examination. He had visited the Research Department at Woolwich and had witnessed one or two demonstrations showing what could be done in that direction. He thought it well to say, however, that we must not be too hopeful, because it appeared to him that there is a long way to go before this test could be accepted for routine purposes in workshops or foundries. It would seem to require a body of men trained in foundry practice to get the best results from this method of examination. Where new designs of castings are concerned, it might be that good use could be made of the method of examination by X-rays. He understood that the greater part of the work done so far had been done on parts which were known to be defective or in which a defect was anticipated, and the location of the probable defect indicated beforehand. Whether X-ray examination would ever become practicable in the foundry for examining large and intricate castings generally he would not venture to say. Nevertheless, it was steadily advancing as a method of investigation, and some very good prints had been obtained.

Mr. H. O. Slater said the Paper was so important that he thought a little time ought to be given to the discussion of it. He asked the author whether he had had any hand in designing the brackets on the casting to which he had referred, or whether they were put on by the founder according to his own ideas of eliminating cracking. He was wondering whether there was any relation between the number and size of the brackets and the thickness of the metal, because he remembered the case of a steel casting upon which 30 brackets had been found sufficient to prevent cracking, where a far greater number, of different dimensions and differently placed had been unsuccessful. Had the author found any difficulty in this connection in similar cases?

The **Author** said that in the case referred to, and in most cases, all the brackets were placed by the maker of the castings, who was given freedom to place brackets and similar additions where he thought they would prevent defects. He had no doubt Mr. Slater was quite right in suggesting that the cracks in this particular case were due to incorrect proportioning of the thickness of the brackets to the thickness of the casting. If that had been given attention the cracks would probably not have occurred.

Mr. Slater said his point was that the practical man might be able to prevent a casting from cracking by judicious use of brackets, easing coremaking, etc.

The **Author** agreed, and said that was a condition which X-ray examination was intended to remove. In the case in point, the crack had produced another defect in a different position, and, although this latter was not such a dangerous one, the casting would have been rejected because of it.

Mr. J. T. MacKenzie (A.F.A.) remarked that in the case of a high-pressure boiler in the United States, the specification called for X-ray examination of each individual casting.

Mr. H. A. Schwartz (A.F.A.) said that had been done in many cases in America and particularly with oil stills. For small castings it was a very satisfactory method.

The **President** agreed that for small castings X-ray examination was very useful, but the difficulties he had suggested were in regard to large castings. He was wondering whether the defects mentioned in the Paper had been found independently by those making the X-ray examination, or whether they had been prompted as to where to look for the defects in castings which had been rejected. In the case of a large and intricate casting, he assumed it would take a very long time to explore the whole of it by means of X-rays to ascertain if there were any internal faults before such a casting was put into service.

On the motion of the PRESIDENT, seconded by MR. J. E. FLETCHER, a cordial vote of thanks was passed to the authors of the Papers read at the Congress and to those who had taken part in the discussions. The President said it was lamentable that so short a time was available for the discussion of the many important Papers presented. The result had been that some of the Papers were not discussed to the extent they warranted. He earnestly asked that anybody who was in the position to do so should contribute his quota by written communication, so that the record of the Paper and the discussion thereon might be as complete as possible.

THE VOCATIONAL TRAINING OF FOUNDRY WORKERS, FOREMEN AND ENGINEERS IN BELGIUM.

(Presented on behalf of the Belgian Foundrymen's Association.)

The following notes give an account of the efforts made in Belgium to solve the problems of vocational training, the importance of which is fully recognised by the leaders of the foundry industry.

I.—Boys who are desirous of taking up moulding as a trade are afforded facilities for systematic training at the following centres:—(*a*) The Labour University of Charleroi; (*b*) The School of Mechanics at Liege (as from 1930); (*c*) The Apprentice Section organised at the Works of the "Compagnie Générale des Conduites d'Eau" of Liége; (*d*) Sections similar to that mentioned above created by important works at Ghent; and (*e*) The Vocational Training School at Verviers.

II.—Qualified young moulders desirous of completing their technical training can attend: (*a*) The Sunday Courses of the Liége School of Mechanics; (*b*) The Courses organised by the Malleable Foundry Owners' Federation of Herstal; (*c*) Evening courses organised by the Labour University of Charleroi; and (*d*) Correspondence courses organised by the Foundry Institute, of Liége, which are also available to foundry foremen and managers.

III.—The Labour University of Charleroi is considering the development of its vocational section with a view to training foremen.

IV.—Foundry managers are trained at the Arts and Crafts School of Pierrard-lez-Virton.

V.—Finally, the Foundry Technical Association of Belgium, a large organisation embracing foundry technologists of all grades, from the humblest to the most eminent, is making great efforts to cultivate the vocational ability of all its members, to encourage enterprise and to maintain a very high standard of technical ability among all its members.

The Vocational Training of Moulders at the Labour University.

The Labour University affords facilities for the vocational training of moulders at its:—

(*A*) Day-time Vocational School; and

(*B*) Evening Classes.

Day-Time Vocational School.

Object.—The training of apprentices likely to qualify rapidly as competent moulders.

Conditions of Admission.—Age 13. Must have attended elementary school for 6 years.

Duration of the Complete Course of Training.—Three years.

Training.—This is of a general, technical, vocational and educational character. The complete course is divided as follows:—

First Year.—The courses are common to all the sections of the day-time vocational school, the weekly division of time being as follows:—General and educational courses, 16 hours; drawing lessons, 5 hours; and practical and technical foundry work, 24 hours.

Second Year.—Students who have completed the curriculum for the first year are divided into two different sections according to their capacity. The first, or so-called "Industrial Section," consists of those students who have shown the greatest degree of ability; the second, or so-called "Vocational Section," is composed of students who have shown no great aptitude for theoretical study.

In the Industrial Section, the weekly timetable comprises 22 hours devoted to theoretical courses and 24 hours employed in practical work. while in the Vocational Section 5 hours per week are given to general and educational classes, 8 hours to technology and drawing, and 35 hours to practical work.

Third Year.—Apart from the Industrial and Vocational Sections attended by second year students who will normally continue their training in the third year, there is a third or so-called "Special Section," consisting of pupils who have shown special ability and desire to prepare for the Special Technical Engineering School.

The third section no longer deals with the training of workers as such, as it is designed to give students a first year's preparation with a view to joining the Special Technical Engineering School, the main object of the curriculum being to assist in the general training of the pupils.

Students holding certificates issued by the various Sections of the Day-time Vocational School may complete their vocational and technical training at the Labour University, because while the pupils who hold a Vocational Section certificate are admitted to the evening continuation-classes, those holding Industrial Section certificates are admitted without passing an examination to the Higher Industrial School where, after four years' further study, they can obtain a diploma as qualified technicians in their particular speciality.

Scheme of Theoretical Courses.

French.—Tuition in the mother-tongue, having as its object to enable pupils clearly to express their own thoughts, to draw up reports on matters related to their trade, and clearly to understand the ideas expressed by others. The courses include reading, talks, grammatical exercises in conjunction with selected readings and texts in which the talks are summarised, and training in the writing of essays and reports dealing with various subjects, such as the inspection and reception of materials, complaints, etc.

Mathematics, Arithmetic and Algebra.—The course is framed so as to train workers in working out sums with accuracy and readily solving the problems which they may encounter in everyday life and in their particular trade. The theoretical tuition is limited to essentials, while the algebra course is intended to enable workers to make adequate use of formulæ (or handbooks containing formulæ) and understand technical demonstrations.

Geometry.—Geometrical forms are always referred to actual machinery parts or castings, and, when necessary, the application of the geometrical properties of the casting is emphasised so as to show pupils the necessity of the pure sciences.

Physics and Chemistry.—These courses deal more particularly with the principles which are being constantly applied in the daily practice of moulding.

Electricity.—As in the case of physics and chemistry, tuition is again confined to the principles applied in ordinary industrial practice, and deals only with what should nowadays be familiar to every qualified worker or foreman engaged in any trade where electricity is employed.

Drawing.—In the first year, one teacher simultaneously instructs the students in geometry, geometrical projection and vocational drawing. The subjects are judiciously divided, all applications being carefully studied so as to emphasise the properties studied. Sketching exercises are graduated with particular care and chosen so that the drawing of the plan or outline of each casting may involve the practical application of the geometrical figures and principles of projection that have been studied previously.

Technological tuition regarding the particular part shown to the pupils is also given at the same time. Thus in the case of a packing-gland, for example, the teacher gives tuition in:—

(1) Sketching (technique of draughtsmanship and rudiments of technology); (2) drawing on the board (use of T-squares, try-squares, etc.); (3) setting out work on tracing boards, and (4) marking out for machining (use of the marking gauge, mechanical marking). Drawing is thus taught in a manner which is simple, easy, progressive, attractive and educational.

In the first year, tuition is essentially collective.—The teacher always explains the theory and the outlines and elements of projections, but the practical exercises are arranged so as to allow students to exercise increasing initiative, but always in proportion to the knowledge acquired and the degree of individual advancement.

First Stage.—The first practical exercises are drawn on the blackboard by the teacher, who makes a detailed and systematic analysis of the casting; the students reproduce the plan in pencil, but with the use of instruments, in their notes-books, strictly following the instructions given. This is intelligent copy-work.

Second Stage.—Commencing with the first half-year, the teacher's first lessons are limited to the general technological rudiments, to an analysis of forms and to the solution of difficulties as they arise (geometrical drawing). After this, the pupils have to make a sketch in their note-book of the casting which is handed to them, while two or three of them execute the work on the blackboard. The work is then criticised by the whole of the class under the direction of the teacher, and the pupils rectify their notes in the light of the remarks and observations made. A fair copy of the sketch is subsequently made, either in the class-room or at home.

Third Stage.—The last lessons are devoted to individual tuition, the pupils being allowed a great measure of personal latitude but the main principles of the method are observed. After one year's tuition on the above lines, pupils are able to sketch simple parts, draw the plans for these, reason out and make practical use in the workshop of the usual geometrical outlines and technological rudiments acquired in the drawing classes.

Teaching Equipment.

To give such tuition as is described above the teacher has at his disposal:—(1) A number of identical and judiciously selected wooden or metal patterns (one for every two pupils); (2) a wooden pattern of large dimensions, which can be taken to pieces if required, so as to give practical demonstration of the individual components of the part; (3) a rough casting; (4) a completely-finished casting; (5) patterns and core boxes used in practice, and (6) the equipment required for imparting the technological rudiments (setting out tools, etc.).

Second and Third Years.

In the two subsequent years, students are given tuition in foundry draughtsmanship of a more advanced character. It has been truly said that drawing is the language of the craftsman. It is necessary, therefore, that the craftsman should be able to make use of it whenever occasion arises, not only in the execution of his work, but also in his relations with his chiefs, his equals and his subordinates.

The moulder must accordingly be able accurately to express his ideas regarding moulding and pattern-making by means of adequate drawings, and to prepare diagrams and sketches of the tools which he will require to use for his work. Exercises in foundry draughtsmanship must therefore consist in the reading of plans and the adjustment on the drawing boards of ideas relative to pattern-making and moulding. At the Labour University, this tuition is given by the "apprentice master" of the Pattern-making Section, assisted in the technological part by the "apprentice master" of the Foundry Section.

The study of any given casting comprises:—(1) Plan-drawing of the casting (exercises in sketching and plan-reading, according to the degree of advancement of the pupils); (2) working drawing of the pattern (showing any loose parts and other peculiarities), and (3) complete study of moulding, including the diagrammatic representation of the various phases of the work, location and shape of the runners, risers, etc.

Amongst the principal subjects studied by third-year pupils in the draughtsmanship classes last year one may cite the following:—Lathe beds, grinder frames, grinding machine and lathe headstocks, bench feet, grooved pulleys, flywheels, sundry sweeps, etc. It should be noted that all the above studies deal with work subsequently produced in the foundry, and that the tuition in foundry draughtsmanship is intimately bound up with practical work in the shop.

Foundry Technological Course.

Instruction in foundry technology is entrusted to two teachers, one of whom is the " apprentice master " of the section, the other being manager in charge of the foundry of a large works in the district. The " apprentice master " gives practical instruction in the craft and everything relating to the material aspects of the trade. His instruction is given exclusively in the workshop, during the practical carrying on of the work. This is suitably selected so as to present all the difficulties usually encountered in ordinary moulding, coring, moulding with patterns that can be taken to pieces, strickle moulding, linear, circular, oval, pit moulding, etc.

FIG. 1.

As regards the manager's tuition, this deals exclusively with the technical and scientific aspect of the craft. His teaching deals chiefly with the following:—

(I) *Study of Sands*, their composition, quality, tests, uses; the use of coal-dust in green-sand and dry-sand moulding and in coring; the study of special sands, incorporating manure, clay wash, coke, silicious and bonded sand, with a study of certain binders, and the use of such materials in ordinary mould coring. Apparatus used in the preparation of sands; critical study of the various types of apparatus: principles, utilisation, advantages and drawbacks. Miscellaneous materials used in foundry work: mineral blacking, vegetable blacking, plumbago or graphite, black-wash, coke blacking, etc.

FIG. 2.

(II) *Casting.*—General conditions for successful casting.

Study of casting in regard to:—(*a*) The preservation of the mould; (*b*) the question of slag and dirt, and (*c*) uniform cooling.

(*a*) *Preservation of the Mould.*—Study of the pressures in the various methods of casting. Position of the runner.

(*b*) *Slag and Dirt.*—Origin, analysis and consideration of the different cases; means utilised to prevent dirt from penetrating the mould:—(1) Stopper type of pouring basin ("German," number of small runners, and "basin" pouring); (2) decanting device with the mechanical elimination of impurities (German pouring with baffle (?), gyratory, tangential and "macaron" pouring); (3) filters (Brunelli, filterer, grain, circle of small runners, and "German" pouring); (4) the cause of holes: analysis, comparison and discussion of the interpretations given by the leading foundry specialists (Brunelli, Ronceray, Gougon, Mathu, etc.), and (5) the study of feeding heads, blind risers, risers, etc.

(c) *Uniform Cooling.*—Preparation of the moulds and casting operations with a view to ensuring uniform cooling. Use of chills and heaters; "chambering," and rapid exposure of heavy sections.

Fig. 3.

(III) *Defects in Castings.*—Causes and remedies.

Method of Instruction.

All the questions treated by the foundry manager-teacher are demonstrated by means of numerous experiments carried out in the workshops. Figs. 1 to 6 illustrate the methods of instruction. Fig. 1 represents 6 thin plates cast with a view to studying the part played by coal dust in sand. It is found, for instance, that the greater the quantity of coal used, the more rapidly is cooling effected, and it is thus shown that with plates cast in green sand containing coal-dust, one plate has rounded off edges, while in the case of another the mould is incompletely filled.

Fig. 2 shows two 400 × 400 × 5 mm. plates, one cast with sand containing an excessive proportion of coal and plumbago, the other cast with sand free from added constituents. In the first case, the plate is perfectly free from sand, but has a cavity caused by a well-defined accumulation of plumbago. In the second case the plate is sound, but the sand is adhering firmly to it.

Fig. 3 shows ten 250 × 100 × 60 mm. blocks cast in green sands of different nature and composition. The remarkable differences observable in the appearance of the parts are analysed and discussed in the technological course.

Fig. 4.

Fig. 4 represents a group of six cast-iron 250 × 100 × 60 mm. blocks separated from one another by layers of sand, the thickness of which varies from 8 to 48 mm. This experiment was made with a view to studying the behaviour of thin sand layers surrounded by masses of metal. It should be noted that where the thickness was 8 mm., *i.e.*, between blocks 1 and 2, the sand yielded under the pressure exerted by the mould.

Fig. 5 shows a number of blocks obtained by means of runners, the diameters of which vary from 15 to 40 mm. This experiment was made in order to determine the most favourable section that can be adopted for casting a given part.

In Fig. 6 are a number of castings of different shapes, which were systematically studied in the foundry technological course, actual experiments

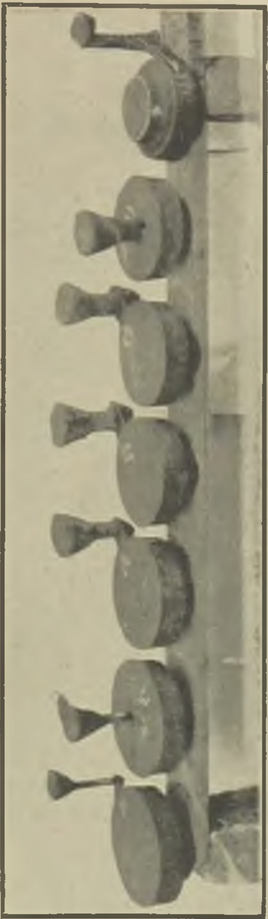

FIG. 5.

being carried out in the case of many castings. Considerable importance is attached to the study of casting processes, and this item in the moulder's technological trade course receives a great deal of attention on the part of the teacher. Instruction in this connection is both experimental and scientific.

Fig. 6.

Practical Work.

The following is the principle of the method of training for apprentices: Constant co-operation on the part of the pattern-makers and moulders. Close association of the drawing and the technological courses, with practical work in the shop. As an example, a study of the production of a lathe-bed will be outlined.

Preliminary Work.—(1) A lathe-bed already cast is sketched by two students—one moulder and one patternmaker (third year); (2) the plan is drawn; (3) consideration of possible moulding methods. Selection: the method is selected by the moulder and the patternmaker under the supervision of the teacher; (4) consideration of

FIG. 7.

the construction of the pattern and of the core boxes (see plans).

Production.—(5) Actual production effected in the schoolshops.

Inspection and Critical Analysis.—(6) After the casting has been actually made, it is inspected and subjected to critical analysis by the teachers and the pupils of both sections brought together, and (7) discussion of all peculiarities and defects noticed in course of manufacture by the marking, machining and inspection departments.

The Labour University has definitely abandoned the system of classical exercises, which is still held in great honour in certain vocational institutions, because whilst these studies may very well be carefully graduated they are devoid of practical value. The shops for vocational training constitute a works of medium importance, in which all the Sections operate for actual production. Consequently, all the foundry work produced there from the first-year is of practical utility. All the parts moulded are cast and subsequently inspected by other departments of the establishment.

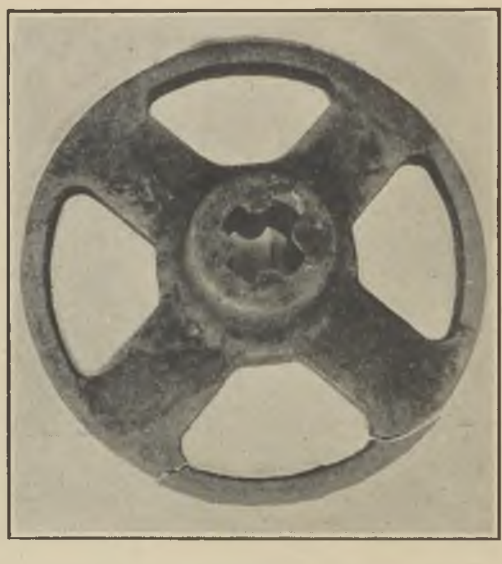

Fig. 8.

Every casting or set of castings is the result of a regular order, and production is carried on under strict supervision, just as would be the case in a modern, well-organised commercial foundry. Every piece of work produced by the pupils is awarded marks in respect of the time taken for moulding, also for the finish of the mould and that of the actual casting.

Students are instructed in the moulding and casting of iron, steel, bronze and light alloys. After casting, each pupil must get his castings together, make a critical study of them, and fill up cards, a model of which is shown in Chart I.

CHART I.

Province de Hainaut

UNIVERSITÉ DU TRAVAIL Cast on the...............19....
Charleroi.

CRITICAL STUDY OF THE PARTS CAST.

Name of part :.......................... No................

Moulded by.................................

Cast by.......................................

Analysis made by......................

1. TYPE OF MOULDING..............................

....

2. CORE MAKING ....

....

3. METHOD OF CASTING ....

....

Defects noticed.	Probable causes.
....	....
....	....
....	....

Recommendations :

....

....

....

These cards are analysed and criticised in the course of a lesson in which the foundry manager, the foundry and moulding apprenticeship assistant-master, and the student-moulders and pattern-makers all take part. The principal defects are photographed and prints are given to the pupils, who have to append such prints to the cards filled up by them. Figs. 7, 8, 9 and 10 illustrate the procedure.

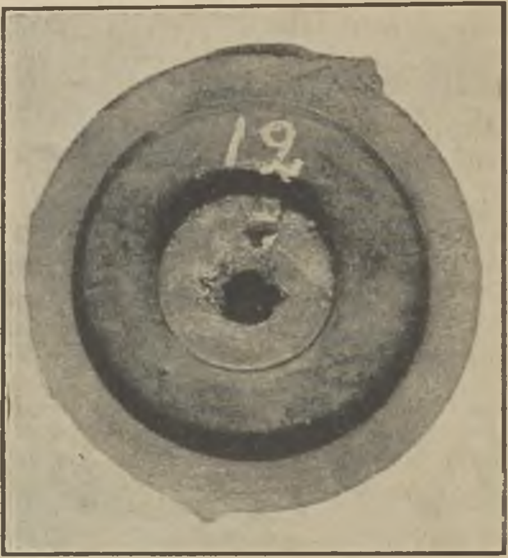

Fig. 9.

In the third year, the pupils who are being trained as moulders are given instruction in the production of pattern-plates of different types. Here again, far from being produced at random, the plates are made so as to comply with actual production requirements. Several of such plates made in the course of the school year just elapsed are detailed in a later section of this Paper.

Evening Vocational Courses.

The evening vocational courses constitute one of the divisions of the Labour University, their object being to enable apprentices and workers employed in local industrial concerns to complete their vocational training. The normal duration of the foundry classes is 3 years. To be admitted, students must be at least 14 years of age, have had a complete primary education, and been in the trade for not less than three months.

Fig. 10

First Year.—The times devoted every week to the various subjects taught are as follows:—Mathematics and geometry, 2 hours; drawing, 2 hours; vocational technology, 1 hour, and practical work, 4 hours.

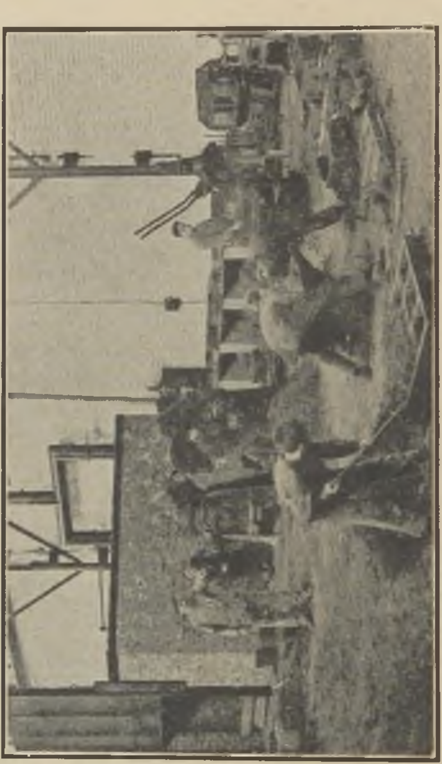

FIG. 11.—MOULDING SHOP AT THE LABOUR UNIVERSITY, CHARLEROI.

Second Year.—Drawing, 2 hours; technology, 2 hours, and practical work, 4 hours.

Third Year.—Technique of foundry work, 2 hours; moulding, 5 hours; practical work, 4 hours, and social education, 1 hour.

Students having obtained their diploma can attend the advanced foundry-courses which will be shortly organised at the Labour University. The theoretical and practical instruction given in the above course is conceived absolutely in the same spirit as that governing the Day-time Vocational School, duly taking into account, on the one hand, the difference in the general education of the students, and, on the other hand, their age and initial practical knowledge.

Plant.

The foundry run by the Labour University comprises the following plant: A cupola having a 30 cwt. per hour capacity, which can be used for the production of cast iron or steel, as required. This furnace feeds a ½ ton converter.

A second ½ ton per hour cupola is used for the production of medium-sized castings for experimental purposes. This furnace was in fact specially constructed with this end in view, and it makes it possible to carry out research work in connection with semi-steel mixtures, the heating of the hearth, the study of combustion, the analysis of the gases, the study of temperatures in the different zones, etc. Other equipment includes drying stoves and a modern shop for the preparation of sand; a series of pit fires for melting bronze and other alloys; several moulding machines, and a machine for removing sand from castings. Mechanical handling is effected by means of a 5-ton electric overhead crane. Figs. 11, etc., show various views of the Labour University.

Communal Vocational School of Mechanics at Liège.

The Vocational School of Mechanics was established in 1902 upon the initiative of industrialists in the metallurgical district of Liège. The practical Sections at present organised are as follows:—Fitting, erecting and machine shops, forge and pattern-shop.

Want of available space has made it impossible to organise the foundry section, the necessity for which has long been recognised by the Administration of the School. A room about 27 metres long by 15 metres wide has accordingly been set apart for the foundry section in new premises, the construction of which has just been commenced by the City of Liége. These will be ready in 1930.

In view of the impossibility for the time being of establishing a well-organised foundry section in connection with the day-time school, and recognising the urgent necessity of doing something towards the vocational training of competent foundry workers, the mechanics institute in 1915 organised a foundry technology course, which is held every Sunday morning, from 8 to 12 a.m., in the winter months. This course, which takes two years to complete, is open to moulders whose ages rank from 18 to 25, or even to older men in certain cases.

Notwithstanding all the efforts made, this foundry course is not sufficiently well attended. Moulding as a trade has gradually grown in disfavour amongst the younger members of the working classes, who prefer to take up trades which are either more fashionable (such as automobile or electrical engineering) or cleaner (fitting, pattern-making, machine-tool minding). The evil is a real one, but the demonstration foundries which make rational training possible, and have met with such conspicuous success at Charleroi and Verviers, give the City of Liége every hope of a greatly improved attendance in the future.

Foundry School organised by the "Compagnie Générale des Conduites d'Eau" at Liége.

This School, which was founded in 1927, provides for theoretical and practical instruction extending over a period of three years.

I.—Theoretical and Practical Courses.

Classes are held for eight hours every day, either one, one and a-half, or two hours of which time are devoted to theoretical instruction, the remainder being occupied by practical instruction. This is given in two shops, one for moulding and one for pattern-making, according to the special line chosen by the apprentice. But all students must attend every theoretical course, irrespective of the speciality selected.

(*a*) *Theoretical Courses.*—The object and tendency of these courses is to give the apprentice some general training and such instruction as will be sufficient to enable him to qualify as a worker of outstanding ability. Both in the selection of the subjects taught and in the mode of their presentation, great care is exercised to avoid anything which could give the pupil the dangerous illusion that he will become a scientist in a small way. This is indeed a peril that must be eliminated, because apart from pedantry which is so highly undesirable in itself, it would tend to awaken in the student the desire to give up manual work, and have the two-fold disadvantage of frustrating the object of the foundry school—which is to succeed in training good and competent workers—and of turning the apprentice into a sort of *déclassé* for whom the future might have painful disillusionments in store.

The object of the theoretical courses is to develop the pupil's critical capacity, sagacity and intelligent judgment quite as much as—if not more than—to impart the rudiments which are the subject-matter of the courses. The instruction also embraces everything calculated to favour the development of a "professional conscience" in the apprentice. It is thus seen that moral education, intellectual training, and the acquisition of useful knowledge constitute the three main objects pursued by this theoretical tuition.

In the first two years, instruction is given in drawing and geometry, patternmaking, scientific rudiments indispensable in foundry work, French and arithmetic. The third year curriculum, which is not to be organised until October, 1929, will be designed merely to develop the pupil's knowledge of the above subjects.

(*b*) *Practical Courses.* — Practical instruction is given in two separate workshops (patternmaking and moulding), in accordance with the special line chosen by the apprentice. During the first two years, the students are not brought into contact with the men employed at the works. In the third year (regarded as a transitory period during which the pupils are expected to adapt themselves to factory life) they are placed in various departments of the works and put under the charge of foremen, while still remaining under the authority of the school instructor (who must see that each apprentice duly continues his vocational education), and also under the vigilent supervision of the principal of the school, who will thus be able to guard the pupils against any detrimental influence exerted by the older men.

This practical instruction continued over periods which vary according to the circumstances of each pupil individually, and, as directed by the principal of the school, has for its sole aim the quality of the work without any regard to rapidity of execution. When the pupil has attained a sufficient degree of proficiency, he is encouraged to execute the work more rapidly by the payment of a bonus. Rapidity of execution, however, is taken into consideration only if a sufficiently high standard is maintained in the quality of the work.

Remuneration of Apprentices.

This remuneration consists of a basic wage, as fixed by the regulations, in respect of each of the three years. The maximum rates may be exceeded in the case of apprentices showing exceptional ability. To the basic wage are added monthly premiums, calculated in proportion to the number of marks awarded in any one month at the theoretical and practical courses. These premiums may be as high as 30 per cent. of the basic wage. In addition, a fixed premium is payable (1) upon the signing of the apprenticeship agreement; (2) at the end of each year of school attendance; and (3) two years after the completion of the apprenticeship, if the worker is still employed at the works. Finally, prizes are also awarded at the end of each year of school attendance.

Apprenticeship Agreement.—This agreement must be signed by the apprentice and his parents at the end of the first period of three months. The agreement is worded as follows:—

Apprenticeship Agreement.

Between the undersigned:—

(1) The "Compagnie Générale des Conduites d'Eau," represented by Mr. ——, Principal of the aforesaid Company's Foundry School, of Quai de Condroz, Vennes, Liége, of the first part; and

(2) Mr. ——, acting in his own name and in the capacity of father (or guardian), of the second part.

IT HAS BEEN AGREED AS FOLLOWS:—

Art. 1.—The contracting party of the second part gives on behalf of his son (or ward), , an undertaking to the effect that his son (or ward) shall undergo training as apprentice for a period of three years as from at the aforesaid Company's School.

Art. 2.—He also undertakes to cause his son (or ward) to comply with the clauses of this Agreement and to perform all the apprentice's obligations and duties towards the management of the works and the school authorities, and more particularly:—(1) To show due regard and respect to all persons in authority; (2) to devote himself with assiduity to the acquirement of such knowledge, both theoretical and practical, as is obtainable from the courses; (3) to comply with all the regulations of the school; and (4) to deport himself honestly and respectably.

Art. 3.—On its own part, the Company undertakes to ensure that the apprentice signing this Agreement shall be given such vocational training as should be possessed by a competent moulder or patternmaker.

Art. 4.—Any accident befalling the apprentice shall be dealt with in conformity with the provisions of the Belgian Workmen's Compensation Act of December 24, 1903.

Art. 5.—In addition to the basic wages and the premiums set out in the School's regulations, the Company shall pay the apprentice signing this Agreement a premium of 2,200 fcs. The said premium shall be payable as follows: 250 fcs. at the end of the three months' trial period referred to in Art. 6 hereof, if the apprentice is deemed to be fit to continue attending the courses; 250 fcs. at the end of the second year; 700 fcs. at the end of the third year, provided always that the said apprentice be still a member of the School at the aforesaid times. Moreover,

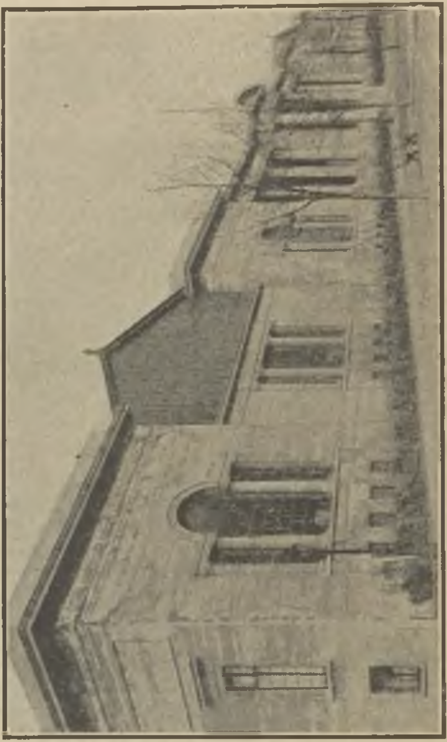

Fig. 12.—Exterior View of the Labour University, Charleroi.

a sum of 1,000 fcs. shall be allowed to every student who, after due completion of three years' attendance at the School, shall have continued in the Company's employ for another two years.

Art. 6.—This Agreement may be rescinded by either party within three months after the signature thereof, subject to 15 (fifteen) days' prior notice. This Agreement may also be determined at any time and without prior notice in the event of serious breach of any of the obligations arising out of its clauses. The fact that an apprentice has failed to obtain half of the marks obtainable for a period of two consecutive months may be treated as a serious breach.

Art. 7.—The apprentice's basic wage shall be at the rate of one franc per hour initially, and increase up to three francs in the case of third-year pupils. The actual increase shall be proportionate to the degree of ability shown by the apprentice. All time spent in theoretical study shall be paid for at the same basic rates as for the time devoted to practical tuition. In addition to his basic wage the apprentice shall, in conformity with the School's regulations, receive a monthly premium calculated on the number of marks obtained by him. The said premium may amount to as much as 30 per cent. of the basic wage. The above rates may be increased in the case of specially deserving pupils, if approved by the Principal of the School. Apprentices will never be required to stop work apart from causes of *force majeure*, such as general suspension of work in the Company's general foundry or pattern shops.

Made in duplicate in ....

Signature of the Apprentice's father or guardian.

For the Compagnie Générale des Conduites d'Eau:

....

DECLARATION BY THE APPRENTICE.

I, , apprentice moulder or patternmaker, hereby declare that I was present when this Agreement was read over and signed, that my attention was particularly directed to the apprentice's obligations and duties specified therein, and that I undertake to perform the said obligations and duties faithfully and loyally.

....

Apprentice.

Teaching Corps.

This consists in the first place of two instructors, who direct the practical work carried out in each of the workshops. The theoretical courses (with which the practical work must be brought into harmony) are conducted by members of the Company's staff, who, by reason of their respective functions, have an expert knowledge of the particular branch taught. In connection with each course there is also an examiner occupying a higher position on the Company's staff than the regular teacher, who gives the latter general directions and sees that his instructions are duly carried out. Finally, the school's principal co-ordinates the whole of the work and exercises a sort of benevolent guardianship over the apprentices, whose moral welfare and intellectual training is looked after by him. The Principal receives his instructions from the general manager as far as the technical side of the instruction given is concerned, and from the Staff Supervisor as regards questions of a moral and educational character. There is thus specialisation in the lower ranks of the teaching body, co-ordination by the principal, and mutual control to prevent the training given from being of a " bookish " nature. To prepare the apprentice for his future life, " *non scholæ sed vitæ*," such is the object pursued, and everything contributes to the realisation of this aim.

The Vocational School of the City of Verviers.

The object of the foundry school is to enable owners to find apprentices, who have already received some measure of training, and also to enable engineering students to become familiar with foundry work. To be admitted students must be from 14 to 17 years of age, hold a primary-school education-certificate, enjoy a sound constitution, sign an apprenticeship agreement and effect a deposit of 50 fcs. as a guarantee for the equipment entrusted to each apprentice. Instruction is free in the case of

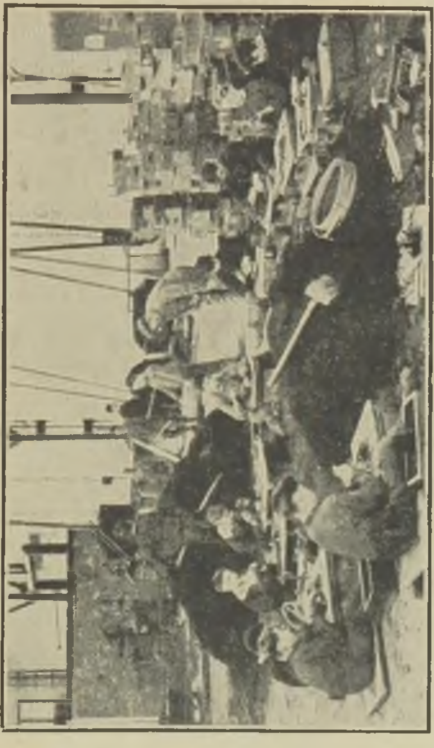

Fig. 13.—Class in Session, Labour University, Charleroi.

students living in Verviers, but those who live in other communes have to pay certain fees. In certain cases, some civic authorities make a practice of helping local young men to pay their fees.

The complete course occupies one year only, classes being held for 36 hours every week, of which time six hours is devoted to theoretical instruction, and 30 hours to practical work under the direction of a foreman moulder. Moreover, the pupils must attend the vocational school's evening classes. The foundry technological course is identical with that adopted by similar organisations. The actual castings produced are either marketed in the district, or used for local municipal works or in the School's engineering section. The installation consists of a moulding shop with cupola, moulding and core-making machines, drying oven, and tools for hand work. Another shop is used for sand-preparation purposes. The examination to be passed by the pupils on completion of the course comprises a moulding-operation with a pattern selected by drawing lots, and questions of a theoretical nature in connection with foundry technique. The pupils number about a dozen.

Courses organised by the Malleable-Foundry Owners' Federation of Herstal.

The Malleable-Foundry Owners' Federation, whose membership embraces all the malleable foundry owners of Herstal, acting on a suggestion made by its president, resolved in 1928 that an effort be made with a view to training and perfecting their foremen and operatives.

Pre-war Position.—In pre-war days, " hand-moulding " was almost the only method utilised at Herstal, and the local moulder was then thoroughly conversant with all the aspects of his craft. In malleable-iron foundries the work was apportioned among various teams, acting, more or less, as regular contractors and very frequently composed of the members of one family, each team consisting of one moulder, one " first lad " (core-maker), and one " second lad " (assistant labourer). No one could become a moulder without having gone through a long period of severe training extending over many years, as "second lad" at first, and subsequently as core-maker. The assistant labourers and core-makers were trained by the moulder, who devoted a portion of his time (frequently after regular working hours) to teaching his assistants what he was wont to describe as the " secrets of his craft." This method had the result of establishing a regular hierarchy among the workers; vacancies in the ranks of the core-makers were

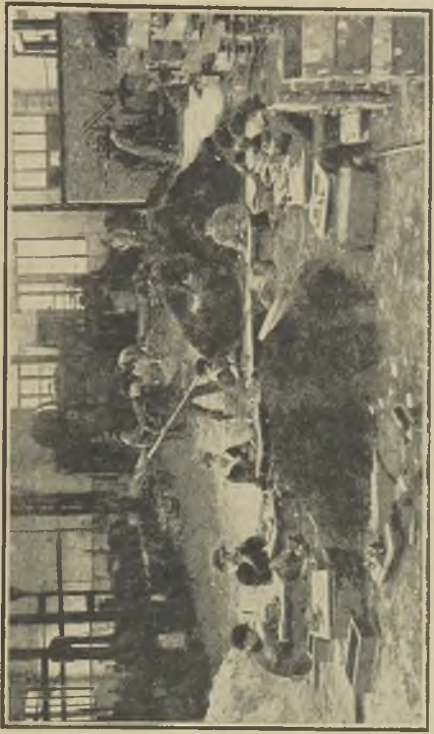

FIG. 14.—ANOTHER VIEW IN THE FOUNDRY AT CHARLEROI.

filled by the best "second lads," and the most competent core-maker would automatically take the place of the retiring moulder. This method of recruiting labour was extremely advantageous to the masters who, when required, were able to find qualified labour among the men already in their employ.

Post-war Position.—These efforts were reduced to naught as the consequence of the war, from 1914 to 1918; a number of men gave up the trade altogether and others gradually disappeared. The advent of moulding machines increased specialisation in production, and the eight hours' day, introduced after the Armistice, completely upset pre-war methods of work. It gradually became more difficult to find competent moulders, and the training of apprentices was completely arrested owing to the ever-increasing use of machinery and also owing to the unsettled state of the workers themselves.

Although it is evident that the new methods of work no longer necessitate the employment of competent workers in such large numbers as in pre-war times, it is nevertheless true that the hand-moulder is still badly needed in all malleable-iron foundries, were it only for the production of small castings and the preparation of "pattern plates."

The Problem that Confronted the Federation.—In view of the foregoing considerations, the Federation were faced with the following problem:—(1) How to obtain competent moulders by training young men at present employed in the foundries, whose knowledge is obviously below the standard that prevailed in pre-war times among the moulders; (2) how to encourage young men to join the malleable-iron industry by showing them the future possibilities afforded by this particular trade; (3) how to improve the standard, prevailing among labourers, by imparting to them some useful general knowledge of malleable-iron foundry work; and (4) how to propagate a spirit of observation and method among young operatives in the foundry trades. The above statement summarises the problems

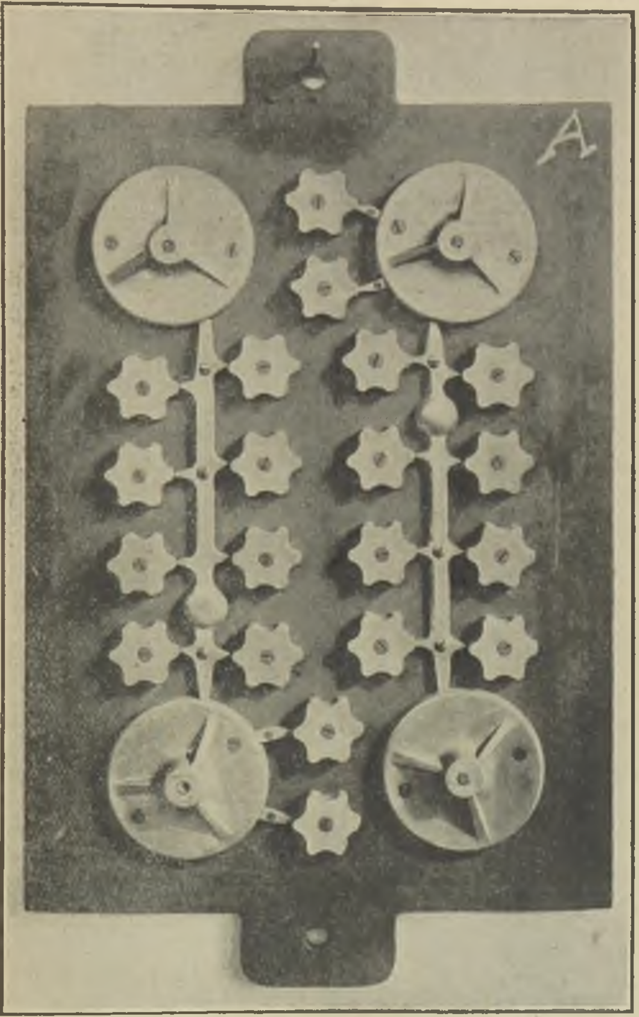

FIG. 15.

which the malleable-iron industry will have to solve as far as the recruitment of the necessary personnel is concerned.

Solution of the Problem.—To solve these difficulties in such a specialised centre as Herstal required courage, but the task was certainly well worth trying. The Foundry Owners' Federation almost immediately obtained the support of the workers' unions and of the Permanent Deputation, which latter body placed the Provincial Technical School premises at its disposal It was, of course, quite impossible to deal with such a vast project simultaneously in all its aspects, so that it was decided to organise in 1928-1929 a series of courses or lectures which all workers, young and old, foremen, foundry managers and owners, were invited to attend.

The main object of this procedure was to determine with accuracy both the extent and the quality of the attendance, and also to gauge what measure of interest would be evinced by those who were expected to attend these popular lectures. It was agreed, however, that there should be formed a special category for "regular students," recruited from the persons attending. Apart from fixing the minimum age at 18, no restriction was made as to the registration of the regular students. The principle of examinations was provisionally rejected, and it was resolved that scholarships should be granted at the end of the year to those students who had attended four-fifths of the lectures. The Committee decided that the courses would be held every Tuesday from 7 to 8.30 p.m., the first hour being devoted to a full exposition of the subject and the remaining half-hour to a general discussion. A summary of each course or lecture was to be handed to each of the persons attending.

The programme consisted of the following lectures:—(i) Inaugural address on "The History and Evolution of Malleable-iron Foundrywork," (ii) and (iii) the study of sands; (iv) the elements of moulding; (v) hand moulding (lecture given in the local dialect by a working moulder); (vi) the moulding of special castings (lecture given in the local dialect by a working moulder); (vii) the production of plaster casts; (viii) the manufacture of "pattern-plates"; (ix) the utilisation of "pattern-plates"; (x) moulding machines; (xi) core-making (lecture given by a working core-maker), (xii) comparative study of various melting methods; (xiii) raw materials for malleable iron, first stage; (xiv) core-boxes and core-making machines; (xv) the pouring of moulds; (xvi) raw materials for malleable iron, second stage; (xvii) annealing furnaces; (xviii) accidents and precautions; (xix) the control of production; tests; (xx) foundry wasters; (xxi) upkeep and maintenance of plant; (xxii) shrinkage and blowholes; (xxiii) Black-heart malleable iron; the future of malleable iron; and (xxiv) Taylorism in foundries.

The first 21 lectures were attended by 764 persons altogether, *i.e.*, 406 regular students and 358 others, which gives an average of 36 attendances at each lecture. The variety of the subjects treated and the fairly-advanced character of the courses were bound to bring about a certain falling-off in the attendance of regular students. Thirty-five regular students were entered at the first lecture, and after the twenty-first lecture there remained 17 students altogether, 10 of whom had attended four-fifths and 7 seven-tenths of the lectures.

The Foundry Institute of Liége.

The Foundry Institute of Liege, under the direction of Mr. Ivan Lamoureux, a retired foundryman, has created a correspondence course for instruction in the technical side of foundry work. The students are given a very complete course, issued in the form of a quarto volume, containing 270 pages of matter and 325 illustrations. The course is divided into 34 lessons, with 34 questionnaires. Each questionnaire is drawn up in such a form as to compel reflection and application of the lessons on the part of the pupil. The replies sent in by each pupil

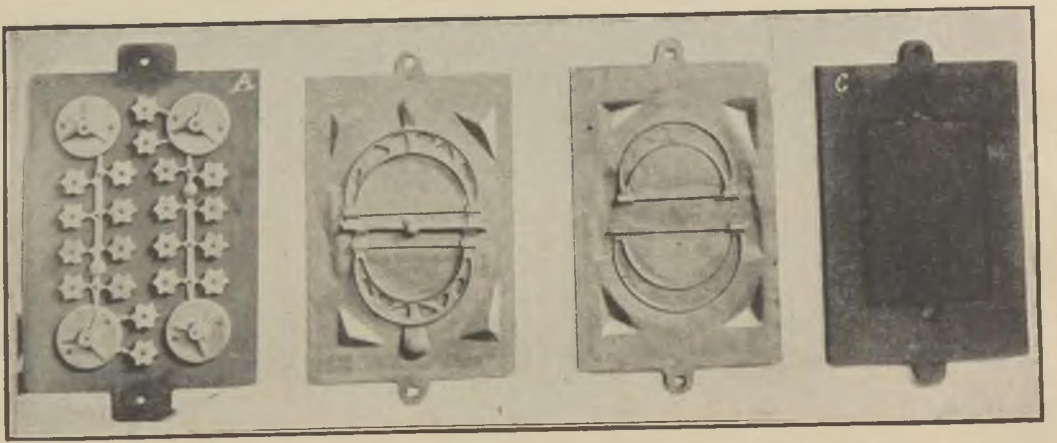

FIG. 16.

are corrected and commented upon by the Foundry Institute. The essential part of the instruction bears upon moulding practice. The normal duration of the course is one year. At the end of the course, the students have to pass a *viva-voce* examination at the Foundry Institute, and if they are deemed to have acquired a sufficient knowledge of the subjects taught, they are awarded a foundry technologist's certificate. The object of the Foundry Institute is to give technical training to managers, owners, foremen and workers living too far away from the various schools in existence to attend there, or having no time to avail themselves of the instruction given at certain centres. The Foundry Institute works in conjunction with correspondents in France, Spain and Italy, who cooperate in the distribution of its courses and in the propagation of technical knowledge in connection with foundry work.

The Arts and Crafts School of Pierrard-lez-Virton.

The Pierrard-lez-Virton Arts and Crafts School was founded in 1900 on the lines of similar training centres already existing in France, so that in the same manner as Châlons, Aix and Angers, Pierrard was equipped with a foundry, a pattern-shop, a forge and an engineering section. Its founders instituted bold guiding principles, which have been followed by the School up to the present day. Their intention was that the workshops should be organised on commercial lines, for they were convinced of the impossibility of producing practical operatives and production engineers if their training was directed only in order that their work might be shown at an exhibition held at the end of the year. The students are accordingly trained so that ultimately they may specialise in foundry work. This training extends over a long period, during which the students have to deal with every branch of the trade, such as sand preparation, core-making, moulding, cupola work, preparing the charge and the cleaning of castings for four hours a day for a couple of

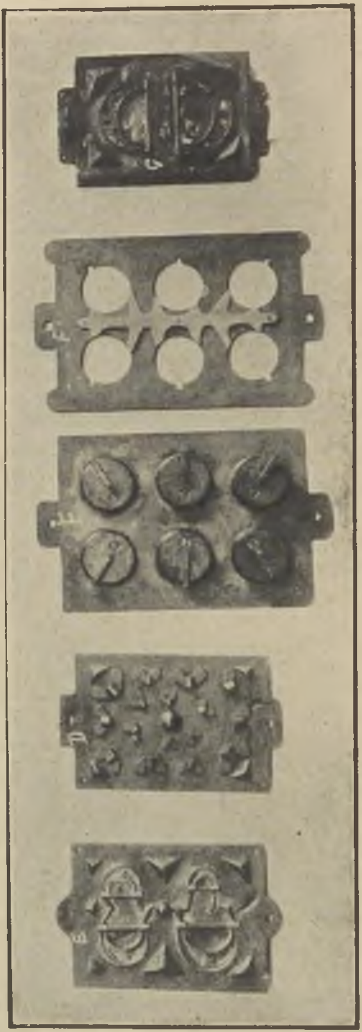

Fig. 17.

years, under the supervision of expert foremen having sufficient technical knowledge to enable them to apply in actual foundry practice the theories expounded in the lessons by the two graduate engineers. These lessons, among other things, deal with the calculation of mixings for cast iron and general organisation, also covering certain subjects such as casting, rate fixing, costing, etc. A course in metallurgy, conducted by a university-trained metallurgist, is provided for the purpose of giving a general technical training. Finally, laboratory work, attended by the students for half a day every week, complete the training received by the future foundry manager.

In order that the foundry may produce commercially, it is necessary that the students should have the practical assistance of experienced workmen, for it is evident that the work turned out by the pupils themselves cannot be remunerative. As a matter of fact, such is not the object pursued by the School, since the students attend in order to obtain training and not for gain.

The Arts and Crafts School has been able to furnish foundries in Belgium, France and the Congo with a number of well-trained foundry managers, who have proved a great credit to the School. The students themselves have also realised that special training in foundry work offers good openings for the future, and they are, accordingly, taking up foundry work as a speciality in increasing numbers. It is, therefore, proposed shortly to enlarge the School's foundry on up-to-date lines, while retaining the training principles and methods of instruction hitherto applied.

METHODS OF TESTING CAST IRON.

By A. Le Thomas and R. Bois.

[French Exchange Paper.]

The question of testing cast iron, which has so greatly interested foundrymen of all countries for several years, has long been studied by numerous investigators, but that agreement which is so desirable as to the choice of the tests to be adopted and the most suitable method of carrying out tests on castings has not yet been reached. Ought the tests employed to be tensile, shock, shear, static-transverse or hardness tests? Ought the test-pieces to be cast separately or taken from the castings?

The question at present is to ascertain how a machinery casting ought to be tested. One of the authors has already described his method,[1] which consists in applying the shear test or the static-transverse test to bars taken from the castings, or by ball-testing the castings themselves. The old method, which is upheld in opposition to this, is to carry out tensile, static-transverse and shock tests on bars cast separately.

In order to define their standpoint on the questions forming the subject of this Paper, the authors find it necessary to examine the views which are opposed to their convictions and which are for the most part contained in a Paper presented by Mr. J. G. Pearce, Director of the Cast Iron Research Association, to the Sheffield branch of the Institute of British Foundrymen. The search for truth on this subject, at present but imperfectly understood, demands, in fact, absolute freedom of judgment and an absence of all prejudice, and it is in this spirit that the authors have quoted a number of passages from Pearce's Paper for the purpose of criticising them.

The Choice of Mechanical Tests capable of Determining the Intrinsic Characteristics of Cast Iron.

The principal tests that occur to one when it is desired to study the properties of a sample of metal are the tensile, transverse, shock, shear, compression, torsion and hardness tests. All of these have been used indiscriminately for cast iron by experimenters, who, unfortunately, have not always considered the significance of the results of their tests.

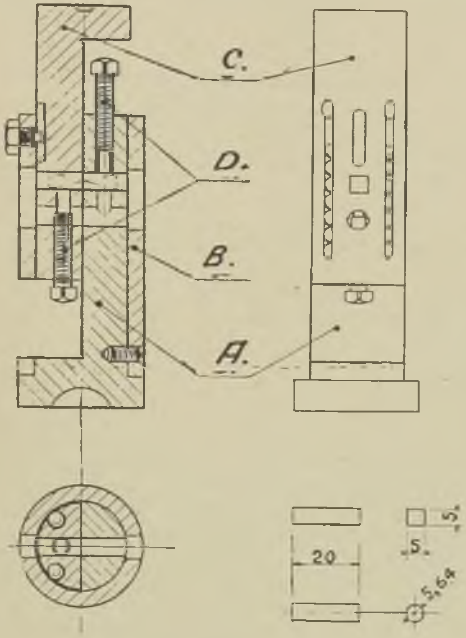

Fig. 1.

(A) Half-Cylinder Fixed in Socket; (B) Socket; (C) Free Semi-Cylinder; (D) Tightening Screw.

A brief review of the examination of the shock and tensile tests which Fremont and Portevin had absolutely condemned in the course of their work is given below. The force of habit and routine is so great that it is deemed necessary to give a short summary of their arguments, for nothing is more difficult to get accepted than evidence regarding original research, while the authors will be well satisfied if they succeed in reducing the too-large number of foundrymen who persist in their error.

Examination of the Tensile and Shock Tests.

The different mechanical tests at present in use provide a certain number of coefficients as shown in the following table[2]:—

Tests.	Elastic deformations.	Permanent deformations.	
		Resistance to deformation.	Deformation capacity.
Tensile ..	M*t* E*t*	R*t*	A
Transverse ..	M*f* E*f*	R*f*	*f*
Shear ..	Ec	Rc	—
Hardness ..	—	—	—
Shock ..	—	—	*a*
		p	

M indicates the moduli, E the elastic limits, R the breaking strength, A the elongation, *f* the transverse-breaking deflection, *p* the resilience, The tensile test should give the modulus of elasticity, the elastic limit, the breaking tensile strength and elongation at the point thereof. In the case of cast iron, however, as the elastic limit is almost the same as the breaking load and the elongation is almost nil, the only result, which the usual test can give, is the breaking strength. " The elastic deformations being very small (the moduli are something like several thousandths) they cannot be determined by this type of test except by having recourse to delicate processes (such as the mirror method, elasticimeters or the Guillery method). The use of these processes shows that pure tensility is an illusion; it is enough to observe elastic deformations on one or more of the jaws associated with the same cylindrical test-bar to find that there are always unequal differences in the value and even in the direction of the deformations produced, which shows the existence of parasitic stresses which complicate the tensility.''[3] It follows, moreover, that these parasitic stresses completely mask the result of the test; the rupture almost invariably takes place in the jaw where the head is held, and it is due to this stress which the cast-iron test-bar will resist the less in proportion to the lowness of its quality.[4] The tensile test, therefore, which is of interest only inasmuch as it gives, in the case of any metal, the elastic limit and the contraction of area (and not, as is generally believed, the breaking strength and elongation),[5] is not merely incapable of doing so in the case of cast iron, but it also gives a breaking strength which is entirely incorrect. It is, therefore, absurd to continue its use. It is not thought, moreover, that such a change in practice would cause any particularly serious inconvenience to the inspection and control services or the laboratories already equipped for these tests. It is true that this opinion is not generally accepted. "These disadvantages,'' according to Pearce, "might be considered sufficient to condemn the testile test for cast iron. The tensile test, however, is specified by certain engineers, certain foundries are equipped for this test and the inspectors are familiar with it, so that there is no apparent reason why the test should not be retained.''

The authors have excluded it entirely from the Piat Concern's laboratory, and they only regret that certain public bodies have retained it for their inspection of castings.

Like the tensile test, the shock test has been used for cast iron in the same way as for steel, which is a serious mistake. "The rupture of cast iron is always intercrystalline; it separates the crystals whether the shear, transverse, tensile or shock test is employed. When any one of these test methods is applied the energy brought into action is always of the same kind.''

This is not the case in regard to most of the other alloys; for example, in the very commonplace case of the rupture of steel, the fracture is intercrystalline (as in cast iron) when the shock test is applied, whereas it is intracrystalline under the tensile test. In steel, therefore, the stresses set up are of a distinct nature in the two cases in question and the total work is also different. Thus, the necessity of providing against the possibility of rupture during service will be apparent, either through a dynamic stress or a static stress, by carrying out these two tests, which, roughly, bring about the conditions which usually accompany such ruptures, hence the presence of both tensile and shock tests in specifications relating to steel.

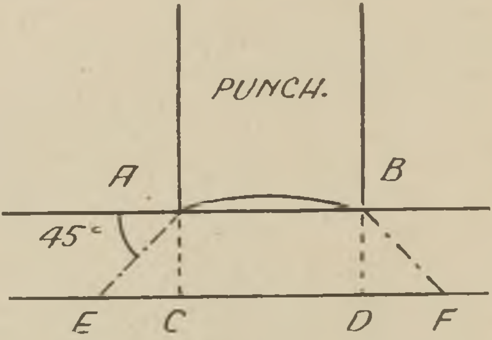

Fig. 2.

But, as in the case of cast iron, the energy indispensable for static rupture and for dynamic rupture is identical, at least as regards its nature, it is useless to create a new method of testing, particularly in view of the difficulties experienced when this test is effectively carried out. In fact, the use of a small-scale rotating hammer, a 3-kilogrammetre Charpy hammer, for example, which eliminates the more serious faults to be found with the *chemin de fer* type of apparatus, does not give sufficiently accurate results to distinguish two irons of different quality. The energy required to break a test-bar of 55 × 10 × 10 mm. is 0.45 kilogrammètre, or 15 per cent. of the applied energy. The errors are also excessive in relation to the strength variations resulting from the differences of composition or structure. The shock test also should, therefore, be excluded from industrial or research laboratories.

Compression and Torsion Tests.

In a previous Paper[6] it has been explained why the compression test has been eliminated. This in itself is perfectly justifiable, as it gives an exact idea of the value of the metal under examination. It is useless, however, if the shear test has been carried out, as it gives an equivalent result and requires a machine which is very much more bulky and costly. As regards the torsion test, it appears to be employed only in Germany, where Prof. Rudeloff has selected it as the basic test in his work on the merits of the shear test. The authors do not use it because, as in the case of the tensile test, it

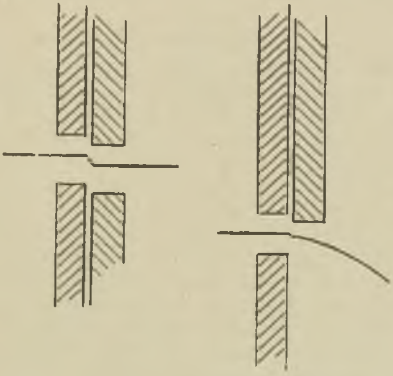

Fig. 3.—Two Lines of Contact between Test-Bar and Shearing Elements. One Line of Contact between the Test-Bar and Shearing Elements.

appears difficult to get rid of parasitic stresses and to twist a cylindrical test-bar accurately about its axis. In any case, it is much more complicated than the shear test.

Shear, Static Transverse and Hardness Tests.

The authors have already explained at length[7] why they have adopted these tests. They will here consider the new machines used in carrying them out, and refute adverse criticisms. For the moment it is proposed to examine these tests only from an intrinsic point of view, reserving until later the study of their application to the problem of testing castings, which is entirely different from that now under consideration.

Shear Test.

For testing cast iron, the shear test is carried out on the Guillery machine, which consists of a ball-test machine, to which two loose pieces for the shear and the static transverse tests can be fitted. The device for the shear-test consists of a guillotine formed of two half-cylinders, one of which is fixed in a cylindrical socket, while the other slides in the space left free in the socket. Each of the half-cylinders is pierced with two holes, one square and the other round for testing the two types of test-bars. These are small bars about 20 mm. in length, with a section of 25 mm^2, the round being 5.64 mm. diameter and the square 5 mm. on the side (Fig. 1).

As the two half-cylinders have a tendency to separate in shearing, the movable half-cylinder of the guillotine has a vertical row of balls, so that its displacement in the socket produces only a rolling friction. To carry out the test the bar is inserted in the rest and the screw is tightened by hand or very gently with a spanner, the end of which is fitted with a depth-gauge, which serves to adjust the position of the bar so that the shear takes place exactly at the centre. Having been prepared in this way, the device is placed beneath the ball-testing machine between the upper and lower balls; an increasing pressure is induced until rupture takes place; a pressure-gauge with maximum indicator shows the breaking load, which is then converted to the sq. mm. of section. When the test is properly carried out no premature rupture by bending ever occurs. For this it is necessary that the test bar, taken with a trepan drill, shall be quite cylindrical, and that the screws of the apparatus shall not exert too great a pressure on it in its bearings. The shearing rupture is always very clean. This apparatus, which is remarkably convenient to handle (its weight is 1.65 lbs. and its dimensions 114 × 40 mm.), enables a test to be made in a few seconds, and gives accurate and constant results.

Criticisms of the Shear Test.

The use of the Guillery machine eliminates all causes of failure in the shear test, and it is probably the use of defective systems that have led to the belief that it is difficult to obtain a correct test. The objections raised are in fact numerous. In the first place it has been said that it is impossible to get rid of parasitic stresses (Pearce). In a paper presented to the International Foundry Congress of 1927 Hermann and Henguin, of the F.N.A. of Herstal-lez-Liége, quote in support of this objection the fact that the shear strength with the punching test is 20 to 40 per cent. greater than with the ordinary shear test, which, they say, must therefore be accompanied by a parasitic stress. But in the punching test the field-of-force of the reactions developed in the sample is differently distributed as compared with that produced by the shear test, and the rupture instead of taking place along the cylindrical surface takes place along the conical surface ABFE, the angle of opening being 45 deg. (Cf. Hypothesis of maximum slide). In rupture by shearing, on the other hand, the fracture takes place parallel to the stress imposed. The two tests are not therefore comparable (Fig. 2).

In the other shear tests studied at Herstal, moreover, " owing to tolerances in making the test-bars used, transversal fissures characteristic of rupture under transverse load occurred in the course of the tests considerably in advance of rupture by shearing." The authors have never been able to observe anything of the kind with test-bars which were obtained with the trepan drill. Pearce has further criticised the shear test on the ground that it gives a result which varies with the conditions of the test—this opinion being based on the following experiments:—Shear tests were carried out on bars 15.5, 9.5 and 5.64 mm. diameter in a double-shear device combined with a tensile machine.

The results obtained are set out in Table I:—

From this Pearce concludes: "a shear-test thus does not measure an absolute value, but one which depends upon the conditions of the test." The authors are not of this opinion. A double shear is different from a single shear as regards the distribution of the stresses in the sheared sections, the more so as they are closer together, and the two cannot therefore be compared. It is enough, however, to choose once for all between these two tests. From these results, moreover, it is apparent that the double shears *a*, *b* and *c* are very concordant. The *d* and *f* tests, in the authors' opinion, are suspect, for a shear-test carried out in this manner ought certainly to show a considerable amount of bending, as shown diagrammatically in the accompanying sketch (Fig. 3). For this reason there is a reduction of about 15 per cent. in the strengths shown, viz.: 25 kg. in place of 33.2 in the case of the double shear, and 25.5 kg. in place of 30.2 in the case of the single shear.

It is not by any means proved, therefore, that the shear-test gives variable results according to the method of operation employed provided it entirely eliminates the parasitic stresses. It has even been maintained that even when the same method is employed the result of the test may be variable. If this objection were well-founded, it would suffice to eliminate the shear-test altogether, for it would no longer possess the fundamental character of every criterion, namely that of being constant. Fortunately

TABLE I.—*Shear Test Results* (*Pearce*).

Reference.	Test.	Diameter of test-bar.	Special conditions.	Strength in kg./mm.
—	Tensile ..	14—.3 mm.		26.8
a	Shear ..	15.8 ,,	Double shear	33.0
b	,, ..	9.5 ,,	,, ...	33.5
c	,, ..	5.6 ,,	,, ...	33.2
d	,, ..	5.6 ,,	Double shear. One line of contact between the test-bar and the shearing element.	28.0
e	,, ..	5.6 ,,	Single shear	30.2
f	,, ..	5.6 ,,	Single shear. One line of contact between the testbar and the shearing element.	25.5

this is not the case. According to Pearce in the Paper already mentioned: " To see whether a regular relationship existed between the tensile tests and the shear test a variety of bars tested in tensile at 20 mm. (0.798 in.) diameter were also tested in double shear at 12.5 mm. (0.5 in.) diameter. The tensile shear ratio varied between 0.52 and 0.93. The constancy of this ratio is an important point in the French proposals for supplanting the tensile test by the shear test." The authors have never claimed to establish the value of the shear test in this way, and the inconstancy of the tensile test is sufficient to explain the variations of the tensile shear ratio between 1 and 2.

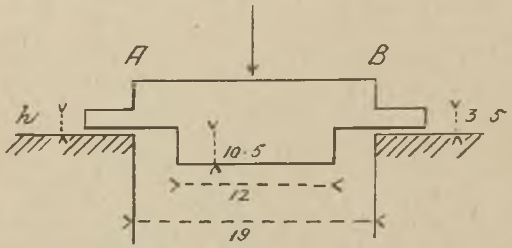

FIG. 4.

For this reason also it is illusory to look for any relation whatsoever between shear strength and tensile strength. Certain writers have thought, moreover, that the machining of the test-bar must be very accurate (Pearce) and that the trepan drill is incapable of ensuring the necessary precision. According to Elliott* " Trepanning gives rather inaccurate test-bars. . . . Even when grooves were made to release the swarf in the drill it was found somewhat difficult to obtain accurate test-bars." For their part, the test-bars which the authors take daily from the castings are always exceedingly uniform, and fit perfectly into the holes of the shearing guillotine.

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* Paper presented to the Detroit Congress in 1926.

Finally, the slight tool marks left on the shear core by the hollow drill has been regarded by some as a fatal defect. "The drill," according to Pearce, "does not leave the test-piece with sufficiently good finish for a shear test, which should be machined as fine as possible; whilst Mr. Walter Wood, in a letter, dated October 7, 1926, to the Cast Iron Testing Commission of the Association Technique de Fonderie, states: "We all know that a test-bar taken with a drill shows tool marks to a greater or less extent. It appears to me that whatever the dimensions of the test-bar taken may be, the tool marks ought to be remedied."

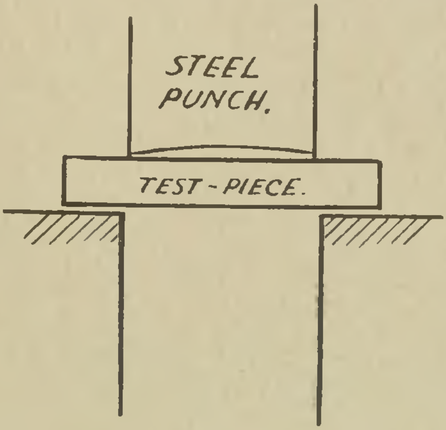

FIG. 5.

Tool marks, however, as Portevin has pointed out, which have a considerable influence when the surface undergoes longitudinal extension, exercise only a secondary influence in the shearing of cast iron. "No one thinks," he says, "of asking that the accuracy of the direction of the tensile stress, which is fundamental in cast iron, should be controlled, yet there are those who worry themselves about tool marks on shear-test bars." The authors cannot do better than express their approval of this observation without making any comment.

It should be pointed out, however, that Mr. Walter Wood's criticism is perfectly justified if the drill used cuts badly, for in that case the tool marks are no longer mere traces but actual holes and furrows all over its surface. A drill that has been properly made produces almost perfectly smooth test-bars.

The Shear Test by Punching.

The Germans have studied and perfected a method of shearing by double punching, and a summary of their work on the subject has been published by Rudeloff, in two Papers which appeared in "Stahl und Eisen," on January 28 and December 23, 1926.

Karl Sipp had examined a new shearing process for cast iron in a Paper published in "Stahl und Eisen" (XL, pp. 1697-1704, 1920), under the title of "The Shear Test and its Application to the Study of the Mechanical Properties of Cast Iron." The test which he recommended was that of shearing a disc by punching, the result being to form a flange round the disc (Fig. 4).

Rudeloff made certain modifications in this test. To obtain a better distribution of the stresses he tried different kinds of surfaces (AB) and adopted a surface with raised edges. Moreover, as the flange formed by punching was always breaking, and as the additional work involved marked the measurements, he decided to saw it radially in three directions as far as the vertical of the sheared section. Finally he reduced the height *h* of the flange in order to eliminate parasitic stresses. This modification of the method was studied systematically simultaneously with the torsion and double-shear tests on a Martens machine, which very much resembles the small Fremont machine, and Rudeloff made the following deductions from his experiments:—*Double-shear strength* = 0.946 × torsional-shear strength; *Sipp-punching strength* = 0.981 × torsional-shear strength, and *Tensile* *strength* = 0.81 × torsional-shear strength; and he concludes: "It must be admitted that the true value of the shear strength is given by the torsion test" (because it is the greatest) . . . and "If the test conditions are well chosen the modified Sipp test is capable of giving a value closely approximating to the true (?) shear strength. This test gives more exact values than the double-shear process on cylindrical test-pieces and rings with an internal diameter equal to the external diameter of the test-pieces."

The test was then slightly modified, the test-piece being a plain disc, sawn radially and sheared with a steel punch (Fig. 5). Having experimented on a certain number of different cast-iron bars, Rudeloff found that *Punching-shear strength* = 0.91 × Sipp-shear strength, and from this ratio and those established by him for the Sipp-shear test he determined all the ratios enabling all the constants of the metal tested to be calculated from that test.

These two Papers describe a method of shear testing which is not without interest, at least theoretically. The extent of the first experiments by the Sipp method was, according to Rudeloff himself, somewhat limited; the tests were not numerous and the conclusions are based on calculations which are too precise for a material so lacking in homogeneity as cast iron.

This critical study of the Sipp method, nevertheless, leads to improvements which eliminate certain parasitic errors (bursting of the flange). It does not, however, eliminate a bending which is due to the disc not being supported in the interior of the matrice and which is not entirely suppressed by the fact that the shearing force is applied almost at right angles to the matrice. (The ratio-punch diameter : matrice diameter varies between 0.97 and 0.98.) This, however, is not the principal objection (Fig. 6).

Why select the test which gives the strength that has the highest value? It does not on that account possess any greater value as a criterion than a test which determines a property showing a lesser figure. What, then, is this "true shear strength" of Rudeloff? If the Sipp test comes nearer this result for the alleged reason that $R_{sipp} = 0.981\ R_{torsion}$, while $R_{double\ shear} = 0.946\ R_{torsion}$, why not adopt as criterion the torsion test itself, which is simpler and more definite? The special value of the Fremont shear test is that it enables cast irons to be classified according to their merits in service and that it is extremely simple. Even admitting that the Sipp test constitutes a good criterion, the fact nevertheless remains that it is much less easy to apply (lathe machining the test-piece, radial sawing of the plunger, the employment of a load of 5 to 10 tons). The test-piece sheared with a steel punch is no doubt a little simpler. But the substitution of a punch for a piece applied to the cylindrical extension partially remedies a bad distribution of the stresses. It leaves the parasitic bending still existing. It appears, moreover, to bring the hardness of the test-piece into play, for the punch must penetrate the disc before the shearing.

Finally, the ratio between the two strengths thus obtained is untrustworthy. It is based on only a few experiments, of which there are no details. It is, therefore, hazardous to calculate the transverse, tensile and compression strengths as a function of the double-punch strength, particularly in the case of material of such imperfect homogeneity as cast iron and with the help of but a few experiments; and this, moreover, is perfectly useless if the double-punch test is an adequate criterion for the classification of iron.

Even if double punching were found to be a good criterion as a result of very prolonged experiments, such as one of the authors carried out at Indret in regard to the shear test, the difficulty in machining the test-piece would still remain. In the case of a circular disc a few millimetres thick and a few centimetres in diameter, sawn radially as far as the circumference of the punch, the difficulty is much

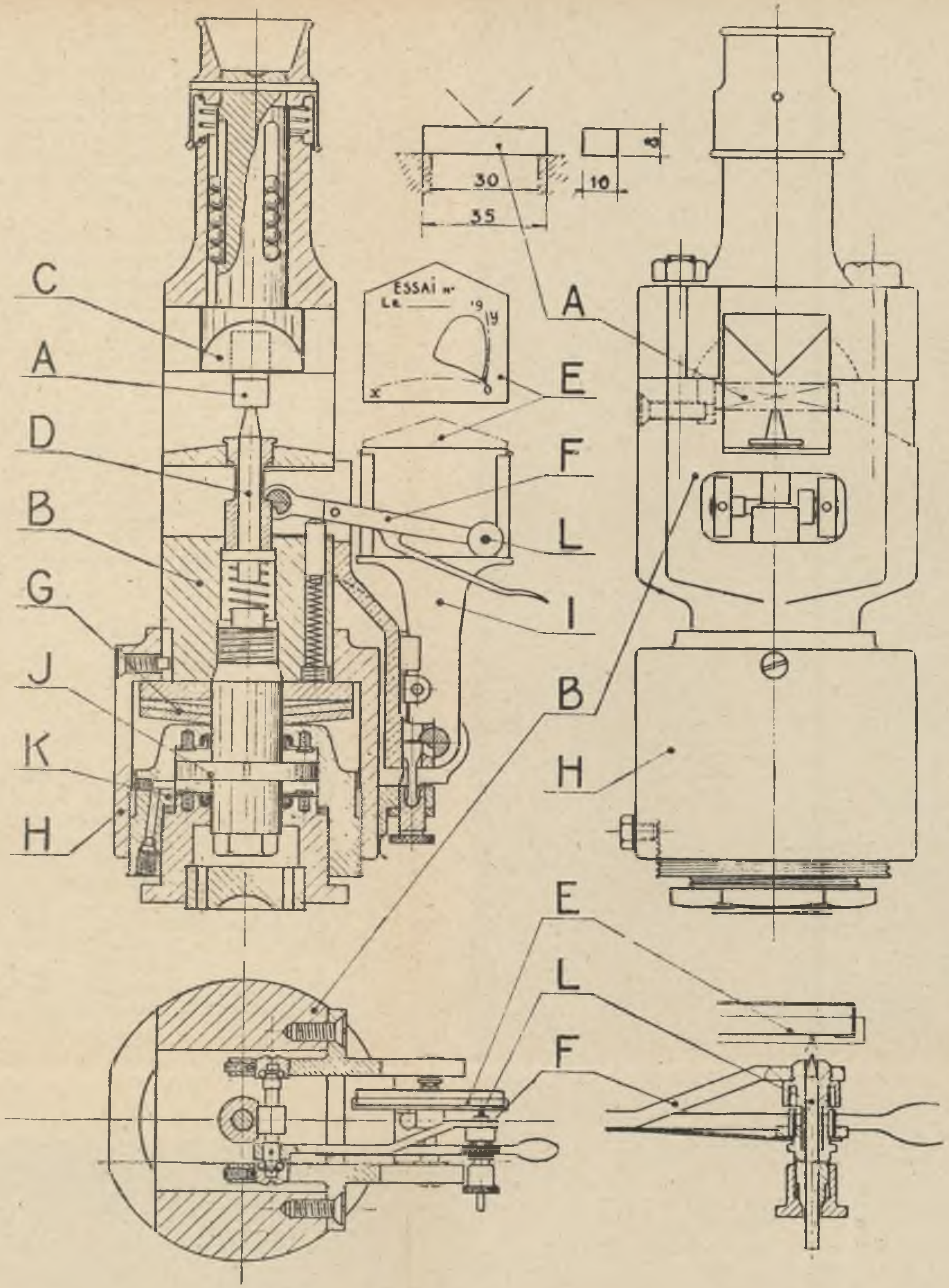

Fig. 7.

(A) Bar to be Tested; (B) Main Body; (C) Cutter; (D) Central Key for Registering Deflections; (E) Sensitive Paper; (F) Deflection Registration Lever; (G) Washers Flattened in Proportion to Loads; (I) Lever Carrying the Sensitive Paper, the Rotations of which are Proportionate to the Loads; (J) Hydraulic Dash Pot Absorbing the Rebound at the Moment of Rupture; (K) Watertight Cylinder; (L) Brass Stylus.

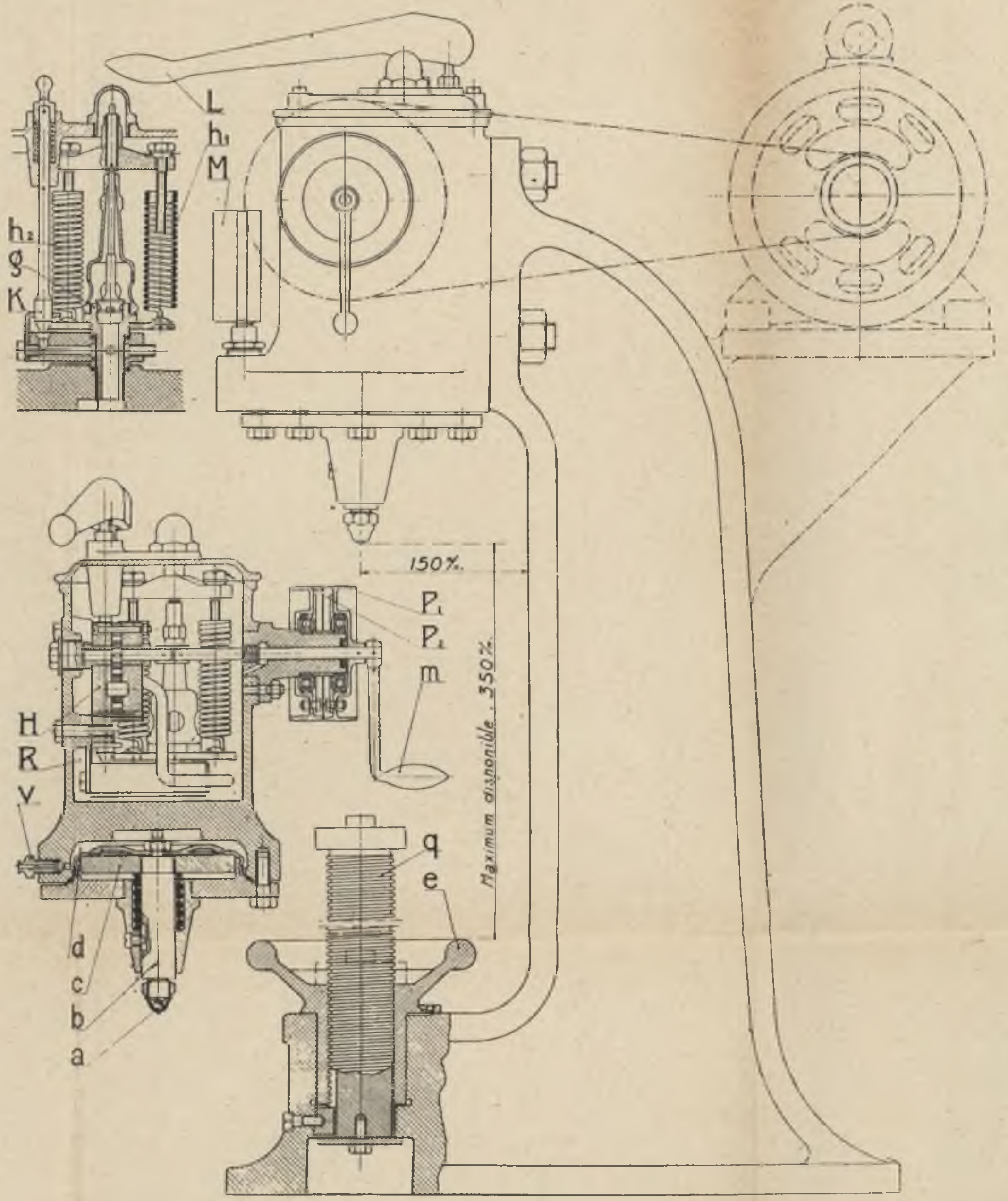

Fig. 11.

(a) Testing Ball; (b) Rod integral with Piston c; (c) Piston; (d) Chamber filleed with Glycerine; (H) Geared Pump; (R) Glycerine Tank; (K) Valve-Closing Chamber d or Connecting it with the Tank R; (L) Control Lever of Valve; (g) Hardened Steel Valve Seat; (h_1-h_2) Regulating Springs; (M) Manometer controlling Pressuure in Glycerine Chamber.

[To face page 504.

greater than in that of the Fremont trepanned core. If the shear test appears of service in interpreting the mechanical properties of metals, it is useless to recast Frémont's researches and to seek for a method of applying this test which has the appearance of being original, but which is, in fact, much more complicated.

Static Transverse Test.

At present the authors utilise the static transverse test on Frémont test-bars 8 × 10 × 35 mm., with the Guillery apparatus adapted to the ball-testing machine. This static transverse apparatus consists, roughly, of a main body, composed of two supports 30 mm. apart, on which the two ends of the test-bar rest, a knife-edge, which rests upon it at the middle, and a cylindrical socket, which takes the lower part of the main body, Belleville washers being interposed.

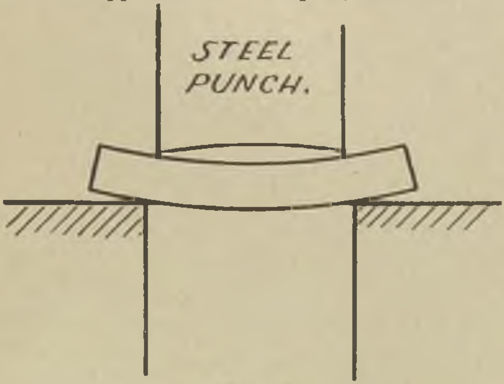

Fig. 6.

The semispherical hollow head of the knife edge receives directly the force exerted by the ball-testing machine, while the lower socket bears against a fixed block. The breaking load is indicated by the maximum gauge of the ball-testing machine (see Figs. 7 and 7a).

The tracing of the deflection-load diagram and consequently the measurement of the breaking deflection are effected as follows: A frame, which is covered for each test with a paper coated with baryta, is mounted movably about a fixed horizontal spindle attached to the main body of the apparatus. By means of a spindle carrying a geared piece and resting on a conical piece with rack-tooth incline it is caused to rotate to an extent proportionate to the relative displacement of the lower socket and the main body, that is to say, practically proportionate to the loads transmitted by the bar to the main body. The deflection to which the bar is subjected is, moreover, transmitted by means of a contactor and an amplifying lever integral with the main body to a brass registering stylus. The movements of the stylus and the frame take place in two rectangular directions, the stylus finally tracing on the sensitive paper the deflection-load diagram in the form of a system of curvilinear co-ordinates. A transparent graph placed over it enables the breaking deflection to be read with an error less than 0.1 mm. The breaking load measured by the gauge is given within about 2 kg. (Fig. 7A).

The play of the parts is eliminated throughout by an appropriate arrangement of springs, and the accuracy of the measurement is superior to what is necessary commercially. Like the shearing machine, the Guillery static transverse machine is very convenient in use: its dimensions are 225 × 120 × 80 mm. and its weight about 5 kg. The test takes a few minutes, and the constants required can be rapidly and easily read, while the machining of the test-piece is quick and inexpensive owing to its small dimensions.

The static transverse test in this form, therefore, possesses in the highest degree all the qualities required for a commercial test: economy, rapidity, simplicity and precision, and it is used in routine work without the least difficulty. It is now proposed to reply to the objections raised to the transverse test on a bar measuring 8 × 10 × 35 mm.

In a paper presented to the European Foundry Congress of 1927, Prof. Pisek, of the Czech Polytechnic at Brno, has published the result of a series of experiments with transverse tests on unmachined bars of different diameters varying from 15 to 40 mm., the distance between supports being shown in Table II (Group A indicates the German method and Group B the American):—

For each of these test-pieces different methods were tried, the unmachined bars being cropped at both ends. The results obtained by the German and American methods gave almost parallel curves. The Frémont test was carried out on test-pieces taken from the lower part, at the centre or near the surface of the bar, and the course of the Frémont curve differs from the two others. From this Pisek concludes that the Frémont test is irregular.

Table II.

Group *a*.		Group *b*.	
Diameter in mm.	Distance between supports.	Diameter in mm.	Distance between supports.
30	600	40	400
25	500	30	300
20	400	25	250
15	300	20	200

The explanation of this apparent irregularity is, however, quite different. In the first place, the Frémont test-bars were taken from the cut-off ends, and therefore varied in soundness; in any case they differed slightly from the main body. Further, the unmachined bars transverse tested by the American and German methods were not homogeneous, their surface being certainly stronger than the centre, while the retention of the skin in the test also played a part in the values of the results obtained. On the other hand, the Frémont tests gave in place of this aggregate result the value of the transverse strength at a particular point in the test-bar—at one time the centre, at another the surface.

The tests, moreover, were carried out with a small Frémont machine, which, according to the author, showed considerable play. The Guillery apparatus is entirely beyond such criticism.

Various writers, Pearce in particular, have proposed the adoption of the modulus of rupture to express the results of the transverse test, and suggest the formula $R = \frac{PL}{4K}$ in which R is the breaking strength per unit of section surface, P the break-load, L the distance between supports, and K the modulus of rupture, a coefficient dependent on the shape and size of the test-bar. It must be observed that K cannot be calculated; it must be defined as the modulus of a test-bar of a given length and form of section, and it must be given an arbitrary value for that particular bar. In the case of variations of the first degree in the dimensions of the section—the shape of the latter remaining unchanged—it may be assumed that K is proportionate to the surface of the section, and $\frac{L}{4K}$ may be calculated in advance for dimensions approximating to those of the standard test-bar. Even if the transverse test has been carried out on a test-bar slightly

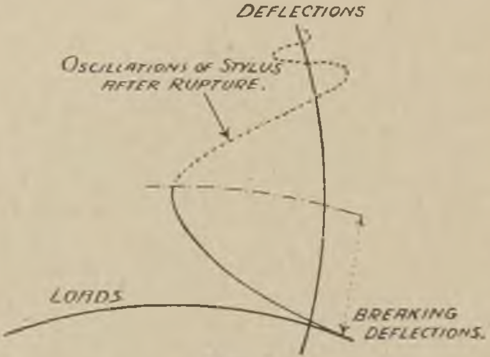

FIG. 7A.

too thick or too small, the value of R corresponding to an accurate test-piece can then be given.

This may be serviceable when the tests are made on unmachined bars, which are always more or less variable. But it is useless in the case of a Frémont transverse test on a test-bar machined to the required dimensions. The authors consider it simpler to represent the result of the test by the breaking load. The adoption of the modulus of rupture has also the disadvantage of referring the breaking strength to the unit of section surface, which is liable to make it be thought that this strength is proportionate to the section. Whatever Pearce may say, it is not desirable that "because the tensile test is expressed in kg. per mm². or its equivalents the transverse test shall be expressed in the same way."

Fig. 8.

Finally, the transverse test, which is the best test for cast iron, as it enables the resistance of the crystals to separation and the elasticity of their arrangement to be measured, ought to take the first place among all other tests on account of its great simplicity, its certainty and its wealth of interpretation. The Guillery machine renders its execution simpler than the tensile test has ever been, and infinitely more accurate.

In regarding it as the test *par excellence* for cast iron, moreover, we are merely following the teaching of Monge in 1794 in the description of his " machine for ascertaining the strength of cast iron " (" Description of the Art of Making Cannons ").

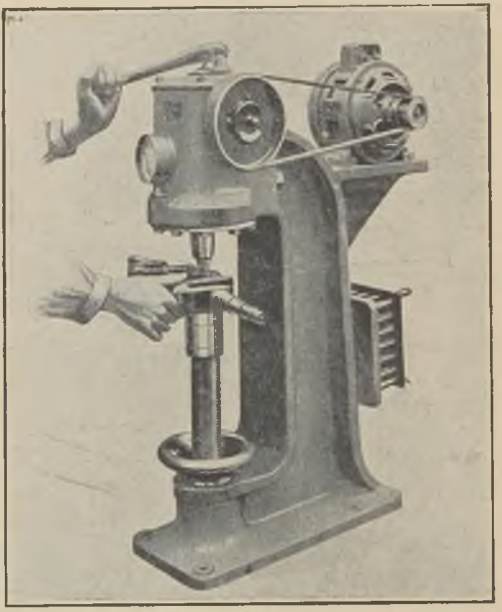

FIG. 9.

Hardness Test.

The authors cannot mention the hardness test without describing the very ingenious machine which they regularly use for testing small repetition castings, the principle of which has been described by M. Guillery in a Paper to the Académie des Sciences on October 8, 1917. The object of his apparatus is to eliminate the influence of the duration of the test on the hardness number ascertained. The theoretical test consists in applying a pressure of 3,000 kg. for at least five minutes to the ball penetrating the metal under examination. It is practically impossible to observe this condition outside scientific laboratories where the value of time is not taken into account. If only ten seconds more or less accurately reckoned are taken, the result may contain errors amounting to some 8 per cent.[8] (Fig. 9).

A very simple mechanical device enables this error to be eliminated. If the stress is suppressed immediately the pressure of 3,000 kg. is reached, the diameter of the impression will be too small by a quantity dD. If, on the other hand, instead of arresting the stress at 3,000 kg., it is continued to $3{,}000+dP$, the diameter of the impression will be increased. For a reasonable value of dP the error resulting from the insufficient duration of the action of pressure may be exactly compensated. It gives practically the ratio: $\frac{dP}{3{,}000}=\frac{2dD}{D}$

It is possible to construct an apparatus in which the maximum pressure reached is automatically regulated by the speed with which the load is applied. Supposing that the pressure is transmitted to the ball by a hydraulic piston without friction, the water-tightness of which is ensured by rubber packing. The pressure exerted on the piston is limited by the raising of a valve consisting of a sphere S (Fig. 10) resting on a seat at an acute angle. The pressure required to raise the valve is then rigorously determined by the free section of the seating and by the stress exerted on the sphere. This stress is produced by springs, the tension of which can be varied at will by means of tension screws V, and the useful length by internal screw nuts E, which screw on to the spirals of the spring when at rest. This gives two independent variables for the regulation: the length and the tension of the spring. The stress opposing the lifting of the valve is dependent on the height of the lift, which increases the stretch and consequently the tension of the spring. The apparatus is regulated by trial and error, so as to have on any given metal the normal impression diameters for two loading speeds varying within the ratio of 1 to 30. The apparatus is simultaneously regulated for all intermediate speeds, as shown by the figures in Table III:—

Loading speed in:

Kilos per sec.	100	200	300	600	1,000	1,500	3,000
Dia. of impression	4.38	4.37	4.40	4.39	4.40	4.39	4.39

This machine (Figs. 10 and 11) consists of a fixed frame provided with a ball, and the shear and static-transverse test appliances already mentioned are placed between the two balls of the machine. Thus arranged, it constitutes a small testing machine for cast iron, enabling the three fundamental tests—shear, static transverse and ball—to be carried out rapidly and economically, and therefore worthy of a place in all foundries, however small.

The ball test, unfortunately, is very frequently misused, and, as it can be made extremely easily and quickly, there is a tendency to deduce from it mechanical constants which it is incapable of giving. The ratios between hardness number, tensile strength, shear strength, compression strength and transverse strength, as given by a large number of writers, generally differ to some extent and give rise to sterile and tedious discussions. Portevin[9] very clearly gives the reason:—

"The compression test which gives the compressive strength and the hardness test which acts by localised compression are primarily affected by the combined-carbon content, and secondarily by the graphite, which behaves as an incompressible substance, whereas in the tensile test it constitutes so many fissures, as it were throughout the mass. It is natural, therefore, to expect parallel results as between shear strength and hardness number. As regards tensile strength, even presuming that the tests are carefully carried out, its value is affected by elongation: when it is very small as a result of graphite in plate form there is a premature rupture owing to parasitic bending and a fictitious reduction of tensile strength. According to the materials under examination, even with accurate tensile tests, a very different ratio between hardness number and tensile strength must be expected."

Nor is the ball test designed to measure "the machining hardness or the abrasive hardness," as Pearce appears to require. There is, in fact, a relationship as yet imperfectly defined between Brinell hardness and difficulty in machining.

Another criticism directed against the ball test by Pearce is that "the results are meaningless unless the position of the impression is clearly defined: a ferritic centre will give a lower Brinell hardness than a harder skin." This is precisely the great merit of this test, which enables the regions differing in composition to be ascertained with great accuracy, so that the homogeneity of a casting can be examined or castings produced in series compared. It is for this reason that the ball-test is, more than any other, a commercial test and specially indicated for the testing of castings.

In view of this examination of the different methods of testing which can be regarded as possible, it would appear that the shock and tensile tests ought to be eliminated, that the compression and torsion tests, while being definite in their indications, are not sufficiently simple for routine use, and that the shear, static-transverse and ball-tests must be regarded as the standard tests which enable the characteristics of a sample of iron to be perfectly determined. Apart from their scientific character, they have all the qualities required in any commercial test: they are economical, accurate and rapid, and since the production of the Guillery machine, which makes it so easy to carry them out, it would seem that no further criticism can henceforth be directed against them.

It must be understood that only mechanical tests are being considered at present, which it

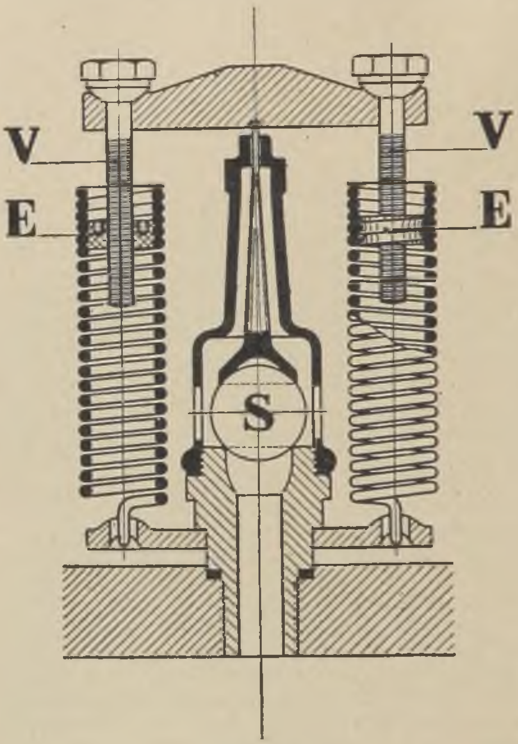

Fig. 10.

is very desirable to supplement with micrographic examination and chemical analyses such as the authors have already had occasion to discuss at length in a Paper presented to the Fifth French Foundry Congress under the title of "Personal Experiences of the Application of the New Methods of Testing Cast Iron."

Effects of the Individuality derived by Castings from their Thermal History on Methods of Testing them.

In the first part of this Paper the effects of the heterogeneity of cast iron and its special characteristics on the choice of the tests designed to interpret it were examined. It is now proposed to discuss the effects due to the individuality which every casting derives from its thermal history in order logically to utilise the measuring methods described for the purpose of determining the mechanical properties of the casting, which is, after all, the end to be attained. How is the problem to be stated? There are available shear, static-transverse and ball-testing apparatus which give an exact idea of the relative mechanical value of a certain number of samples of cast iron—bars, for instance, for the sake of precision. From the classification obtained, it is logical to conclude that machines entirely constructed of metal identical with that of each sample will be classified when in use in the same order. In other words, the figure resulting from the test carried out on the sample will enable the relative value of the casting when in use to be predicted: the test will enable the characteristics of the casting to be determined.

All this assumes, however, that the casting in question is composed of metal identical with that of the sample tested, and identity means the same chemical composition and the same crystalline structure. But, for any given chemical constitution, this structure is dependent upon the predominance during the course of cooling following the pouring of either the stable or the metastable system of the iron-carbon combination. The authors have already had occasion to point out the influence of the various constituents which then arise upon the mechanical properties —graphite, ferrite, cementite and pearlite—and will not revert to them again here. Be it noted merely that according to their relative proportions the strength will vary considerably, as also elasticity, fragility, hardness and machinability. The law of cooling which governs the crystalline structure, and consequently the mechanical properties, is dependent upon no less than twelve factors, some of which in particular are inherent in the casting, such as wall-thickness and distribution of the masses in the casting, others being peculiar to the mould, such as temperature and humidity of the sand, while yet others are inherent in the external conditions, such as the surrounding temperature. It follows in the first place that two identical castings poured from the same metal taken at the same temperature may be subject to different laws of cooling and may therefore have a different crystalline structure; and also that the different parts of a single casting may undergo the same cooling only exceptionally and may therefore have different mechanical properties. Even the chemical composition will not be uniform, as the solubility of the different impurities such as sulphur and phosphorus and the gases in the alloy will vary with the more or less advanced state of solidification, and as their concentration will be greater in the parts which are the last to solidify. It should also be noted that to these numerous causes of heterogeneity must be added the influence of internal stresses which, moreover, are the more dangerous, as they are less understood and are impossible to discover and measure.

After all, the problem to be solved is to foretell the mechanical properties and the behaviour in use of a casting of varying chemical composition and heterogeneous crystalline structure, that is to say, mechanical properties varying at its different points and, finally, subject to unknown and variable internal stresses.

METHOD FOR FREMONT TESTS.

Application of Frémont Tests to Castings.

Be it noted, in the first place, in order to simplify the question that chemical heterogeneity is not very apparent and may be disregarded in the initial examination. Internal stresses will also be left out of consideration, although they are of considerable importance and their effects are frequently unexpected, because up to the present there has been no means of studying them, and all that is done is to try to reduce them by a judicious choice of design and thickness and, possibly, by suitable heat-treatment.

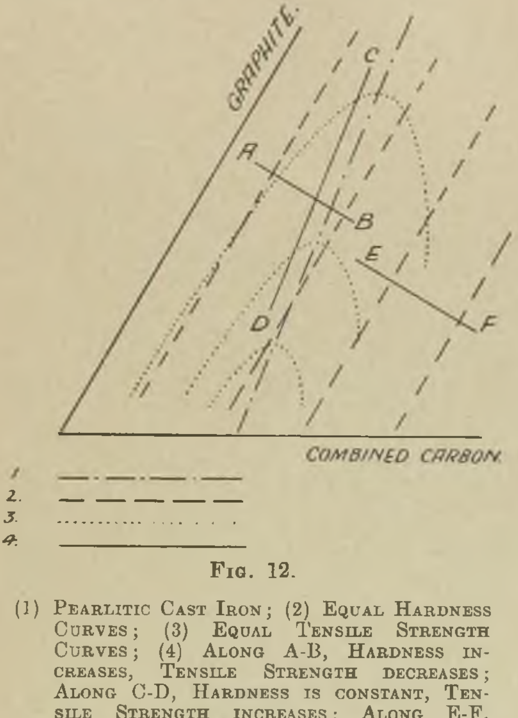

Fig. 12.

(1) Pearlitic Cast Iron; (2) Equal Hardness Curves; (3) Equal Tensile Strength Curves; (4) Along A-B, Hardness increases, Tensile Strength decreases; Along C-D, Hardness is constant, Tensile Strength increases; Along E-F, Hardness increases, Tensile Strength decreases.

Since it is not possible to make a casting of a well-defined material, which can be tested separately in order to know it accurately, it is proposed to reverse the problem and take from a finished casting a sample capable of defining the properties of the material constituting it. It must be noted, however, that by so doing information will only be available as to that part of the casting from which the sample is taken or a small portion in its vicinity. One may then consider the application of this method to the problem posed and to the more general problem of finding the best parameters to adopt for the production of particular castings from the point of view of design, thickness, shape, method of casting, etc.

The problem of determining the properties of castings, and, therefore, the problem of inspection by the buyer will be solved as follows:—Among the points subjected to the greatest mechanical stress, several taken at random, or selected among those which always turn out weakest in casting, will be examined. The casting will thus be sounded at the weakest parts amongst those required to show a good strength figure. If the tests in regard to these are satisfactory, this will constitute a guarantee to the buyer, and it will not prevent the testing points from being sufficiently distributed to give a true idea of the casting as a whole.

As regards the problem of improving the design and the method of casting which concern the foundry engineer, it will be already half-solved, since he will have at his disposal a certain and easy means of knowing the quality of the casting designed by him in its various parts. The method of taking test-pieces from the casting, therefore, appears to the authors completely to solve the question of testing engineering castings. Before examining and refuting the criticisms that have been directed against it, showing why the other methods put forward are worthless, and submitting that it is the only test of any value, it is proposed to describe in detail how the test is carried out in practice.

Method of Carrying Out the Frémont Tests on Castings.

The test-pieces are small, either a cylinder about 20 mm. and 5.64 mm. in dia. for the shear test, or a prism 8 × 10 × 35 mm. for the static-transverse test. For the shear test, the test-piece will be taken with a trepan drill, by means of a portable boring machine, from all the parts desired, the hole being stopped with a plug. As the latter is only 11.5 mm. in dia., the operation does not, as a rule, affect the strength of the casting. It should be noted that it is possible to go to any depth, so that in this way a sample of the metal can be taken from the interior of a thick wall. As the shear test is the routine test it is, as will be seen, very easy to carry out.

The static-transverse test, it is true, requires rather a larger test-piece, although it also is small. As it is used only for castings generally of large dimensions (see typical specification given at the end of the Paper), it is easy to take it also directly from the casting.

There are cases, however, where owing to the trepan drill being temporarily unavailable, where the casting is such that it would be unwise from considerations of strength to drill it, or where the part in question is particularly delicate and its strength might be affected by the insertion of a plug, it is impossible for the sample to be taken from the casting. It is in that case necessary to produce at the point selected a small boss forming part of the casting, its length along the axis being a few centimetres and its section approximately the thickness of the wall. This boss will be cut in the mould during moulding by means of a cylindrical tube of the required diameter, which is let into the mould-wall to the necessary depth. After stripping the casting the boss is detached and the test-piece is taken from the centre and as close as possible to the face which adjoined the casting. As the mass of the boss is very small in relation to that of the casting and as the ratio of their calorific capacities is also very small, the cooling of the casting is practically unaffected and that of the boss is identical with that of the wall to which it was joined. Thus carried out, therefore, the test is entirely justified and may be substituted for the method of taking the test-piece from the interior of the casting.

As regards the ball-test, it is obvious that it can be carried out at any point in the casting desired by means of the portable Baumann machine or any other apparatus ensuring sufficient precision. This test will enable the homogeneity of the casting and its general soundness to be ascertained. In the case of several castings in series, cast from the same ladle, it will enable their uniformity to be compared; not, of course, that identity of hardness proves identity of substance, but because identity of substance implies equality of hardness. The Brinell test will give, if not the certainty, at least a strong presumption regarding the equivalence of the mechanical properties of several identical castings poured under the same conditions, and will simplify the method of their inspection. Portevin has given the best proof of the efficacy of this test by reclassifying during the war semi-steel shells in lots which later were found perfectly satisfactory when fired, whereas their classification according to the cast produced a most heterogeneous collection.

It should be remembered, moreover, that the micrographic examination and chemical analysis which is recommended in addition to the mechanical tests can be carried out very easily on shear and static-transverse test-pieces, and this will extend the field of investigation of the microscope to the very centre of the castings.

To sum up, the inspection and specification tests for castings will be the shear, static-transverse and ball-tests. At the end of this Paper is given a specification based on their use. The long series of trials of the Fremont tests has justified their principle and the method of applying them which has just been described. It comprises thousands of results confirming personal conclusions.

Criticisms of Methods outlined for Testing Castings.

The solution just described, which settles the problem of the characterisation of engineering castings so simply and surely, has not been generally adopted in many foreign countries, particularly England and the United States. In these countries the Fremont methods have as yet been little studied, and the testing of finished castings is done on bars cast separately by means of the tensile, shock and transverse tests. Before examining the characteristics of this method and demonstrating that it is bad, it is proposed to review the various objections that have been raised against the Fremont methods. They are nearly all included in a Paper on "The Test-Bar Problem and Some Recent Developments," presented by Pearce to the Sheffield Branch of the Institute of British Foundrymen.

The first objection—and it is this which appears to trouble the majority of objectors—is that it is impossible to judge a casting by a test made at a single point of it. According to Pearce, when referring to the shear test:—"The objection to the Fremont test lies mainly in the fact that it attempts to test the casting by such a small size of bar. On a single small piece, several shear tests can be made and averaged, from the skin of the casting inwards, but such an average is meaningless when applied to castings of different thicknesses. The test appears ingenious for research purposes . . . but for routine testing it cannot be recommended." Here is proof of the complete misunderstanding of the Fremont method. No one ever thought of classifying a casting by a figure obtained from a single test. This is one of the many reasons for which testing on a separate bar was rejected. The test carried out at one point only gives the mechanical value of the casting at the particular point in question, and our method of testing makes no other claim but that of examining the important points, sufficiently numerous and judiciously distributed to furnish an index of its mechanical physiognomy. Moreover, it has been fully demonstrated that a machinery casting is heterogeneous, and it would therefore be absurd to judge it on the examination of a particular point. It will, perhaps, be objected that the specification postulated provides for the taking of a number of test-pieces in proportion to the weight of the casting, and that the strict application of the rule laid down leads to only one test-piece being taken in the case of small castings. But in that case the casting is characterised by the result of the shear test and by the ball-tests, of which a sufficient number are made in addition. This is not in contradiction with the principle enunciated that a single figure resulting from a test cannot give the characteristics of the casting. For, assuming that the point chosen is one of the weakest among those which will be subjected to hard wear, the shear test guarantees a minimum strength as regards all the other parts of the casting, when the testing point is judiciously chosen and the casting is roughly homogeneous, which is ascertained by the ball-tests.

The second objection raised is that the test-piece is too small, whether in the shear or the static-transverse test.

Again, according to Pearce: "The suggestion to test a bar of such small diameter cannot be viewed without apprehension," and the expression "such a small test-piece" is repeated several times in the Paper. The authors are unable to see why the use of such a small test-piece is unjustifiable. What, then, must Pearce think of the ball-test which makes use of 25 mm^2. of the surface of the casting, or of a micrographical examination which embraces an area one-tenth as large? Yet these tests appear to him legitimate because a sufficient number of them are carried out at all points desired in the casting. The same is the case with the shear test. To those who may be disposed to object that the graphitic aggregates or even the plates of cementite or ferrite, which sometimes attain the dimensions of some tenths of a millimetre, are not sufficiently small in proportion to the dimensions of the test-piece, it may be pointed out that according to Czochralski a metal test-piece may be regarded as quasi-isotropic when a transversal dimension encounters ten particles.[10] By adopting 5 mm. as the transverse dimension of the test this condition is fulfilled. It is therefore quite legitimate to make tests at one point even of a large casting with small Fremont test-pieces.

It would seem, however, that this British writer has not entirely freed his mind from recollections of the old theory, which consisted in testing a large casting by means of a large test-piece, the only purpose of which, however, was to obtain in the two cases rates of cooling which were only too dissimilar.

Objection is also taken to the Frémont test-pieces on the ground that it is impossible to take them from the castings, at least in routine work: "The design of a casting," according to Pearce, "is based on the strength of the material of which it is composed, but this cannot ordinarily be checked by testing the casting itself. It is necessary to make the test by a test-bar." And, a little further on: "Ordinarily it is not practicable to test the casting itself. Furthermore, in ordinary cases it is not practicable to cut the test-bar from the casting. This being so, there are two alternatives: (1) A test-bar can be cast as an integral part of the casting; and (2) the test-bar can be cast separately, but with the same ladle of metal as that from which the casting is made."

The methods habitually employed when taking test-pieces from the castings are extremely simple, whether the casting is drilled directly with a trepan mounted on an electric boring machine or whether a sawn-off boss is used. Since employing this method the slightest difficulty has never been experienced, whatever may have been the size or shape of the casting. It is, therefore, regrettable that, as the taking of test-pieces from the castings appears to have been found impossible in England, most of the work carried out under the direction of the Cast Iron Research Association has been done on separate bars.

Test-pieces taken from the casting or cast integrally with it are also criticised on the ground that their cooling is affected by that of the casting. "In the case of a cast-on bar," according to Pearce, " the cooling is complicated by that of the mass of the casting," and, later: " The logical procedure, therefore, is to cast a bar from the same metal at the same time as the casting; this method excludes the influence of the proximity of the casting."

The authors have sufficiently demonstrated how, on the contrary, this cooling influence of the casting is necessary, since the object in view is to obtain a test-piece with precisely the same rate of cooling. This, moreover, is why we reject the principle which consists in taking pieces connected with the castings by means of two or more small channels and having dimensions independent of those of the castings, the result of which is that the influence of the cooling of the casting on that of the test-piece is to a great extent eliminated, and the sole utility of which is to prove that the test-piece and the casting were actually cast together.

With regard to taking test-pieces from an attached boss, this method meets with the serious criticism on the part of Pearce that it gives an inaccurate result: " Experience may enable a cast-on bar to be so placed and dimensioned that it does in effect give a strength similar to that of the casting, but such cases must be very rare." It is very remarkable, then, that these rare instances should have occurred regularly in thousands in practice during the last five years. The extended tests made using this method of taking test-pieces constitutes a formal refutation of this criticism.

Finally, according to Pearce, the method of taking test-pieces from the casting prevents any comparison being made between the results obtained in different foundries. " Comparison between the results from cast-on bars," he says, " is impossible." And again: " With such a bar (cast separately) it becomes possible to compare the results from different foundries and from the same foundry on different days." It must not be forgotten that the individuality of each casting makes it difficult to compare it even with a casting of the same type poured with the same metal from the same ladle. It would, therefore, be absurd to attempt to compare intrinsically different metals when one metal is not even comparable with itself. A comparison of the metals must be made on different well-defined test-pieces, which will be real test-pieces of the utmost simplicity, and for that reason comparable. This comparison of the metals, however, has nothing to do with that of the casting, and if that of test-pieces taken from the castings is not possible, it is for the simple reason that these castings themselves are not comparable.

To sum up regarding the objections raised against the Frémont methods as used by the authors, viz., the isolated nature of the test, the smallness of the test-piece, the impossibility of taking the piece from the casting, the inaccuracy of the results given by pieces taken from attached bosses, and the non-comparability of the results obtained—some of them are refuted by the long-continued use of the tests, while the others fall to the ground if one will only consider for a moment the principle and the import of the method.

METHOD OF TESTING CASTINGS ON SEPARATE BARS.

Description of the Method.

As to the testing method which is upheld against those outlined, the principle of this is to make the tests on separate test-bars cast in a special mould with the same metal as the casting. It is favoured chiefly by British and American founders, whose specifications are very similar, and it will again be Pearce's Paper from which its definition is derived:—"The logical procedure, therefore, is to cast a bar from the same metal at the same time as the casting (in a green-sand mould for a green-sand casting, in dry sand for a dry-sand casting)." The dimensions and shape are specified for three standard types recommended by the British Engineering

Standards Association, and are given in the following table:—

Shape.	Diameter.	Distance between supports in transverse test.	Maximum thickness of castings represented by test-pieces.
	In.	In.	In.
Cylindrical ..	0.875	12	$\frac{3}{4}$
Cylindrical ..	1.2	18	2
Cylindrical ..	2.2	18	$>$ 2

The medium test-bar has been adopted as the standard type in America, under the name of the "arbitration bar." The cylindrical form was chosen because in the tests it gave results showing higher values than bars with a square or rectangular section. The cause of this phenomenon has been ascribed by Norbury to a difference in crystallisation at the angles. In reality, all that can be proved by his experiments—the results of which are given in Pearce's Paper—is that the influence of angles, if they have any, does not operate alone; but the greater strength of round test-bars may equally well be due to a difference in the distribution of the stresses in the two types.

The tensile test-bars must necessarily be machined, but not the transverse bar, which would show a higher strength figure in consequence. As regards the dimensions chosen, there are three categories. "It is not satisfactory," according to Pearce, "to cast bars less than 0.875 in. thick, and this is the diameter of the smallest bar in the specification. It is taken as representing castings up to $\frac{3}{4}$ in. across the main section. Very heavy castings cannot be represented by too big a bar, as the breaking load must be within the limits of ordinary testing machines. The larger bar recommended is, therefore, 2.2 in. dia., to represent castings whose main section exceeds 2 in. The medium bar of 1.2 in. probably represents the bulk of engineering castings." It is on these test-pieces that the tensile, transverse and shock tests are carried out.

Criticism of the Method.

It has been shown in the first part of this Paper that the shock and tensile tests were adopted wrongly. The British test-bar is cast separately. It is, therefore, possible that it may have the same composition as the casting. There is no possibility of its having the same crystalline structure, as the conditions under which the cooling of the casting and the test-bar might be similar are systematically discarded. The result is that two castings entirely differing in form and in the distribution of their masses, but cast from the same ladle, and such that their thicknesses classify them in the same type of test, will be represented by the same test-bar, which is absurd, for they are as dissimilar mechanically as two castings produced from two metals chemically different.

This objection is in itself sufficient to justify the rejection forthwith of the method of testing castings by separate test-bars, and no argument will ever be able to prove the contrary. How can a casting be interpreted by a single result? For this the material composing it would have to be homogeneous, and the test would have to be applied to the material. Neither of these conditions, however, is fulfilled. Pearce criticises the Frémont method for testing a casting with a single test-piece. A test at a single point, he says, " is meaningless if it is intended to represent castings with different sections or different sections of the same casting." The authors do not appreciate how the separate test-piece is capable of doing this. Yet this is precisely the function which its advocates claim that it performs.

They would also like to know what are the reasons that governed the choice of the number of kinds of test-bar and their dimensions. How ought a casting with a maximum thickness of 2 in. to be tested—with the small or the medium bar? The results in these two cases will be different, and even incapable of comparison, as the transverse test is made with a distance of 12 in. between supports in the first case and 18 in. in the second. Similarly, how are castings to be classified according to mechanical value when some will have to be tested on the medium and others on the small test-bar?

It must be noted besides that the reasons which determined the choice of the bar's dimensions have no relationship with the castings which they are required to represent. In the case of the large one, for example, " not too big a bar was chosen, as the total breaking load must be within the limits of ordinary testing machines." All the conditions governing the casting of the test-bars, moreover, were laid down after discussions in which one important consideration seems to have been that of obtaining from the test the highest possible figure, whatever its significance might be. Thus, with reference to the transverse test, Pearce states: " If deflection is wanted, the bar should be machined, but if stiffness (high breaking load) is required, it should be tested as cast."

Finally, separate test-bars are subjected to the special condemnation of cast-on pieces expressed by Pearce, viz., that special attention is given them by the founder to the detriment of the casting itself. It is much easier, in fact, to fake a separate test-bar. To sum up, the separate test-bar is incapable of representing a casting, and no arguments can exist to justify the method of testing based on its use. The work done in England on these lines has not therefore solved the problem of testing castings. It, however, furnishes interesting data for the establishment of a method of testing the metal as such. This, moreover, is of considerable value from the point of view of research—as regards improving the composition of a charge, for example. But this interpretation of " the metal in the ladle " has nothing in common with that of the castings themselves, and one must be very careful not to assume that because a metal has given excellent results on separate bars it will produce castings of excellent quality. The two things are entirely different.

Specification for Engineering Castings.

In a previous Paper the authors published a model specification for testing the manufacture of engineering castings. They have been led to modify slightly the conditions required for each category of metal. The following are the provisions at present in force:

Tests.

General Soundness of Castings.—The castings shall be free from flaws, cracks, pipes, gas-holes, cold shut, or any other defects which might injure their strength or render either their strength or suitability in use doubtful.

Scabs, if slight, few in number and such as not to jeopardise the strength and proper working of the casting, shall be tolerated. In the examination of defects, moreover, the directions given below regarding the different qualities of metal shall be followed.

Castings showing defects in any part intended to remain visible after it is erected, which would disfigure their appearance without injuring their strength or their fitness in use, may either be repaired as described below or form the subject of a proposal for acceptance with a discount.

If the castings may not appear absolutely sound the inspector may, before authorising despatch, require the castings to be lightly machined at those parts where this is recognised to be necessary and possible, even if such parts are not intended to be machined ultimately, and subject to the thickness not being reduced below the minimum tolerances fixed above. Should such machining not be practicable the inspector may have the doubtful parts subjected to pickling with dilute acid or to any other equivalent process; he may also, if he considers it preferable, ascertain the importance of the cracks, scabs, pipes, etc., by a test with petrol or water under pressure.

Castings required to be water-tight or steam-tight shall be subjected to a water or steam test for a minimum of fifteen minutes at the pressure specified in the contract.

In castings intended to receive steam no defect, whether repaired or not, shall be admitted, with the exception of slight and localised defects, which shall be repaired as indicated below in respect of the different qualities of metal.

All castings intended to be erected, in which subsequent work may disclose defects prejudicial to their use, shall be returned to the supplier. The latter shall not refund the cost of machining or other charges incurred by the Navy, but shall refund the cost of the return transport, for which he shall be responsible. Such castings shall be replaced, or repaired if the inspector authorises their repair. In the latter case steps shall be taken after their repair to ensure, by carefully checking the measurements, that their dimensions are sufficient to permit of their being incorporated into an engine.

Nature of the Tests.

The following tests shall be made:—

(1) *Shear tests*, preferably on a test-bar taken with a trepan drill from the casting, but if necessary on a piece taken from a cast-on boss.

(2) *Hardness tests* for the purpose of judging homogeneity, made on parts with the skin removed.

(3) If required, and under the conditions specified below, *static transverse tests* on a bar taken from the casting or from a cast-on boss.

(4) If necessary, and under the conditions specified below, *compression tests* on a test-bar taken from the casting or from a cast-on boss.

Classification of Engineering Castings.

Engineering castings shall be classified in three categories:—(1) Extra strong, (2) strong, and (3) ordinary.

Special Conditions relating to Extra-Strong Castings.

The total number of tests, with the exception of the ball-test, shall be the whole number immediately below the quotient of the weight of the rough casting, serving as the basis for payment, divided by 200 kg., but such number of tests shall not be less than 2 or greater than 5. If it does not exceed two the tests shall be exclusively shear tests. If it is equal to or greater than three, one of the tests shall be a static-transverse test and the others shear tests. All the shear bars must show an average strength of at least 25 kg./mm^2. The static-transverse bar must stand at least 550 kg. and the breaking deflection must not be less than 30/100 mm.

In case of need, as when the shear-test machine used in the foundry is temporarily unavailable, the shear tests may be replaced by an equal number of compression or static-transverse tests on a test-bar taken from the casting or attached to it. The minimum compression strength shall in that case be 78 kg./mm^2, and the minimum static-transverse strength of the bar, the deflection not being measured, 550 kg.

Ball-tests distributed over the casting, the number of which prescribed by the inspector shall be sufficient to enable the homogeneity to be verified (on a basis of about one-ball test per sq. metre of surface), shall in principle give a Brinell hardness between 170 and 240. An excess in hardness, however, shall not involve rejection unless it occurs at a part which is to be machined, and a machining test made at such part (by file or machine) gives a negative result; while a deficiency in hardness shall not involve rejection unless a test made on a test-bar taken in the vicinity of the ball-test gives an average shear strength below the minimum allowed (the test-piece being taken, if required, with a trepan drill and replaced by a plug unless the strength of the casting prevents this).

In the case of repetition castings moulded in the same manner and cast with the same mixture (taken from the same ladle), the mechanical tests prescribed above shall be made on only one casting of the series at the option of the inspector. The other castings shall be subjected to ball-tests at least equal in number to the shear (or static-transverse or compression) tests carried out on the same casting. The Brinell hardnesses must remain within the limits indicated above. If any of the tests made on the type casting should not be satisfactory, each casting shall then be subjected to the entire series of tests.

Repair of Defects.

Only defects of extremely slight importance shall be allowed, and only when they quite obviously could not prejudice either the strength or the satisfactory service of the casting. If they impair the outer appearance they may be repaired, but only by plugging.

Special Conditions relating to Strong Castings.

Shear and static-transverse tests shall be carried out in the same manner as for extra-strong castings, except that the total number of them shall be equal to the whole number immediately below the quotient of the weight of the casting divided by 500 kg., but this number shall not be nil or greater than five. If it is less than three the tests shall be exclusively shear tests. If it is equal to or greater than three, one of the tests shall be a static-transverse test, the others being shear tests. All the shear bars must show a minimum average strength of 20 kg./mm^2. The static-transverse bar must stand a minimum load of 450 kg. and its breaking deflection shall not be less than 25/100 mm.

If necessary, as in the case of extra-strong engineering cast iron the shear tests may be replaced by an equal number of compression or static-transverse tests. The compression strength shall in that case be at least 63 kg./mm^2, and the static-transverse strength of the bar shall not be less than 450 kg., the deflection not being measured. Ball-tests distributed over the casting, as in the case of extra-strong cast iron, shall in principle give a hardness between 150 and 240. An excess or deficiency in hardness shall not involve rejection until it has been ascertained that machining is practically impossible, or unless the shear strength is insufficient, as in the case of extra-strong castings. In the case of repetition castings, the provisions specified above for extra-strong castings shall be applicable to strong castings.

Repair of Defects.

Only defects of slight importance shall be allowed, and only when they cannot prejudice either the strength or the satisfactory service of the casting. If they impair the appearance they may be repaired by plugging, or the insertion of special alloy (monel or an equivalent).

Special Conditions relating to Ordinary Castings.

In each lot of castings, whether similar or not, but cast from the same ladle, two castings selected by the inspector shall be subjected to shear tests. Both the test-bars shall show a minimum strength of 15 kg./mm^2. If they do not do so, each casting shall be subjected to the shear test, and only those which fulfil the foregoing condition shall be passed. If necessary, the foregoing tests may be replaced by an equal number of compression or static transverse tests made on test-bars taken from the castings or attached to them. The compression strength shall in that case be at least 48 kg. and the static-transverse strength of the bar at least 350 kg. Moreover, if the test made on the two type castings is favourable, all the other castings shall be ball-tested, their hardness shall be above 130 and below 240, but an excess in hardness shall not involve rejection unless, after trial, the parts intended for machining are not capable of being machined practically; while deficiency in hardness shall not involve rejection unless the shear strength of the casting in question is below 15 kg./mm^2

Repair of Defects.

Defects of slight importance which could not prejudice the strength or the satisfactory service of the casting shall be allowed. They may be repaired by plugging, the insertion of special cement or a special alloy, the application of metal of suitable composition, or by any other process sanctioned by the inspector.

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THE INFLUENCE OF SIZE OF SECTION ON THE STRENGTH OF GREY CAST IRON.

By J. G. Pearce, M.Sc., M.I.E.E. (Member).

Introduction.

The author has previously suggested* that there is a continuous change in strength of cast iron as the section alters, and that the transverse test is a cheap and simple method of following this change, provided the results are expressed as transverse rupture stress and not merely as breaking load. The experiments on which these conclusions were based were somewhat limited in scope, the sizes of bars used being largely the three specified in B.E.S.A. Specification 321 for grey iron; 2.2 in., 1.2 in. and 0.875 in. diameter round bars. The interest they aroused has enabled the author to obtain data on a wider range of sizes and compositions, and although the whole of the work in progress is not yet completed, some further points of interest have emerged.

If a cylindrical transverse bar is cast and tested, the transverse rupture stress R is readily obtained by the usual formula $\frac{2.5\ WL}{d^3}$ where W is the central breaking load, L is the span, and d is the diameter. If W is in tons and L and d in inches, R is in tons per sq. in. In all tests recorded below, unless otherwise stated, L is 21 in. Heavy bars do not give a suitable deflection at the usual 12 in. and 18 in. spans recommended in B.E.S.A. Specification 321. In view of the slight change in rupture stress with span it seems desirable that this should be standardised for all sizes of test bar.

If a pig-iron is melted and a set of separately-cast, cylindrical bars made of varying diameters,

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* "Journal Iron and Steel Institute," 1928, II, p. 73, and FOUNDRY TRADE JOURNAL, January 24, 1929.

the strength of the bars can be related to the size, as shown in Fig. 1, where the line AB represents a mean curve drawn through the actual points showing the transverse rupture stress at various diameters from 0.8 in. to 4.7 in. As would be anticipated, the smallest bar (0.8 in. diameter, which remained grey) was strongest (just over 35 tons per sq. in.), and the larger bars became progressively weaker per sq. in. of their section, the 4.6-in. bar being only 22 tons per sq. in. AB is the size-strength curve for the particular mixture and set of melting conditions employed.

Influence of Machining.

The author has previously suggested that although the skin is normally the strongest part of a casting, the increase in strength following on skin-machining may be due to the fact that minute fissures and skin cracks result in premature fracture when the bar is tested as cast in transverse. In Fig. 1 the curve AB referred to above represents the strength of a set of bars tested after skin-machining, while CD represents the strength of a set of bars cast from the same metal at the same time from the same patterns, but tested as cast. The actual figures obtained for the various bars of the unmachined set are shown by the broken line as well as the mean curve CD. The amount removed in machining varied from 0.02 in. to 0.05 in. It will be noticed that the machined series is the stronger, the difference being about 8 per cent. Further machining would doubtless have shown a reduction in strength, the amount depending on the composition and structure of the metal, for some irons weaken towards the centre more rapidly than others.

The favourable effect of skin-machining is, of course, well-known, but this case is quoted because the points representing the strengths of the machined series lie much more closely on the curve than those of the more erratic unmachined series. In other words, the variations from the mean are less pronounced in the machined than in the unmachined series. Local heterogeneity and other differences inevitable in ordinary cast iron, as well as slight variations in testing procedure, cause slight variations from the expected even on machined bars, but there is no doubt that more uniform results are obtained from skin-machined bars, and the difference shown in Fig. 1 has been repeatedly confirmed for other series of bars. The remaining tests given in the paper, unless otherwise specified, refer to skin-machined bars, and the strength given is based on the tested diameter taken at the fracture. There is much to be said for testing machined in preference to unmachined bars, and the use of the round test bar renders this a much more practicable proposition than was the case for the old square or rectangular bar. In the series shown in Fig. 1, tested as cast, a 0.5 in. diameter bar is included, and the fall in strength on this is probably due to mottling. It is particularly difficult to determine whether mottled or white iron is or is not actually stronger than grey iron because of its brittleness. Analysis is given in Table I:—

TABLE I.

Curve.	Fig.	T.C. Per cent.	Si. Per cent.	Mn. Per cent.	S. Per cent.	P. Per cent.
1A, 1B, 2A	1 & 2	3.51	1.03	0.61	0.14	0.73
2B	2	3.44	1.13	0.50	0.16	0.95
3A	3	3.55	1.95	0.50	0.08	0.72
3B	3	3.71	1.29	0.62	0.09	0.59
3C	3	3.50	0.68	0.35	0.18	0.64
5A	5	3.16	2.06	0.39	0.14	1.12
5B	5	3.24	1.41	0.56	0.10	0.55
5C	5	3.42	1.17	0.39	0.13	0.60
7A & 7B	7	3.46	1.57	0.45	0.10	0.43

It was possible to obtain a set of bars made from iron very similar in general character to that used for the bars in Fig. 1, except that the phosphorus was slightly increased. The result is given in Fig. 2 as curve B, and for comparison the curve AB of Fig. 1 is reproduced as curve A. The two irons differ, as will be seen from the analyses of Table I, only slightly in the other elements.

Influence of Melting Conditions on Strength.

Dr. A. L. Norbury has recently shown* in the laboratories of the British Cast Iron Research Association that cast irons may present marked differences in mechanical properties in spite of similarity of chemical composition, due to differences in melting conditions resulting in differences in structure. That such differences are experienced in ordinary cupola-melted irons is evident from data given by Mr. W. Jolley,† and indeed the conclusion is borne out by practical experience, for unaccountable differences and anomalies not explained by chemical composition and often ascribed to gases, small quantities of rare elements and so on, are met by most foundrymen. In these circumstances it might appear erroneous to suggest any relationship between composition and strength, and indeed a considerable body of foundry opinion views pessimistically any attempt to relate the two, since these differences occur in castings which have compositions as close together as ordinary practice permits. This in some quarters also has the unfortunate effect of discrediting chemical analysis and the guidance which it can give. It can now be taken as established that the differences referred to are due to differences in melting conditions, and their effect on the metal is not always recognised.

An ordinary foundry melting a similar mixture, say a pig and scrap mixture, day after day in the same furnace, works under a set of melting conditions which is subject only to comparatively minor variations. The product of such a foundry remains, so far as the composition and structure of the metal is concerned, within practical limits, the same. The foundry, however, may unconsciously alter the structure, and hence the strength and other properties of

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* "Journal. Iron and Steel Institute," 1929, Vol. I., p. 443.

† FOUNDRY TRADE JOURNAL, April 4 and 11, 1929.

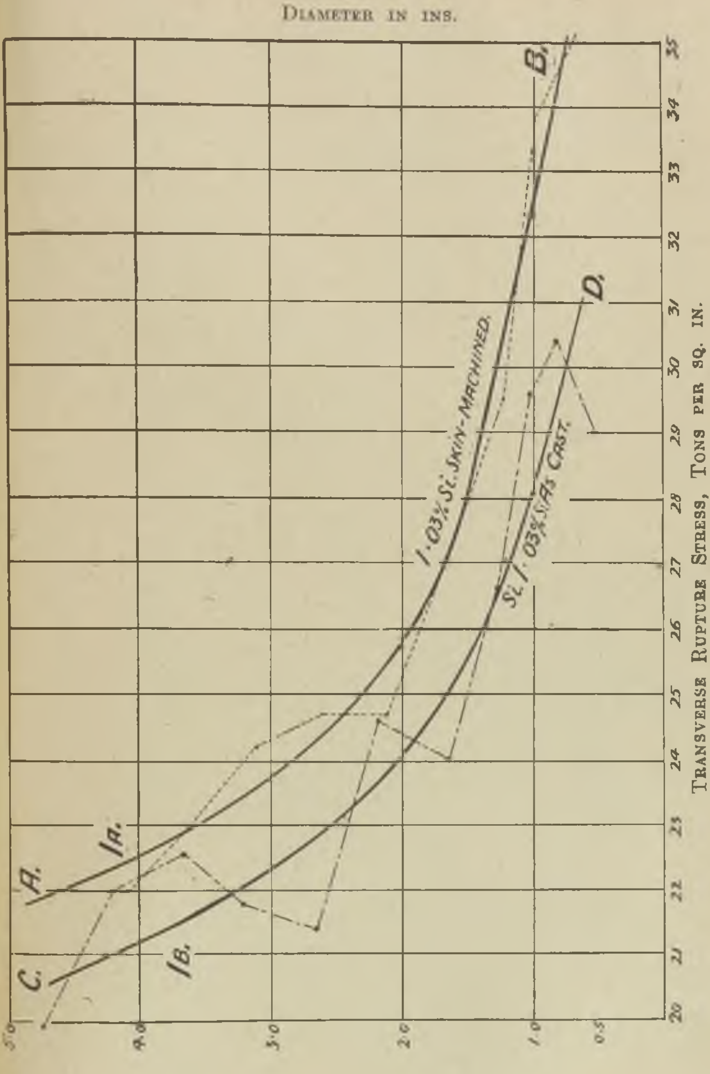
DIAMETER IN INS.
TRANSVERSE RUPTURE STRESS, TONS PER SQ. IN.
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
5.0
4.0
3.0
2.0
1.0
0.5
A.
/A.
B.
/B.
C.
D.
1·03% Si. SKIN-MACHINED.
Si. / 1·03% Si. AS CAST.

FIG. 1.

its castings, by introducing a change in melting conditions, even when an attempt is made by scientific mixing to produce the same composition as before; this may arise from an alteration of the brand of pig-iron, by introducing steel into the charge, by the use of foreign scrap of unusual composition, by changing temporarily from one composition of ferro-alloy to another (*i.e.*, from a lean to a rich ferro-silicon), or by changing from a cupola to a crucible or air furnace. The effect of such changes can now, with some measure of accuracy, be forecast. They may affect composition in the absence of scientific mixing, but in any case they affect structure—mainly the size and distribution of the graphite.

An illustration of the differences between irons of somewhat similar composition made in ways which many founders would consider calculated to give similar results was recently furnished by Mr. John Shaw, who kindly arranged for the Brightside Foundry & Engineering Company, Limited, to melt two mixtures in the same cupola and cast them into 1.2 in. (M) and 2.2 in. (L) bars, as far as possible under identical conditions. The first charge was made up of equal proportions of steel and white iron with enough 12 per cent. ferro-silicon and ferro-manganese to yield a strong grey iron. The second charge was made of the same materials with the exception that 40 per cent. ferro-silicon was used in the place of 12 per cent., the proportion, of course, being altered to give the same silicon content in the melt. Unfortunately the silicon contents differed slightly in the bars, which were tested strictly in accordance with B.E.S.A. Specification 321. The results are

TABLE II.—*Analyses.*

	T.C. Per cent.	Si. Per cent.	Mn. Per cent.	S. Per cent.	P. Per cent.
A	3.2	1.37	0.94	0.09	0.18
B	3.5	0.98	1.01	0.09	0.21

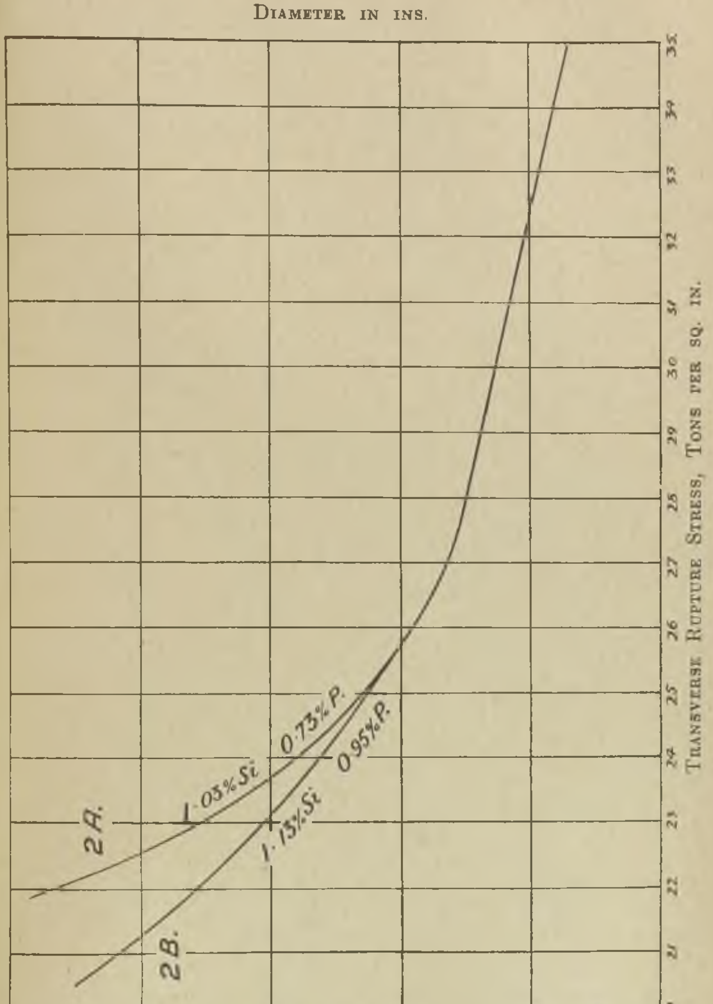
DIAMETER IN INS.
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
5.0
4.0
3.0
2.0
1.0
0.5
2A.
2B.
1·03% Si
0·73% P.
1·13% Si
0·95% P.
TRANSVERSE RUPTURE STRESS, TONS PER SQ. IN.

FIG. 2.

given in Tables II and III. The combined carbon was about the same, 1 per cent., in each. The difference in total carbon should be regarded as due to melting conditions rather than composition. Micro-examination showed a slightly coarser graphite structure and a rather larger quantity of graphite in B, which is the weaker iron mechanically and the lower in silicon.

Thus a change in melting conditions which many foundrymen would assume would not produce any marked difference in the product is shown to produce a decided difference in strength. This example shows that differences occur in cupola-melted irons as well as in crucible-melted irons found by Dr. Norbury. Criticism directed against attempts to correlate composition and strength is often based on experience in which differences arise from alterations in the melting conditions. If these remain the same comparison is possible, and the illustrations used in the paper are all based on the melting conditions remaining the same for all irons compared on a basis of composition.

It is, of course, not possible to compare, until a good deal more work has been done, strengths of irons produced under varying melting conditions, but from the same raw material a curve of the type shown in Figs. 1 and 2 enables different foundries to compare their melting conditions. Bad conditions give poor results and vice versa. Furthermore, in the same furnace the results of different raw materials can be compared, and so on. No very definite conclusions, however, can be drawn from curves prepared for different raw materials melted in different ways.

Influence of Composition on Strength.

Adhering rigidly, therefore, to one type of raw material mixture and one cupola, size-strength curves have been prepared for irons of varying silicon contents. Fig. 3 shows curves A, B and C for three such irons. It will be noticed that they are approximately parallel, but that a drop of 0.5 per cent. silicon from 2 per cent. to 1.3 per cent. increases the strength less

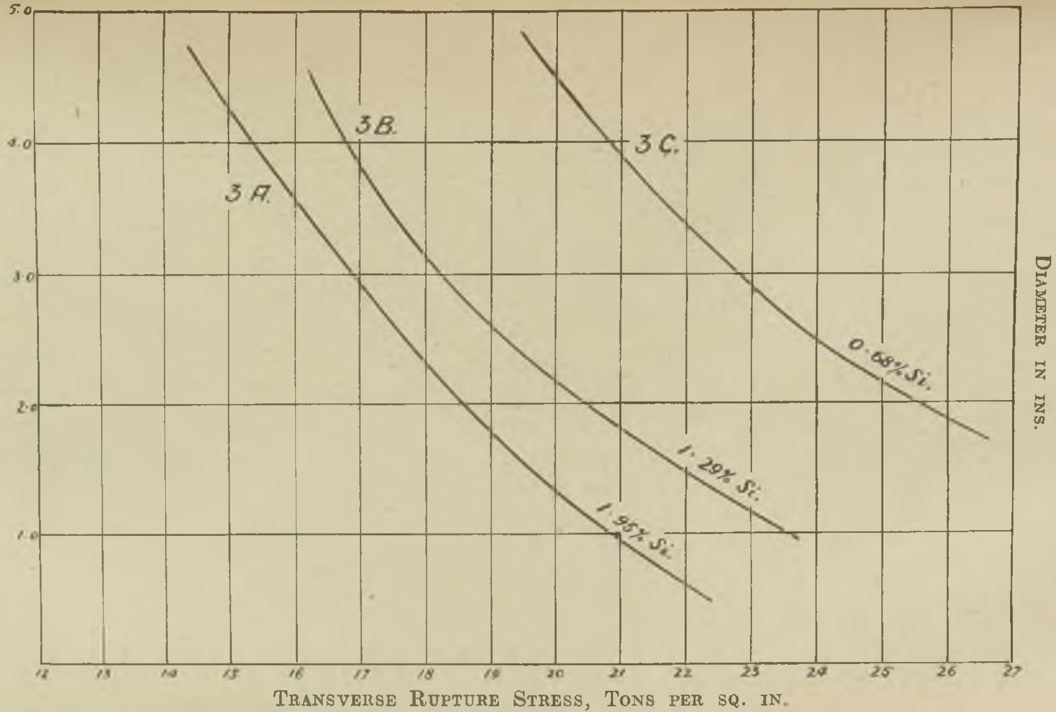
Diameter in ins.
5.0
4.0
3.0
2.0
1.0
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
Transverse Rupture Stress, Tons per sq. in.
3 A.
3 B.
3 C.
0·68% Si.
1·29% Si.
1·95% Si.

Fig. 3.

than the drop from 1.3 per cent. to 0.7 per cent., the smaller bars of the latter series being white. In Fig. 4 silicon content has been connected with strength for various sizes of bars, 4 in., 2.2 in. and 1.2 in. being chosen. From this curve can be read off the strength of a cylindrical bar of any silicon content and conversely the silicon required in a given bar to give a specified strength. For intermediate sizes of bars values may be either taken from the size-strength curves or judiciously interpolated.

In Fig. 5 size-strength curves A, B and C have been drawn for three foundry mixtures of varying silicon contents, analyses being given in Table I. It was naturally not possible to keep total carbon and other elements within the same limits as fixed for irons in Figs. 1, 2 and 3, where only one pig-iron was melted, but here again composition-strength curves have been drawn in Fig. 6 connecting silicon and strength, and the general similarity between the curves in Figs. 5 and 6 with corresponding curves for irons much closer in composition shown in Figs. 3 and 4 will be noted. The reason for this probably is that differences in chemical composition (other than silicon) are of comparatively minor importance compared with differences in melting conditions. Hence the reason for ignoring small composition differences between irons melted under similar conditions, such as those shown in Fig. 3, as well as the more considerable ones shown by the irons in Fig. 5.

On the other hand, when the melting conditions differ, there are considerable differences in strength even where compositions are similar, as may be seen by examining Figs. 1 and 2 and comparing the results with those shown in Fig. 3, and comparing the results of each of these with those of Fig. 5. The comparison is best shown by Figs. 4 and 6 and illustrates the virtue of remelting.

When such differences can arise from factors other than composition it will be appreciated that differences in composition, such as those be-

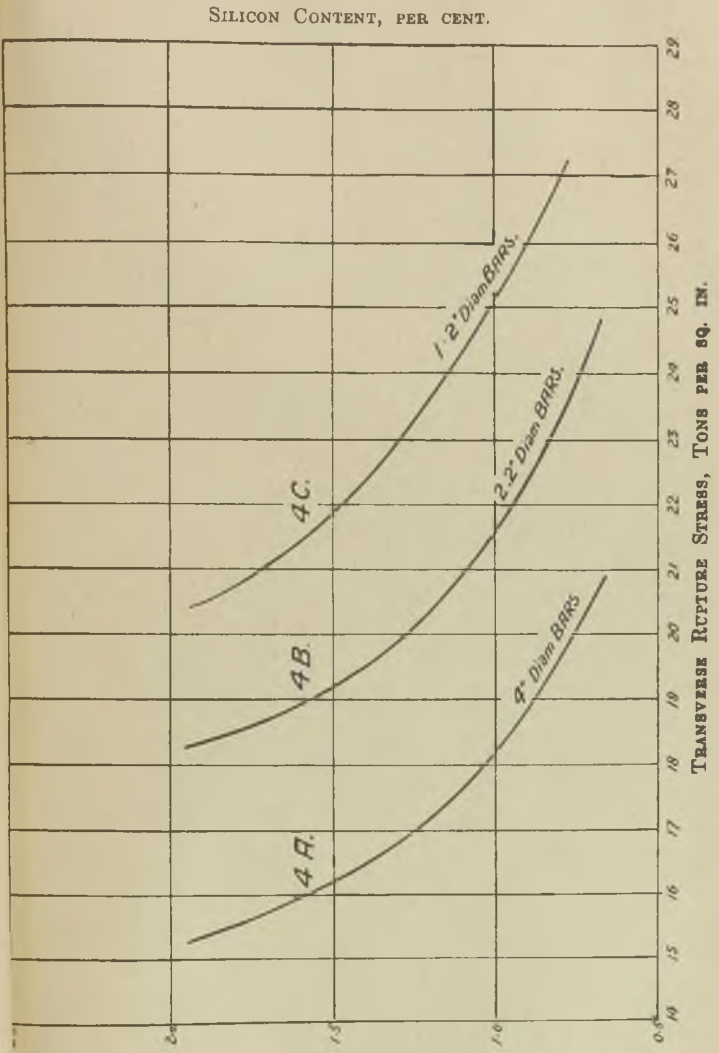
Silicon Content, per cent.
2.0
1.5
1.0
0.5
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
4 A.
4 B.
4 C.
1·2" Diam BARS.
2.2" Diam BARS.
4" Diam BARS
Transverse Rupture Stress, Tons per sq. in.

Fig. 4.

tween A and B in Fig. 2, between A, B and C in Fig. 3 or between A, B and C of Fig. 5, are of comparatively minor importance.

Size-strength curves similar to those shown in Figs. 1, 2, 3 and 5, and composition-strength curves for a given set of melting conditions similar to those in Figs. 4 and 6, have been obtained on a number of sets of bars. Little useful purpose, however, is served by multiplying illustrations which only apply to one set of melting conditions. The aim of the Paper is to suggest a method which enables comparisons to be made between different irons melted under the same conditions and the same irons melted under different conditions.

The transverse test, of course, is only one mechanical test and may offer little guidance as to the ability of the metal to withstand fatigue, fluid pressure, abrasive wear, corrosion or heat.

Tensile and Transverse Strength.

If a series of bars from a cast be tested in tension on the same-sized test-piece, the values will not, under ordinary conditions, depart far from the mean, and the same applies to transverse tests. For the particular mixture and the sizes of test-bars chosen there will, therefore, be a definite ratio of transverse to tensile strength. For ordinary irons and the usual standard bars this ratio is about 1.8 to 2. Through the courtesy of Vickers-Armstrongs, Limited, Barrow-in-Furness (Mr. W. Machin and Mr. W. B. Goudielock), the author tested bars of 1.2-in. and 2.2-in. cylinder iron in transverse, averaging three results in each case. The broken bars were then turned to tensile pieces of different diameters varying in the 1.2-in. bars from 1.0 in. to 0.2 in. and in the 2.2-in. bars from 1.9 in. to 0.2 in. The variation in tensile strength with diameter is shown in Fig. 7, A representing the 2.2-in. and B the 1.2-in. bars, and Table I gives the analysis. It will be seen that tensile strength falls off very rapidly as the machined diameter decreases, but that at the specified B.E.S.A.

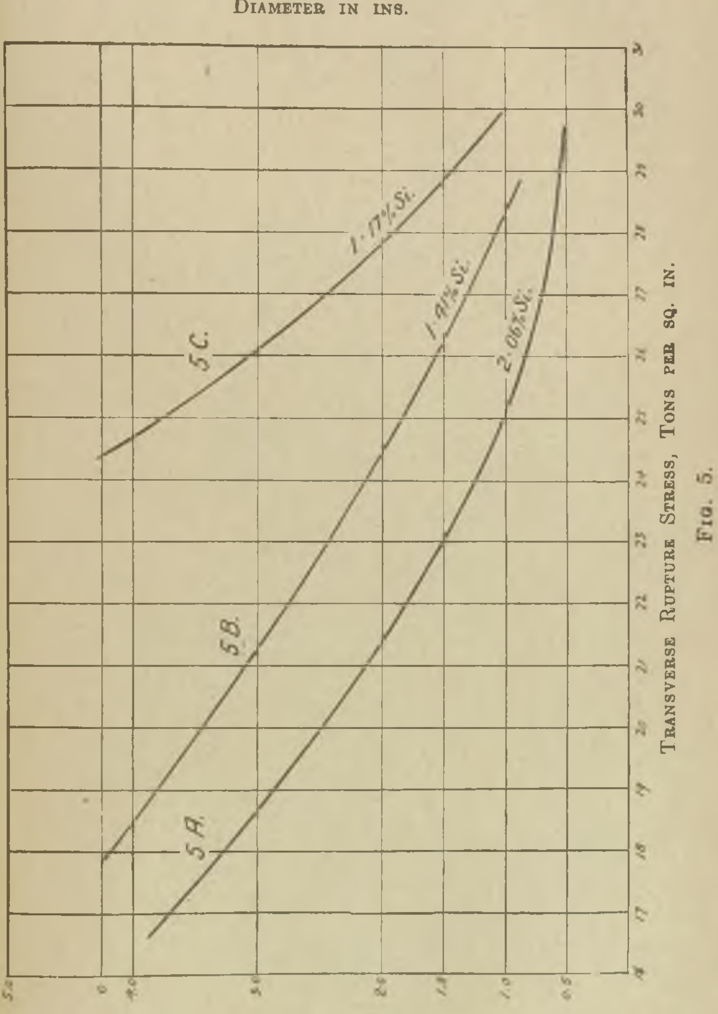
DIAMETER IN INS.
TRANSVERSE RUPTURE STRESS, TONS PER SQ. IN.
5 C.
1·17% Si.
5 B.
1·91% Si.
5 A.
2·06% Si.
5.0
6
4.0
3.0
2.0
1.5
1.0
0.5
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16

FIG. 5.

TABLE III.—*Mechanical Tests.*

Cast.	Transverse—18-in. centres.				Tensile. Tons/sq. in.
	Bar.	Load. Tons.	Deflection. In.	Rup. stress. Tons/sq. in.	
A	M	1.22	0.24	32.4	20.1
	L	6.35	0.19	28.7	16.0
B	M	1.24	0.24	31.3	18.0
	L	6.0	0.22	26.7	14.9

diameter for each size of bar, the tensile strength falls within the range represented by transverse strength divided by 1.8 to 2.0. Clearly the ratio of transverse to tensile depends on the size of the test-piece, and tests on other compositions will enable the influence of composition to be determined. In a set of bars of four compositions kindly provided by Metropolitan-Vickers, Limited (Mr. W. Jolley), a 1.2-in. transverse bar was broken and one half turned to the standard tensile diameter of 0.564 in. and the other to the standard tensile diameter of 0.798 in. The transverse/tensile ratio varied between 1.59 and 2.18, and the question undoubtedly demands further examination. The mechanical tests of the last-mentioned set are given in Table IV.

Conclusion.

The author would again stress the fact that the curves shown have no general validity and apply only to one type of charge melted under one group of conditions. The aim in view is to suggest a method which will enable a foundry to compare different melting conditions by using the same charge, and to compare different mixtures by using the same melting conditions. Such tests should enable the best melting-conditions to be established, and in some respects this problem is more urgent than that of obtaining good raw materials. It can afford little satisfaction to makers of high-class pig- and refined-irons to have their materials degraded in quality under poor melting-conditions, and the cheaper the grade of pig-iron used the more important does it become to melt it so as to get the best out of it.

The author thanks the Council of the British Cast Iron Research Association for permission to publish this Paper, and, in addition to the acknowledgments made in the Paper, has to express his indebtedness to the Lilleshall Company, Limited (Mr. T. E. Freeston), for the large amount of work willingly undertaken in preparing the bars on which Figs. 1 to 4 inclusive are based, and to Lee, Howl & Company, Limited

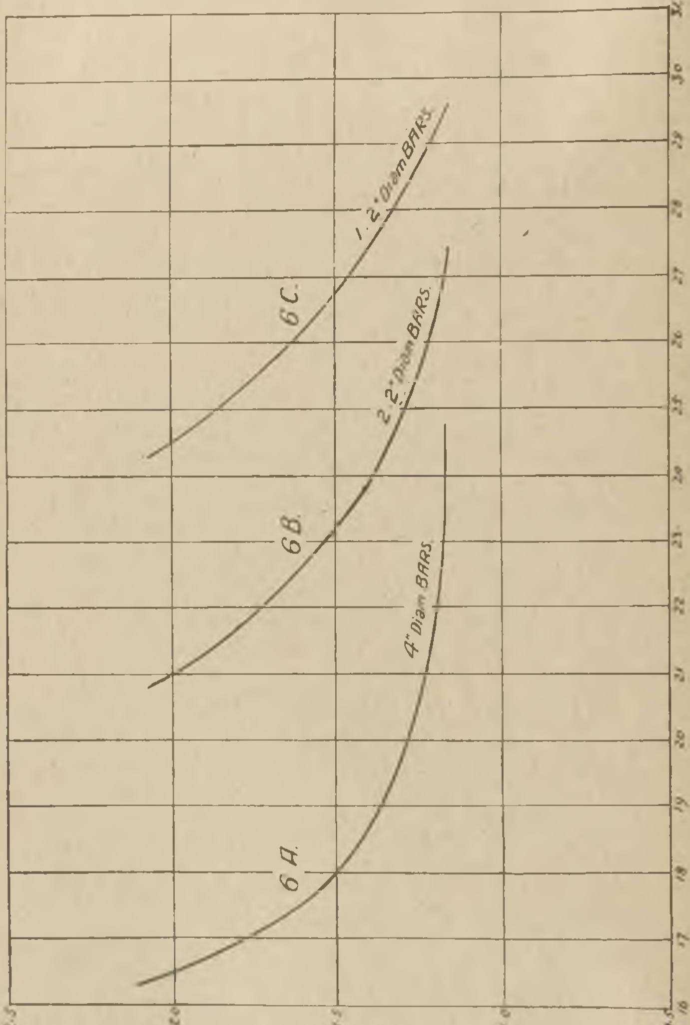
SILICON CONTENT, PER CENT.
2.5
2.0
1.5
1.0
0.5
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
6 C.
1.2" Diam BARS.
6 B.
2.2" Diam BARS.
6 A.
4" Diam BARS.
TRANSVERSE RUPTURE STRESS, TONS PER SQ. IN.

FIG. 6.

(Major C. Howl), for similar help in preparing bars on which Figs. 5 and 6 are based.

Summary.

The strength of cast iron is determined by its composition and its structure, these factors being fixed in part by constitution of the charge and in part by the melting conditions. For a given type of charge melted under the same conditions and poured into a series of cylindrical bars, transverse strength increases continuously as section diminishes. Skin-machined bars are not only stronger than bars tested as cast, but the results are less erratic.

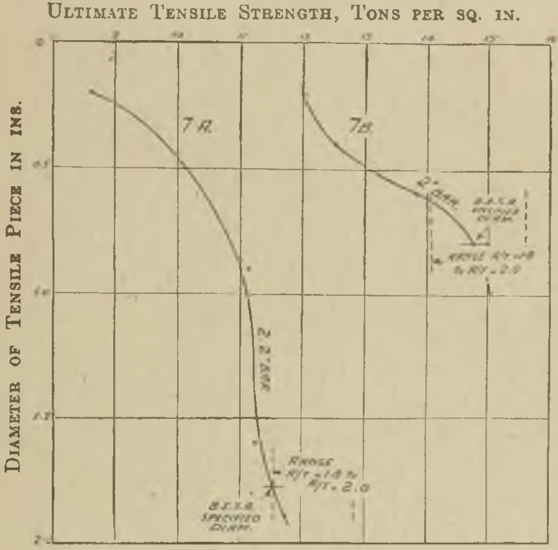

Fig. 7.

Illustrations are given of size-strength curves for two series of irons, both cupola-melted, one series being pig-irons and the other foundry mixtures. Each series has three silicon contents and its own set of melting conditions. From

TABLE IV.—*Mechanical Tests.*

Mixture.	Transverse R. on 1.2-in. bars, 12-in. centres.		Tensile T. Tons/sq. in.		$\frac{R}{T}$	
	Rup. stress. Tons/sq. in.	Deflection. In.	0.564	0.798	0.564	0.798
S	32.0	0.13	16.04	18.24	1.99	1.76
SS	29.8	0.11	18.76	18.54	1.59	1.61
C	20.8	0.13	9.52	10.00	2.18	2.08
CC	22.5	0.08	13.28	11.8	1.70	1.91

each set of size-strength curves composition-strength curves are deduced. The curves are of the same type in each series of mixtures.

For a cylinder iron the ratio of transverse strength to tensile strength is shown to fall within the range 1.8 to 2 for standard B.E.S.A. conditions of testing.

JOINT DISCUSSION ON THE FOLLOWING PAPERS.

Methods of Testing Cast Iron and The Influence of Size of Section on the Strength of Grey Cast Iron.

Mr. John Shaw said the Convention was indebted to MM. Le Thomas and Bois for a clear statement of their views concerning tests for cast iron. This discussion could but clear the air. He said at once that the limitations of the separately cast bar were recognised, but to say "That in no case will these bars give reliable information as to the casting be made from it" was but the exaggeration of a biased mind. So far as British experience went, while they recognised its limits, they had received more information regarding physical properties of a casting by testing a suitably-sized bar cast on the casting than by any other method, except testing the whole casting. Any test cut from the casting, at best, but represents that portion of the casting. The number that could be taken were limited, and often the places most liable to segregation, etc., such as the thick places in the ports of an engine, could not be tried.

Controlled Conditions Yield Constant Shear-Tensile Ratio.

There was also no doubt that under the very closely controlled conditions such as were specified by Le Thomas and Audo in their excellent Papers on foundry control, the shear tests would give fairly concordant results or that these results might have a fairly constant ratio to the tensile results on the same material. But that ratio would only hold good for the specified metal under consideration. That was the crux of the whole matter. Engineers the world over used the tensile strength factor to compute the thickness of their scantlings. Inspecting engineers also depended on this and the transverse result to pass with confidence the material examined, so far as the strength of the metal put into the casting was concerned. Could the shear test result be converted into the tensile result by a single constant? Or if not, could the shear test result be used for designing machine requirements? The answer to both these questions was in the negative. It was claimed that tensile results for cast iron were never correct. This, however, he did not admit if done carefully in a proper machine. After testing eight different bars it was found that, on testing again the broken halves, no result of any half varied more than 0.5 tons from the original bar. Norbury, before starting a recent investigation, also tried out this matter. From each of the two mixtures he cast four bars. His results were as follows:—12.8 tons, 12.7 tons, 12.4 tons, 12.9 tons. The other material gave 18.9 tons, 18.2 tons, 18.7 tons, 18.3 tons. Surely these figures are near enough for practical requirements. Even if it were granted that the machine or structure of the bar did not return true tensile results, the test would always be below the true strength figure and would thus only give an additional factor of safety to the engineer. On the other hand, it was always found that where shear and tensile results of metal of varying composition were given, there was a premium accorded to poor material by the shear test. Take but one example from experience: MacKenzie sent him a 2-in. by 1-in. bar of acknowledged poor iron. The modulus of rupture figure was 14.4 tons, whilst the shear test gave 26.4 tons. Such results might enable foundrymen to get poor material accepted, but it would recoil on them and deal a blow at the industry in which they were all interested.

History of Frémont Test.

Examining the history of the Frémont shear test, Mr. Shaw said that this engineer was not satisfied with the test methods in vogue 28 years ago, and turned his attention to the shear test. After designing a small machine for this purpose he collected 140 bars of known tensile and impact values and compared these results with shear tests taken from small pieces cut from these bars. From these results he drew certain conclusions. It was known now that these conclusions were open to serious doubt; in the first place, it was known that even the improved and modified Frémont shear machine shown at the last Exhibition held in London was not perfect. Attention was drawn to this by both Elliott and Rother. The author admitted this in his reply to Professor Pisek and also the fact that he did not use this type of machine himself. It was known that in the foundries of 25 years ago the tensile machine was of a very crude character and its results not dependable. There was no information given of the chemical composition of the bars, nor if all were cast and tested in one size, and certainly there was no knowledge of their structure, and it seemed to him that the whole of Frémont's work was so doubtful, owing to causes over which he had no control, that it would be better left out of any argument. Surely, after six years' intensive propaganda such as had been made, more recent and dependable information could be produced. Unfortunately, this was not so, or at least it had not been published. There was the excellent unbiassed Paper by Professor Siegle given in 1923, whose conclusions were much in line with our own. There were also the two American reports by Elliott and Rother. They both agreed that on the same bar on the same machine the shear results were fairly concordant, but, as Rother pointed out, both workers obtained a different ratio of shear to tensile. Rother's figure was 0.75, whilst Elliott's was 1.3. Neither of them noticed that shear ratio to tensile increased in both cases with the lower tensile results, but it was so. Bolton's Table also demonstrated the same feature. If the 1.2 bars only were abstracted, the low tensile results a ratio of 1.5, whilst the highest showed 1.26. Pisek also produced confirmatory evidence, but he personally had not a copy of his figures. Ronceray gave a Paper on the subject, but it contained no other data but Frémont's original figures. There were also two excellent foundry-control Papers by Audo and Le Thomas, in both of which the same type of material was used, namely, a low-phosphorus, low-sulphur iron, and each strove to obtain a full pearlitic matrix. Very complete control was exercised from the initial raw material to the machined casting. As already stated, under these conditions concordant results might be expected, but this was for one type of material only and was of little use in arriving at a conclusion as to the value of the shear test when applied to the large variety of work both in design and mixtures that were now in use, where tests were called for. After all, it was an international test and not a works routine test that was sought for. It must be remembered also that both in France and in this country there were large quantities of useful iron carrying 1 per cent. phosphorus. That, to his mind, summed up the available information outside Britain, but there was no doubt that more work on a scale dealing with varied compositions had been done here than elsewhere, and these results were open for anyone to check in their own works.

British Opinion Crystallised.

Briefly, the findings, as the result of the work done on shear testing in this country, were:—

(1) The machine would need to be standardised if similar readings, even from the same sample, are to be obtained; also the least wear affects the results.

(2) That trepanning out a sample is useless unless that sample is either ground or machined to dead-size. Jolley has shown that with every reduction per $\frac{1}{1000}$ in. the result per square inch and ratio alters.

(3) That the 0.22-in. dia. bar is too small to give true results and is sensitive to graphite-size much more than 0.5 in. dia. Pearce found an increase of over 4 tons between 0.22 in. and 0.5 in. dia., three of each being tested from the same bar and position. A glance at Jolley's results also confirmed this. As the finer-structure metal is tested this difference ceases.

(4) If test bosses were drilled, as suggested by Le Thomas, it was found it depended again on the structure. Elliott stated one test taken from the centre of the boss gave 14.2 tons, whilst near the edge it showed 17.2 tons. Hyde obtained from the middle of the end section of a 2-in. by 1-in. bar, 15.4 tons, whilst tests from either side gave 18.6 and 19.5 tons respectively. A second bar from the same boss showed the same result. If the sample were taken from the casting itself it was found that by taking shears ⅛ in. each time that the results were as follows:—15.3 tons; 14.6 tons; 13.8 tons. Reversing the same sample so as to start again with an outside edge, but taking cuts ⅜ in. each time, the results dropped to the following:—15.3 tons; 13.5 tons; and 12.9 tons. Le Thomas mentioned the danger of separately tested bars being faked. With bosses cast on as he suggested, this was a much more real danger; a chill plate on the end or a few flat-headed nails flush with the mould would alter the boss structure entirely, and the fraud would be very difficult to discover.

(5) The dominating factors were that the shear-test result had no constant ratio to either tensile or transverse with varying composition. That in every case by this test a premium is placed on poor material, whether it be soft or brittle. In the case of Jolley's results, which extended over twelve months and covered at least 150 tests, the metal was always run into castings, and the test-bar used throughout was 14 in. by 1 in. by 1 in., the tensile and shear being taken from the broken transverse, yet the shear ratio to tensile varied from 1.37 to 1.84. Pearce's figures were from 1.07 ratio to 1.92; Hyde's figures on two mixtures only were 1.2 ratio to

TABLE A.—*Tests arranged in Order of Transverse Strengths.*

Transverse. Tons mod.	Deflection in in.	Shear. Tons.	$\frac{\text{Shear}}{\text{Trnvs.}}$ Tons.	Difference. Tons.	T.C.	C.C.	Si.	Mn.	S.	P.
14.4	—	26.4	1.83	+12.0	3.1	—	2.0	0.39	0.37	0.85
16.74	0.260	14.7	0.88	− 3.0	3.04	—	3.19	0.63	0.057	1.32
16.87	0.307	22.8	1.35	+ 5.9	3.25	1.12	1.56	0.27	0.128	1.17
17.75	0.346	23.7	1.34	+ 5.9	3.25	1.12	1.56	0.27	0.128	1.17
17.71	0.274	15.2	0.85	− 2.5	3.04	—	3.19	0.63	0.057	1.32
18.16	0.287	17.4	0.95	− 0.76	3.01	—	2.93	0.61	0.059	1.14
18.35	0.290	17.8	0.97	− 0.55	3.01	—	2.93	0.61	0.059	1.14
18.69	0.361	22.7	1.21	+ 4.01	3.25	1.12	1.56	0.27	0.128	1.17
18.78	—	26.1	1.38	+ 7.32	2.65	1.07	2.15	0.32	0.168	1.27
19.72	—	18.9	0.96	− 0.82	3.38	0.58	1.47	0.79	0.106	0.64
19.32	—	19.95	1.00	+ 0.63	3.44	0.49	2.03	0.72	0.089	0.86
20.0	—	13.5	0.67	− 6.5	3.50	—	2.00	0.57	0.08	0.57
21.1	—	12.4	0.59	− 8.7	3.30	0.60	1.75	0.65	0.08	0.39
21.17	—	13.67	0.64	− 7.48	—	0.28	—	—	—	1.00
21.68	—	14.31	0.66	− 7.37	—	0.36	—	—	—	0.90
23.45	—	20.0	0.85	− 3.45	3.51	0.61	1.61	0.72	0.10	0.74
25.2	—	18.2	0.72	− 7.0	3.22	—	1.54	0.61	0.07	0.36
25.6	—	18.4	0.72	− 7.2	3.16	—	1.50	0.56	0.06	0.56
26.5	—	12.9	0.49	−13.6	3.41	0.77	1.75	0.51	0.08	0.55
27.3	—	18.0	0.66	− 9.3	3.35	0.60	1.68	0.65	0.117	0.56
27.13	—	17.9	0.66	− 9.23	3.36	0.56	1.91	1.20	0.103	0.58
29.2	—	18.4	0.59	−10.8	3.17	0.87	0.68	0.67	0.156	0.166
32.8	—	20.47	0.62	−12.33	—	0.70	—	—	—	0.50
34.68	—	23.13	0.67	−11.55	—	0.95	—	—	—	0.50
35.4	—	18.7	0.53	−16.7	2.03	0.72	1.39	0.87	0.04	0.157
40.5	—	20.7	0.51	−19.8	2.03	0.72	1.39	0.87	0.04	0.157

1.42. Personally derived figures on turbine mixture were 0.99 ratio to 1.91 on hard but machinable iron; Cameron's figures on six mixtures were 1.04 ratio to 1.17. In every case the higher ratio went with the low tensile result. In conclusion Mr. Shaw assured the Continental visitors that the British had no other object than to serve our common trade. It did not matter from what source a better test procedure could be produced; if fully approved it would receive their whole support.

In justification of his conclusions, Mr. Shaw submitted Tables A to C.

The **President** remarked that the discussion revolved round whether a certain section of the foundry industry approved of the shear test or whether they did not. He hoped subsequent speakers would be as brief as possible. There was no necessity to stress the fact that different results were obtainable from different thicknesses of sections; such a condition of things was common to all and every test applied to cast iron. What it was desired to bring out in the discussion was whether the shear test as submitted by our French colleagues was a reliable and practical test for use in the examination of castings.

The Function of Testing Defined.

Mr. J. T. MacKenzie (American Foundrymen's Association) said that, speaking for himself, it seemed to him that the British and the French had arrived at some unanimity of opinion on this matter, although in different directions, but there seemed as many different opinions on this matter in America as it was possible to have. The principal exponent of the shear test in the United States was Mr. Bolton, who found it very useful for surveying castings, as he called it, but personally he did not think the fact that the shear test did not show a rectangular function of the tensile meant that it was not a function of the tensile. He was certain that in the case mentioned by Mr. Shaw there was a pipe in the centre, and the tensile test on such a bar

TABLE B.—*Effect of Cupola Practice and Steel Additions on Physical Properties.*

Tns. T.sq.in.	Tns. sq.-in. 0.5 shear.	T.C.	Si.	T.C. + Si.	$\text{T.C.} + \frac{\text{Si}}{0.3}$	$\frac{\text{Shear}}{\text{Tensile}}$	C.C.	Mn.	S.	P.
9.8	16.8	3.44	1.56	5.00	3.91	1.71	0.59	0.68	0.11	0.64
10.0	16.2	3.46	1.60	5.06	3.94	1.62	0.56	0.65	0.114	0.48
10.9	18.2	3.41	1.93	5.34	3.99	1.67	0.51	0.76	0.103	0.54
13.4	20.0	3.43	1.49	4.92	3.88	1.49	0.63	0.71	0.113	0.68
13.5	19.9	3.44	2.03	5.47	4.05	1.47	0.49	0.72	0.089	0.86
14.9	20.4	3.43	1.98	5.41	4.02	1.37	0.53	0.74	0.110	0.61
17.6	24.5	3.35	1.49	4.84	3.80	1.39	0.60	0.76	0.12	0.51
18.1	27.0	3.36	1.47	4.83	3.80	1.49	0.56	1.20	0.103	0.58
18.8	18.6	3.43	1.91	5.06	4.00	1.00	0.58	0.72	0.116	0.76

would necessarily be low. He would never have used that example, because he was certain there was a pipe. In one case mentioned by Mr. Shaw he had a transverse test of 24 tons and 20 tons shear, with 2 per cent. carbon and 1.4 per cent. silicon, and if that bar were taken from the centre of the casting he did not see how one could expect to get a good shear test. In another case mentioned by Mr. Shaw the transverse was only 14 tons and the shear was 26 tons, the analysis being carbon 3.1, silicon 2.0 and phosphorus 0.85 per cent., and in that case 14 tons transverse appeared to be a very poor result indeed.

Mr. Shaw said these results were obtained on a sample supplied by Mr. MacKenzie.

Mr. MacKenzie said his idea was that the test-bar was the evaluation of the metal in the ladle, and all the engineers could do was to take the service records of particular metals and try to assure themselves that new castings were the same quality as the one that had given good service. The endeavour was now being made to find that out in a little better way than formerly, but the fact that a shear or a tensile or a transverse test showed the properties of a casting did not mean that any one of them was good enough to set down as a complete engineering specification. At the same time, it was felt in America that all the tests now in existence were too valuable to be disposed of by adverse criticism.

Official Belgian Attitude.

The following communication from the Scientific Committee of the Liége Section of the Association Technique de Fonderie de Belgique was then read :—

This interim report acknowledges that tests made on separately cast test-pieces do not give an absolute guarantee of the value of a casting.

Blowholes, slag inclusions, porosity, shrinkage cavities and internal stresses are amongst the many factors which react adversely upon the value of the casting, and which a test from a test-piece, even if of similar thickness as that of

TABLE C.—*Tests arranged in Order of Tensile Strengths.*

Tensile. Tons.	Shear. Tons.	$\frac{\text{Shear}}{\text{Tensile}}$ Tons.	Difference. Tons.	T.C.	C.C.	Si.	Mn.	S.	P.
9.8	18.7	1.9	+ 8.9	—	—	—	—	—	—
9.82	17.0	1.72	+ 7.18	3.44	0.59	1.56	0.68	0.11	0.64
10.0	16.25	1.62	+ 6.25	3.46	0.56	1.60	0.65	0.114	0.48
10.5	22.8	2.2	+12.7	3.25	1.12	1.56	0.27	0.128	1.17
10.8	14.9	1.35	+ 4.0	3.01	—	2.93	0.61	0.059	1.14
11.0	26.1	2.3	+15.1	2.65	1.07	2.15	0.32	0.168	1.27
—	26.4	—	—	3.1	—	2.0	0.39	0.37	0.85
11.7	23.7	2.0	+12.0	3.25	1.12	1.56	0.27	0.128	1.17
11.7	20.7	1.77	+ 9.0	2.03	0.72	1.39	0.87	0.04	0.157
11.7	13.69	1.17	+ 1.99	—	0.28	—	—	—	1.00
12.2	14.31	1.17	+ 2.11	—	0.36	—	—	—	0.90
13.2	20.0	1.52	+ 6.8	3.51	0.61	1.61	0.72	0.10	0.74
13.6	18.2	1.34	+ 4.6	3.01	—	2.93	0.61	0.059	1.14
15.5	21.6	1.4	+ 6.1	3.23	0.58	1.14	0.72	0.124	0.60
15.7	19.2	1.22	+ 3.5	3.20	0.88	0.86	0.67	0.17	0.17
16.0	18.2	1.14	+ 2.2	3.22	—	1.54	0.61	0.07	0.36
16.4	18.4	1.12	+ 2.0	3.16	—	1.50	0.56	0.06	0.56
16.4	24.3	1.42	+ 7.9	3.38	0.58	1.63	1.25	0.113	0.59
17.0	12.9	0.76	− 4.1	3.41	0.77	1.75	0.51	0.08	0.55
17.3	18.4	1.06	+ 1.1	3.17	0.87	0.68	0.67	0.156	0.166
18.3	21.9	1.20	+ 3.6	3.15	1.44	0.63	0.50	0.12	0.36
19.76	20.47	1.04	+ 0.71	—	0.70	—	—	—	0.50
20.56	23.13	1.125	+ 2.47	—	0.95	—	—	—	0.50
20.4	26.6	1.3	+ 6.2	—	—	—	—	—	—
21.3	28.0	1.3	+ 6.5	—	—	—	—	—	—
16.7	18.9	0.96 to 1.2	—	3.0	—	1.5	0.65	0.10	0.20
—	17.8	0.90 to 1.0	—	2.97	—	1.61	0.40	0.07	0.26

the average section of the casting, cannot reveal with certainty.

The Committee cannot reject the declarations of reputable foundrymen and painstaking engineers, setting forth the whole value of the information obtained during the last 15 or 20 years, based on the one side on tests made on separately cast test-pieces, nor, on the other hand, can they disregard the corresponding results obtained from daily practice established over very long periods.

The time necessary for the collection of such information is, in some degree, a measure of the fully justified fears of engineers with regard to any change in the type of test to be utilised.

The problem posed has three possible objects:—(1) To establish the value of a casting; (2) to establish the value of a type or mixture of cast iron; and (3) to establish the value of a new method of testing.

To Establish the Value of a Casting.

From the foregoing the Committee believe that the value of a casting (apart from such faults in the casting as have been mentioned above) may be judged from the properties of the iron, as ascertained by tests on separate test-pieces.

The Committee fully recognise the ingenuity of the shear test as applied to test-bars obtained by trepanning, and consider it as an interesting method worthy of further study and of being carried to the point of efficiency. The opinions of its members, however, differ on this subject. The test-bar obtained by trepanning is very irregular, and on that account gives only approximate results.

The principle of utilising transverse or shear tests is excellent under the condition of being applied to machine-finished specimens. The test-bars obtained by trepanning can only indicate local conditions existing in a small part of the material, the thermal history of which may be as different from that of the whole casting as in the case of a separately cast test-bar.

The Committee has not rejected this method of testing. A series of experiments are to be made shortly, so as to permit of the giving of an opinion based upon figures.

To Establish the Value of a Type of Iron.

Our Committee have thought it useful to study the two British and American suggestions, both accepting the idea of a transverse test on a large-sized bar, and differing only as to application.

The British method provides three diameters of test-piece according to the average thickness of the castings; the American (and also the German) method, prescribes only one size of test-piece.

In order to be able to judge of these two methods, six foundries in the Liège district, represented on the Committee by their technicians, undertook to cast a series of test-pieces, in different qualities of iron, according to the three British dimensions. The results are summarised in the diagram annexed (Fig. A).

What are the purposes to be served by the ideal test-piece? Is it to determine the properties of different types of iron, cast in moulds for similar test-pieces, whilst actually these irons will have entirely different thermal histories?

Or is it to determine the maximum tensile that can be given by the iron—a question which supposes an inquiry into the most favourable thermal conditions?

The first direction leads us to the single test-piece (the American solution). The second to types of test-pieces of different dimensions, or to the British solution.

Conclusions.

In the majority of cases, where irons of inferior or medium quality are employed, the variation of results according to the size of the test-pieces is regular. From the results given with one test-piece one can anticipate within reason the results given by test-pieces of another size.

For certain special irons the variation follows another law. The medium-sized test-piece gives higher results than the two others.

It must be admitted that, according to the thermal history of the test-piece, the strength

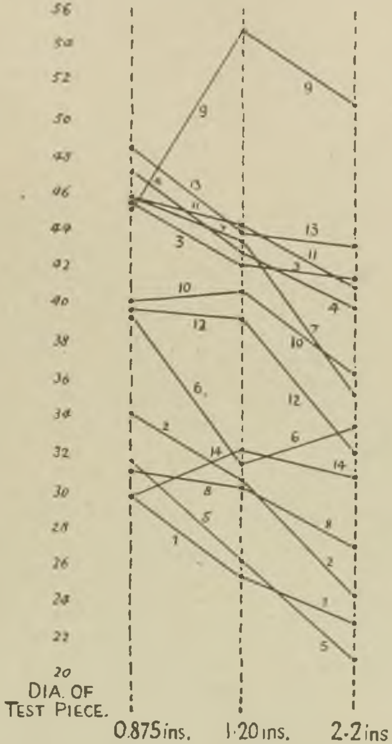

FIG. A.—BELGIAN EXPERIMENTS ON THE BRITISH TEST-BAR SCHEME.

reaches a maximum, all other things being equal, for a definite diameter of test-bar. For the majority of their tests the Committee find it on the falling branch of the curve of the diagram; for other cases, the maximum corresponds to a diameter of about 30 mm. These observations conforming to theory, have led us to conclude in favour of the British specification, since a test on a single dimension, applied to all cases, will not permit one to draw conclusions as to the quality of the metal when cast in a greater or lesser thickness. It appears to us useful, if not necessary, to determine the quality of the metal when cast at a greater or less thickness. It appears to the Committee decidedly useful, if not essential, to determine the quality of the metal under conditions approximating to those met with in the actual castings.

To Establish a New Method of Testing.

With reference to a new standard test to be taken as a basis of comparison, the very great variety of results obtained with the same type of iron, according to the differences of its thermal history, induces the Committee to foresee the necessity of taking, as a basis of comparison, a measure corresponding to a single point of the curve of possible strengths of the iron, viz., that of maximum tensile strength, a consideration which brings us back again to the British thesis.

Fundamental Differences in French and British Views.

Mr. J. G. Pearce (British Cast Iron Research Association) said that the divergence between the British and French points of view on the test-bar question was so fundamental that it was really very difficult to discuss the present Paper without either apparent discourtesy or the use of methods of controversy that were not in the best interests of technical progress. He felt that both countries were aiming at the same goal but were approaching it by two entirely different ways, and mutual criticism might serve a very useful purpose in preventing the limitations of either country's methods being overlooked. He thought, however, that the authors of the present Paper damaged their case by lectures on the " force of habit and routine " and on the errors of the foundryman. The names of Frémont and Portevin were well known and esteemed in Great Britain, but the fact that they have "absolutely condemned" the tensile test did not justify us in abandoning the tensile test unless our experience supported their conclusions. This, however, was not the case. It was unfortunate, too, that the authors should so frequently brush aside the objections and difficulties raised by other experimenters by the remark that "the authors are not of this opinion" or "have not been able to observe anything of the kind."

The Paper of his own so much criticised by the authors did not find any place in their bibliography, but was reported in the Proceedings,* and he was flattered to think that it should have been treated so fully, for only a cogent statement of the objections to the shear test could have merited so much attention. So far as criticisms of the transverse and tensile tests and of the cast-off bar were concerned, the considerations he had put forward were not personal views but were the views which had guided the Grey Iron Committee of the British Engineering Standards Association in issuing the general specification 321-1928. This specification embodied both transverse and tensile tests, and the authors' criticisms were therefore criticisms of a British national specification, in the preparation of which every responsible body concerned had been consulted.

Development of the B.E.S.A. Specifications.

For many years the quality of particular cast irons for pipes, automobile, aeroplane and oil-engine parts had been governed by B.E.S.A. specifications. The preparation of a general specification issued in 1928 was the logical extension of this work, and the movement for a general specification was initiated by Mr. John Shaw before 1920. The general specification was being very widely adopted, and the testing provisions, which were the part which concerned us most at the present moment, would doubtless

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* Proceedings, Inst. British Foundrymen, Vol. XXI., p. 517.

very soon be adopted for all British national specifications for cast iron. We were not seeking to impose the tensile and the transverse test on any other country, and we were prepared to discuss their disadvantages very frankly with a view to improvement. We were prepared to examine any new tests but we could not adopt them—and thereby undo all the work that had gone before—without overwhelming evidence of their advantages. That evidence was not forthcoming, either in the case of the shear test or in the particular form of the single shear test on a small bar advocated by Frémont. It would be interesting to know whether this test was used throughout France; whether it was specified by consulting engineers, or whether it found a place in the national specifications of France, Spain, Italy, Belgium or Czechoslovakia. Surely tests proposed for international use should first of all find general acceptance in a national specification.

Shear-Test Rarely Specified.

The authors were very critical about the drop or impact test, but since this test found no place in British national specifications we should never seriously suggest it for an international specification. Equally, however, we should not interfere with those who desired to use it for special purposes, for research work, and so on. The shear test was not new in this country. It was familiar to testing engineers and there was no demand for the single shear and only a very weak demand for the double-shear test on any material. The disadvantages of the tensile test given in his (Mr. Pearce's) Sheffield Paper applied in some cases (such as the necessity for accurate machining) even more to the shear test, and he therefore took exception to the authors quoting his comments after their own statement of the disadvantages of the tensile test, which could, with proper care, be corrected. The authors also quoted some of his test figures and concluded that there was little difference in shear value between 0.22-in. and 0.5-in. bars, quite overlooking the specific statement given in the

Sheffield Paper that the piece of iron taken was specially chosen to try out the test and was very uniform throughout the section. There was ample evidence that in ordinary irons the 0.22-in. bar gave a shear value markedly lower than the 0.5-in. bar. The work of Mr. W. Jolley showed this clearly. In view of statements made and diagrams published in recent Papers, it was particularly interesting at this stage to learn that "it is illusory to look for any relation between shear strength and tensile strength." Other speakers would deal with the difficulties of the shear test and trepanning, and he could safely leave to Belgian, German and Czechoslovakian members to deal with criticisms of work done in their respective countries. He also took exception to the wholesale condemnation of the use of the rupture modulus. Doubtless, if this could be discouraged, the use of a single test-bar would be brought nearer to realisation, and on the single Frémont transverse machined bar the breaking load was enough, but when various sizes of test-bar were used, an inherent feature of the British proposals, the rupture modulus was the only rational way of comparing the strength of one size with that of another.

There appeared to be a slight error, possibly in translation, with regard to the section modulus K. This is described as the modulus of rupture and as not being calculable. K, of course, is the section modulus and is susceptible of mathematical calculation for any given section.

The Paper continued by a logical process of development to impracticable conclusions to which we have been accustomed in previous Papers on this test, with regard to the necessity for small pieces, trepanning, etc. His (Mr. Pearce's) view with regard to the ball test and micro-examination was perfectly consistent, and he thought of them exactly as he thought of the shear test, as a useful method of examination in investigating a casting for any purpose, but he would not for a moment consider putting the ball test or micro-examination in a commercial specification, any more than he would think of including the shear test. The authors did not dispose of the small test-piece difficulty by quoting Czochralski.

French Shear-Test Specification Analysed.

He would, however, be content to leave the consideration of the value of the new tests to be assessed by the specifications given at the end of the Paper, the first specification which had been available embodying these new tests. The tests are shear, hardness and transverse, with, under certain considerations, the compression test. The number of test-pieces may vary according to the weight of the casting, but is between two and five. Castings under 4 cwt. have two tests and these are both shear tests, but for 3, 4 or 5 test-pieces one is a transverse test. The ball test specified is such that by itself it carries practically no weight at all. Thus for ordinary, strong and extra strong castings the range of Brinell hardness is 130-240, 150-240, and 170-240. The figures given for the other tests are shown in Table D. They have been obtained by converting the figures to English measurements and assuming a ratio

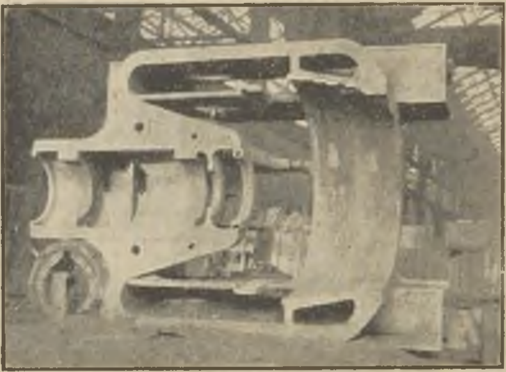


Fig. B.

of shear to tensile of 1.3. In the transverse test, since the load on the bar, only one-eighth of a sq. in. section, tested at 1 in. centres would be meaningless to British readers, the load is expressed as modulus of rupture, which is usually 1.8 to 2 times the tensile. He was not clear whether the transverse test-bar was tested in the upright or the flat positions, but had assumed the case most favourable to the authors, that it was tested flat. In this case the transverse test was rather high compared with the tensile which, incidentally, agreed very well with the compression test. The conclusion drawn from these figures was that as specification figures for extra strong, strong and ordinary castings they are extremely low and would not be acceptable to British engineers. The tensile figures quoted in the French specification would probably require under British conditions, to be, say, 16, 12 and 9 tons per sq. in. A deflection figure of 0.01 in. would seem almost meaningless.

Table D.

	Extra strong.	Strong.	Ordinary.
Tensile—tons/sq. in.	12.2	9.8	7.3
Transverse rupture stress—tons/sq. in.	27.0	22.2	17.3
Deflection—in. ..	0.01	0.01	not specified
Compression—tons/sq. in.	49.6	40.0	30.5
Brinell	170–240	150–240	130–240

The figures quoted in the specification suggest that they refer to the weakest portions of the casting taken on small bars trepanned from thick sections, thereby tacitly admitting what has so often been criticised as the drawback to the Frémont shear and transverse tests.

Assessing Relative Importances.

Mr. W. Jolley said that MM. Le Thomas and Bois had given a good account of the shear-test method for testing cast iron. Although he did not fully agree with their views it was realised in this country that the shear-test method was worthy of full examination, and it had been given every consideration before stating that the British did not consider it a satisfactory test for cast iron. Apparently the views of the suppliers of steel castings were the same. M. Le Thomas stated that the transverse test was the best test for cast iron, and ought to take the first place amongst all other tests, yet the specifications in the Paper placed the shear test as first test and suggested a static transverse test if required. Did not the authors consider the transverse test, coupled with the deflection test, to be the best test for giving an indication of the quality of the cast iron? The tensile test appeared to be the most satisfactory for giving an indication of the structure of cast iron. No engineer would consider buying castings on a tensile test only, but they bought castings with a deflection and transverse test. All foundrymen realised they could obtain high tensile tests with low transverse and deflection, also high shear test with low transverse and deflection. The authors considered the tool marks left on the shear-test-core did not vitiate the result. His experience when obtaining shear-test-cores from large castings, especially with portable drilling machines, was the lack of uniformity in the diameters of the specimens, and in some instances a difference of 0.007 had been obtained, necessitating the machining of the test-pieces to 0.22 dia.

Problem of Choice of Location of Tests.

As the authors pointed out, it would seem absurd to judge a casting by its examination of a particular point, but the different points must be sufficiently numerous and judiciously distributed; he would like to ask the authors who would decide these points and what would be the variations allowed in the tests?

Fig. B showed a bottom-half turbine casing. The black spots show the positions from where shear-test-pieces were trepanned.

Table E showed the physical and chemical results of the bars cast separately, also the shear-test results of the trepanned test-pieces that had to be machined owing to the wide variation in the diameter of the test-cores, due to the use of a portable drill and the grinding action of the cuttings.

Where did the authors suggest, asked Mr. Jolley, the test-piece to be trepanned from in a casting of this description? If there were to be a test-piece for every different section, he was afraid the inspecting engineers would object strongly to the number of plugs required; also, what specification would cover a casting such as this with so many varying sections.

Fig. C showed the results obtained from bars machined to reduced diameters varying by 0.001 in. and tested in the 0.5 in. dia. testing apparatus, published in THE FOUNDRY TRADE JOURNAL of April 4, 1929. It would be seen that any slight reduction in size from an exact fit in this method of testing was a great factor. An examination of the fractures showed a clear shear for the bars machined to size, but those under size had a fracture that indicated a bending action had taken place. Did the authors consider that the shear-test-piece as trepanned was sufficiently accurate to be the controlling test for the acceptance of large and intricate castings?

TABLE E.—*Tests from a Large Turbine Casing on Cast-Off Bars.*

Analysis.

G.C., 2.75; C.C., 0.62; Si, 1.33; Mn, 0.67; S, 0.095 and P, 0.61.

Physical tests. (Bars cast 1¼ in. sq., machined 1 in. sq., tested 12 in. centre .)

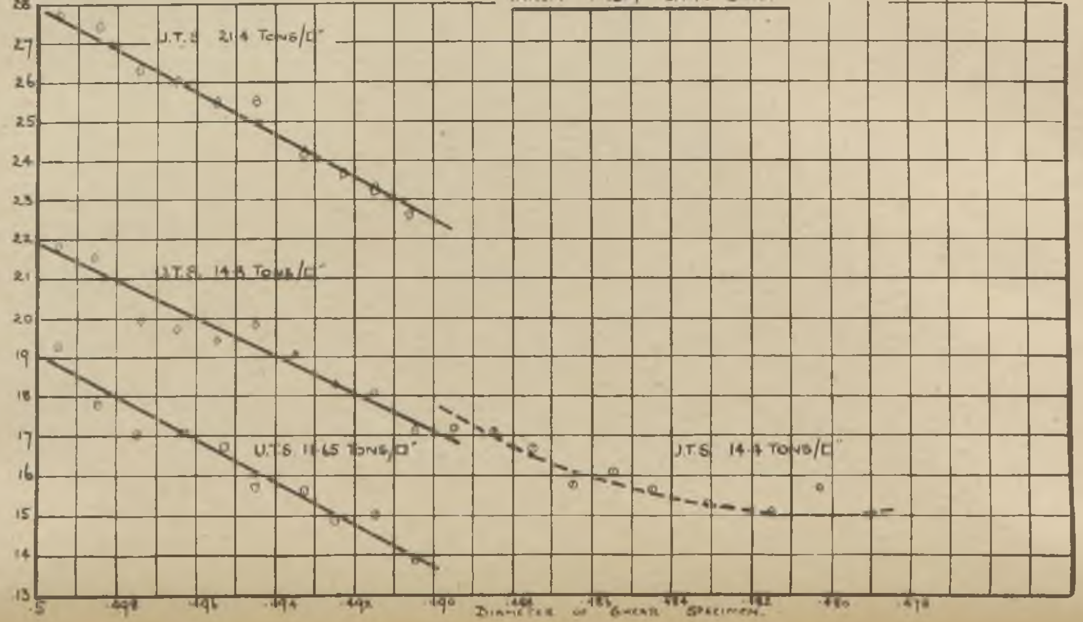
Transverse. Lbs.	Tensile. Tons.	Deflection. In.	Brinell.	Shear. Tons.
3,130	14.6	0.128	229	21.4

Shear test. (Bars trepanned from 3-in. and 1¼-in. sections, machined to 0.22 in. dia.)

3-in. section	14.8 tons.
1¼-in. „	17.2 „

FIG. C.

RESULTS OF REDUCTION IN
THE DIA. OF SHEAR TEST SPECIMENS
WHEN TESTED IN 0·5" DIA TESTING APPARATUS
TENSILE AND SHEAR TEST SPECIMENS
TAKEN FROM SAME BAR.



Brinell Hardness and Machinability.

Regarding the Brinell hardness-test specification of 170 to 240, had not the authors had the experience that steel mixtures with 250 and over gave castings readily machinable? Owing to the lack of data on this method of testing he did not consider it advisable to introduce it yet in a specification for cast iron.

Table F showed the relationship that had been found to exist between the shear test and tensile tests taken from daily tests over a period of six months. As the same specimens were used for shear and tensile the question of errors in composition and physical condition of castings were eliminated.

TABLE F.—*Shear Relationship to Tensile.*

Shear 0.22 *in. dia.*

Bar cast 1 in. square and machined to 0.5 in. dia tensile, afterwards tensile test bar machined and used fo shear tests.

10.5 tons tensile	1.61 ratio	17.0 tons shear.
13.5 ,, ,,	1.47 ,,	20.0 ,, ,,
16.5 ,, ,,	1.39 ,,	23.0 ,, ,,
19.4 ,, ,,	1.34 ,,	26.0 ,, ,,
21.3 ,, ,,	1.31 ,,	28.0 ,, ,,

Shear 0.5 *in. dia.*

Bar cast 1 in. square and machined to 0.5 in. dia. tensile, afterwards tensile bar used for shear tests.

9.5 tons tensile	1.84 ratio	17 tons shear.
12.5 ,, ,,	1.60 ,,	20 ,, ,,
15.5 ,, ,,	1.47 ,,	23 ,, ,,
18.5 ,, ,,	1.40 ,,	26 ,, ,,
20.5 ,, ,,	1.37 ,,	28 ,, ,,

These ratios were from the curves plotted from over 150 tests. From the results it was found that the lowest tensile result 9.5 tons showed a ratio of 1.84 to the shear test, whereas the ratio for the tensile test of 21.3 tons was 1.31. It appeared that the ratio between shear and tensile test was definitely, inversely proportional and was not a constant figure for cast iron.

A curve plotted from over 150 tests showed that it was practically impossible to obtain a line for the transverse tests against shear tests, and if one compared the chemical composition nothing but confusion arose as results were so contradictory. Some examples were given in Table G.

Graphite Size and Small Test-Pieces.

Fig. D showed an attempt to demonstrate the results obtained from an 8-in. block of cast iron with a core cast in to allow for varying wall thickness. It would be seen that the wall thicknesses were $\frac{5}{8}$ in., $\frac{7}{8}$ in., $2\frac{1}{4}$ in. and 3 in. A 1-in. slab was cut off the bottom of the casting and then shear-test specimens were taken from the eight positions as shown by rings. Two 0.5-in. test-pieces were taken from each wall so as to obtain duplicate tests on each thickness. In the bottom right-hand corner would be seen the analysis of the cast iron which was obtained from drillings taken at various points. In the centre space of the block would be seen the shear-test results, and there was a very noticeable difference between the 3-in. and $\frac{5}{8}$-in. sections, although they were both from the same metal and the same casting.

Round the edge of the block could be seen micrographs showing the size and structure of graphite at the points where the shear-test specimens were taken from. These were self-explanatory, especially when one compared the large flakes in the 3-in. wall with the smaller one in the $\frac{5}{8}$-in. wall.

It would probably be of interest to visualise the volume space the graphite flakes would occupy in a 0.22-in. shear-test specimen taken from the 3-in. wall just where the graphite flakes bunched together, and would it be a representative piece for the metal used in the casting?

From the results shown in Fig. D and further tests that had been carried out, it was considered that the position on the casting and section where the test-pieces were taken from would govern the results. To explain the variable results that would be obtained in a casting it would be necessary for all inspectors to be

TABLE F.

No.	0.5-in. shear.	0.22-in. shear.	U.T.S.	Trans-verse.	C.C.	G.C.	Si.	Mn.	S.	P.
29 ..	18.8	19.1	12.05	2,550	0.58	2.8	1.63	0.76	0.117	0.58
35 ..	18.6	19.1	18.8	2,640	0.58	2.85	1.63	0.72	0.116	0.76
42 ..	24.3	23.8	16.4	3,360	0.58	2.8	1.63	1.25	0.113	0.59
49 ..	17.8	17.8	11.3	2,590	0.57	2.85	1.66	0.77	0.117	0.69
				Block	0.55	2.85	1.63	0.71	0.11	0.81

thoroughly familiar with all carbon changes in cast iron due to different section structures which did not appear in steel castings.

Where the British Test Fails.

MR. H. J. YOUNG said the French Fremont test is a genuine attempt to find out what a casting is like. It must be granted that one might need to take a few tests from each complicated casting; it must be granted that in certain castings it would not be practicable to do this. Nevertheless, the Fremont test is, without any doubt whatsoever, a definite and commendable effort to provide a test which will indicate the properties of the iron as it appears in parts of the casting itself. Mr. Jolley had shown a slide of a casting having four sides of very different thicknesses; he could not have chosen any more unfortunate example, because the British test would fail entirely to indicate the properties of that particular casting, whereas the French Fremont test might—and if performed accurately, undoubtedly would—do so.

The PRESIDENT: I had made a note to the same effect myself.

Cast-Off Bars Disparaged.

MR. YOUNG, continuing, said we needed someone half-way across the Channel to censor the correspondence on this subject passing between the two countries. It should be possible to agree to what the French Fremont test is designed to show; its value and the best manner of carrying it out could come later. If, however, we agree to recognise the main idea behind the Frémont test, it is no less necessary to disclose the same purpose with regard to the British test and to do so in no different spirit. A grave error had crept into our procedure; an error which may well explain, and certainly excuses, any ill-feeling on the part of our Continental friends. He (Mr. Young) had been a member of the original test-bar committee of this Institute, of the next test-bar committee ruled by the British Cast Iron Research Association, and of the committee later formed under the auspices of the British Engineering Standards Association. He had followed closely everything said and done by all three committees, and having, for fifteen years, made thousands of separately-cast test-bars, having made hundreds upon hundreds of cast-on bars to Admiralty specifications and those of many classification societies, having likewise—for his own protection and information—invariably cut out test-bars from the casting heads, runners, risers, flanges, and so on of all important castings, he was in a fair position to know the truth. The truth is that *a separately-cast bar does not represent the metal in the casting and is valueless as a comparison of what different works are doing.* For instance, many different qualities of iron will, on a separately-cast test-bar, give 11 tons tensile and 2,500 lbs. transverse (on the Admiralty square bar), but only a few of those many irons will produce any one particular type of casting so that it possesses the desired hardness and strength.

B.E.S.A. Specification Examined.

The one and sole way by which the results from a separately-cast bar can be valuable as a comparison from works to works or as showing the properties of the casting, is when the composition of the metal and the components of the cupola charges are known factors. This is common knowledge which the new British Standard Specification ignores and which the Annual Statement of the B.E.S.A. denies. Let us clear up this point and start afresh with our French friends. Clause 2 of our Standard Specification says that " the composition of the iron as cast shall be left to the discretion of the manufacturers, but the maximum percentage of phosphorus may be specified by the engineer or purchaser if he so desires." Clause 5 says that " the engineer or purchaser may also specify cast-on bars where the design of the casting and method of running permit." It is to be noted that the above wording has not by any means the same meaning as if it had said: *The engineer or purchaser may specify cast-off bars where the design of the casting does not permit them to be cast on.* Therefore it is clear that the British Specification not only allows but *inclines towards* separately-cast bars of unknown composition. Let us turn now to the statement of the Tenth Annual Meeting of the British Engineering Standards Association, which, on page 13, reads: "The problem of securing a test-bar *which would accurately represent the mechanical properties of the metal in the casting* has been one of the difficult problems industry has had to face, and this has involved a large amount of experimental work on the part of the British Cast Iron Research Association, to whom the thanks of the Association are due." When the writer, as an active member of those committees, as one who, like many others, willingly gave his time to them, saw that statement he felt the whole thing was spoiled and that we were, in the eyes of the scientific world, no more enlightened, no more wishful for the truth, than before. His (the speaker's) feelings do not matter, but what about those of the French people? They know the meaning of what we suggest in that last statement. They know that the suggestion is misleading and inaccurate. Can we complain, then, if they find themselves unable to accept with great pleasure our criticism of their own attempt to solve a problem which we wrongly claim to have solved by means of our separately-cast bars of unknown composition? Had we not made this unfounded claim the British Standard Specification would have gone down to history as a praiseworthy endeavour to meet the many and diverse interests involved in the commerce of this country, and, moreover, British criticisms of the French test would have come, not from "competitors," but from fellow-seekers after truth.

He (Mr. Young) believes there is no common ground for discussion of British and the Frémont test. In its correct pigeon-hole and properly labelled, the new British Specification is excellent for the use of British founders and engineers as they are to-day; as a solution to the problem of "securing a test-bar which would accurately represent the mechanical properties of the metal in the castings," it is ludicrous. The Fremont test in its present youthful state appears to be just the opposite. He did not think it would suit our engineers and founders of to-day, but, nevertheless, it was a definite step towards securing test-bars which represent the metal in various parts of a casting. It is a very welcome move in the right direction, and he (Mr. Young) has no hesitation in suggesting that had the idea of trepanning test-bars out of the castings been advocated in the first place by a British institution, we should have been "as proud as Punch" about it. It is difficult indeed to see where our claims for it would have ended, considering what we have claimed for the separately-cast test-bars. Let us assess our own test at its true value in order that the French may welcome our efforts to assess the value of theirs, and have sound reason to believe that we are unbiassed and as anxious to learn as to teach.

British and Fremont Tests not Comparable.

He (Mr. Young) said he contributed this criticism of ourselves in order "to bring the war into our own country." He deplored greatly the international acrimony which appeared to have sprung up on this question and which he felt had arisen directly from an atmosphere which ended by inspiring, or permitting to pass uncorrected, that unfortunate statement, as quoted above, of the Tenth Annual Meeting of the B.E.S.A., concerning the new British specification. It was his belief that it was advisable to form an international test-bar committee, composed of those who, having no prejudice on matters scientific, would be as critical of their own and of their own nation's work as that of anyone else or of another nation.

The Polish Attitude.

Mr. Branson, speaking on behalf of the Polish Delegation in general and Mr. K. Gierdziejewski in particular, said it was hoped to contribute something to this subject of testing materials in the near future as work was being started in Warsaw. As regards the present discussion, it was felt that it would be very useful in preparing an international standard to introduce a new shock test for cast iron, since the existing shock test, tensile test and shear test did not appear to be very satisfactory. The reason was that certain classes of castings, such as crank cases, had to stand up to continued shocks, and in such cases brittleness was a great disadvantage. It would be an advantage to find a shock test in which the results would be more concordant, notwithstanding the shape of the section, than is now the case. Further, it might be a good thing to do away with the notch in the shock test. It would then be possible to found some relationship between brittleness, bending, etc. This was the point of view the Poles were taking up, because they had found out that shear tests were not satisfactory, and that although tensile tests were very good they also were not altogether satisfactory. Therefore they were intending to try and find a shock test.

Transverse Testing Commended.

Mr. J. E. Fletcher said he took very much the same view of this matter as his confrères. This subject had been thrashed out many times and, after all, the final thing they were all interested in was the obtaining of a good casting. Our French colleagues had, like ourselves, been trying to find a method which would indicate the value of the structure, under varying conditions, of a casting, and he felt that the French were to be congratulated on having brought forward this truly interesting point.

He agreed with Mr. Young that we want something which will enable us to know more of the structural strength of different points in a casting, and several things had been studied by him in connection with the transverse test which many of them thought gave the best criterion as to the strength of the metal used in a casting

Founders must, for example, consider more carefully the ratio between the shear stress and what we call rupture stress or modulus of rupture, which is an estimated value.

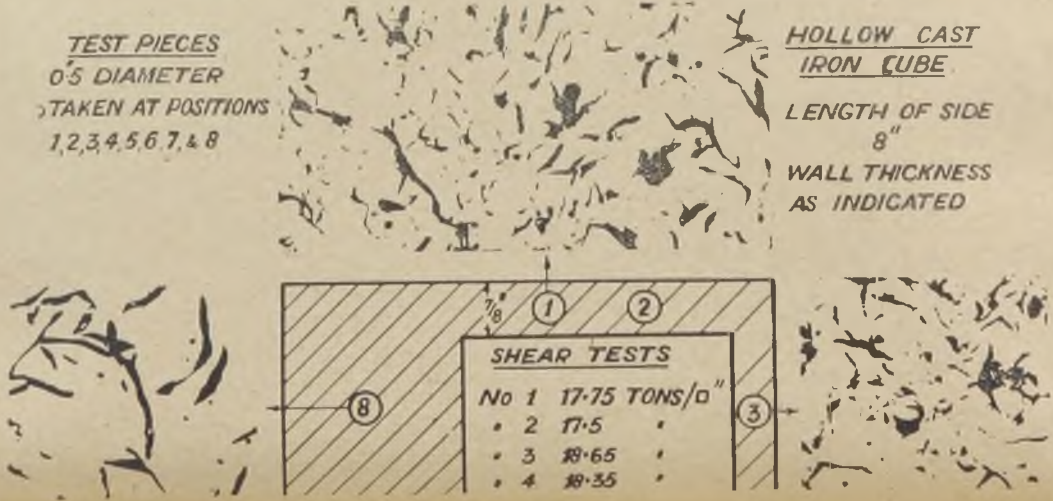
In cast iron there was a continually varying ratio between the compressive and the tensile strengths of the material, and he thought the tables in the Papers should be extended so as to express not only the ratio between the estimated rupture stress in the transverse test and the shear stress in the French test but also, in the old-fashioned way of putting it, between the centre breaking load and the shear stress on the standard test-piece or bar. If one examined the work of Fremont and Portevin it would be found that there was a close relationship between transverse deflection and the shear-stress values. It was very difficult to say what these relations should be, but all such parallel comparisons were of great use.

We should look seriously at our transverse-test results, not altogether in the light of a simple estimated rupture stress—which he did not consider was a satisfactory figure at all for cast iron—but in relation to the centre breaking load which was not an estimated but a definite value.

He would not like our French friends to feel that we in this country did not appreciate to the full their attempt to deal with this most difficult problem. As a matter of fact, our appreciation is one of thankfulness for the boldness they had displayed in facing this problem, and he hoped that the Institute would not neglect to show their great appreciation of the splendid work done by M. Portevin and his associates.

Formality Not Yet Reached.

Mr. W. H. Poole expressed the view that the discussion had rather drifted away from the real point at issue. With regard to test-bars, in looking at a large number of results there was a lack of uniformity in them although taken from the same source and produced under the


TEST PIECES
0·5 DIAMETER
TAKEN AT POSITIONS
1,2,3,4,5,6,7,& 8
HOLLOW CAST
IRON CUBE
LENGTH OF SIDE
8"
WALL THICKNESS
AS INDICATED
7/8
1
2
3
8
SHEAR TESTS
No 1 17·75 TONS/□"
" 2 17·5 "
" 3 18·65 "
" 4 18·35 "

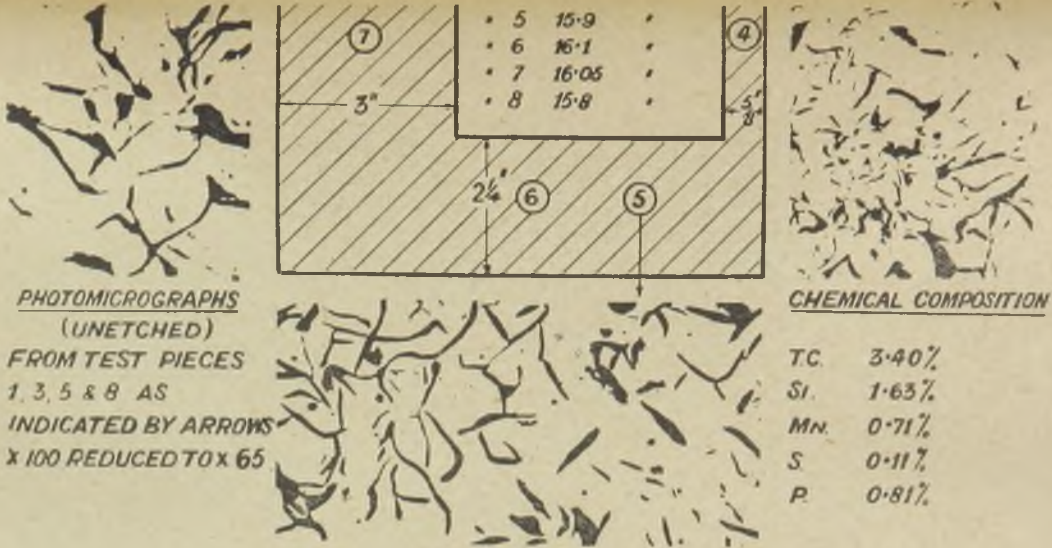

• 5 15·9 •
• 6 16·1 •
• 7 16·05 •
• 8 15·8 •
⑦
④
3"
5/8"
2¼"
⑥
⑤
PHOTOMICROGRAPHS
(UNETCHED)
FROM TEST PIECES
1, 3, 5 & 8 AS
INDICATED BY ARROWS
X 100 REDUCED TO X 65
CHEMICAL COMPOSITION
T.C. 3·40%
Si. 1·63%
Mn. 0·71%
S. 0·11%
P. 0·81%

Fig. D.

same manufacturing conditions. It was surprising that sound test-bars could be made in the ordinary commercial way. He also agreed with Mr. Young that the shear test has some advantage in enabling us to ascertain something about the internal structure of a casting, although he was afraid that the founders in this country would seriously object, from the casting point of view, to having such tests. It was a difficult thing at times to persuade foundrymen to make as much use of the transverse test as they should on account of the additional cost. Whilst he felt that we had to thank the French for their efforts in this matter, however, his experience of testing work generally in this country led him to agree that our tests were more likely to be useful as a standard of comparison than the shear test. At the same time, he felt we have a long way to go yet before we are likely to devise a means of testing which would give an indication of what is likely to happen under practical conditions in regard to all sections and weights in a manner that would suit everybody.

French Proposals are Tentative.

M. Ronceray said it would be very satisfactory if we could devise some means of ascertaining the quality of the casting itself. Although in France they had suggested the shear test, they would be only too willing to adopt any standard test agreed upon by all the other Associations. The French Association had absolutely no desire to impose their views upon the other nations. They were merely trying to find what is a good test, and the Paper was an attempt in that direction, without any suggestion that what was suggested should be accepted as final. If anything better was devised and was universally agreed, the French would be delighted to adopt it. The difficulty came through mixing the technical and commercial sides, because that inevitably introduced differences of opinion.

Elastic Materials Present Difficulties.

The PRESIDENT remarked that cast iron is by no means an easy metal to test. One must have a perfect testing machine, and the test specimens must be held therein in absolute alignment if concordant tensile results were to be obtained from the same material. It was possible to take bars which were practically homogeneous and alike one with the other, but when the test figures were received quite different results would be found unless the conditions of testing were as near ideal as possible. Any material which had practically no ductility, or so little ductility as cast iron, was a difficult material to test. In these circumstances he felt that our French colleagues had really done something in an attempt to solve a very difficult problem. They had instituted the shear test with the one desire he believed, of introducing means to enable one to find out what is the relative quality of the metal in a casting. Unfortunately, it is considered by some research workers that for such a test to be trustworthy the bars must of necessity be of so large a diameter that it often meant spoiling the casting. It was not a simple operation to trepan a test-bar of the requisite diameter, and there was always the difficulty of getting an accurately dimensioned specimen. It was necessary, therefore, further to machine the trepanned piece in order to secure a test-bar for the shear test which will afford really reliable test figures. He did not propose to say anything of a controversial nature as to whether a single or double shear test was the better, although he personally favoured the double shear test. In either case, however, the test-pieces should be of accurate dimensions, and the bushes, especially the shearing edges, must be kept up to concert pitch. If the test-bar did not fit as accurately as practicable, it would be impossible to get a true shear.

We in this country—and he believed he could speak also for other nationalities—truly realised that our French colleagues had made an honest attempt to provide a test which would really indicate the qualities of the casting.

Certain recommendations had been put forward which we at the moment could not adopt on account of the difficulties that were foreseen, and have now, to a certain extent, been proven, but this fact gave not the slightest reason for any suggestion of hostility. On the contrary, he felt that all other countries should be very thankful to the French for having done such a great amount of pioneer work.

The **President** then proposed from the Chair that the Congress express its sincere appreciation of the researches of their French colleagues in connection with the proposed shear test. This was carried with acclamation. At the same time the President expressed the hope that complete harmony would exist between the various members in any future discussion of the matter.

Basic Principles Outlined.

Mr. J. E. Hurst wrote that in all these discussions on the methods of testing cast iron it seemed to him that the matter of the definition of the purpose of the application of mechanical tests was involved. Two definitions presented themselves. One might define the purpose of the application of mechanical tests as a means of ascertaining the strength of the metal in the castings, or alternatively as a means of standardising the quality of material which went into the casting. Whilst it is not clearly stated, the French method for which MM. Le Thomas and Bois are sponsors in this French Exchange Paper appears to have for its object a means of ascertaining the strength of the metal in the casting. Naturally, testing applied with this object is confronted with the many practical difficulties which are familiar to all foundrymen, and are amply discussed in the Paper. Furthermore, in order to make some attempt at an adequate realisation of this object, some such special forms of testing did appear to be necessary.

Whether it was desirable for commercial purposes even to attempt to ascertain the strength of the material was another matter. The statement of Pearce, used by the authors, that the design of a casting was based on the strength of the material of which it was composed, used broadly and unqualified, was wrong and misleading. Most generous concessions have to be made in practice on the score of reliability, and the value of any strength determination of the material, however determined, was largely depreciated on this account.

The very first clause in the model specification proposed by the authors covered these sources of unreliability, and, short of testing the casting as a whole under the conditions which it had to sustain and maintain in practice, there was no other method of being absolutely certain as to the reliability of any casting.

However carefully carried out, the commercial value of any mechanical tests of the strength of cast iron in the casting was of little or no use in determining the reliability of the casting, and goes no further than establishing the quality of material of which the casting is made. This brought one to the second definition of the purpose of mechanical testing, *i.e.*, a means of standardising the quality of material which went into the casting. From a commercial point of view, there could be no doubt that the separate test-bar satisfies this object in the simplest possible manner.

This being granted, the logic of the series of test-bars put forward in the B.E.S.A. specification could not be disputed. This matter, however, had received ample consideration in other quarters.

Variation of Tensile Test with Composition.

Dr. A. L. Norbury (British Cast Iron Research Association) wrote that there were many statements of the authors with which he disagreed, particularly their suggestion that tensile tests on cast iron were unreliable. He had tested several hundreds of grey-iron test-bars in tensile during the past year, and the systematic variation of tensile strength with composition and the close agreement between duplicate results was such as to prove that the test was an accurate and reliable one.

The authors referred to some tests he (Dr. Norbury) made on round and square transverse bars,* but they mis-read or misunderstood what he had written. The object of the tests was to show that the greater modulus of rupture transverse strength of round bars than square bars was, in the tests in question, entirely due to a difference in the distribution of stresses in the two types, and was not due to a difference in crystallisation at the angles.

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* Bulletin, British Cast Iron Research Association, July, 1928.

A Symposium on Steel Castings.

Joint Meetings of Scottish Branch of the Institute of British Foundrymen, and Glasgow and West of Scotland Branch of the Institution of Mechanical Engineers.

The first meeting of the series was presided over by Mr. James Richardson, B.Sc., chairman of the Glasgow and West of Scotland Branch of the Institution of Mechanical Engineers.

ADMIRALITY REQUIREMENTS IN STEEL CASTINGS.

By Engineer Commander Sedgwick, R.N.

Eng.-Commander Sedgwick said he took it that the common desire was to obtain a final understanding between the founder, the engineer and the user.

Requirements to be Met.

The material suitable for the production of castings to stand up to superheated steam must (*a*) be free from " growth " when exposed to high temperatures; (*b*) possess high strength at elevated temperatures; (*c*) possess the necessary properties for a casting material; and (*d*) be cheap.

There were a number of metals that would meet the first two of these requirements, a variety of alloys, both ferrous and non-ferrous, which were, however, objectionable in varying degrees as regards non-fulfilment of the two final conditions. That was to say, they could neither be cast nor, if they could, they were by no means cheap. Cast steel alone appeared to meet all these needs, and the Admiralty had decided to encourage in every possible way the use of this material, and it was specified to be used to the fullest possible extent for all those castings which might be exposed to the action of superheated steam, as well as for bed-plates, engine columns, etc. The relevant specifications were worded so as to require the use of this material to the fullest extent. In requiring the more general use of cast steel, the Admiralty was encouraged by the apparently sound and frequently intricate castings that had been made of this material, not only in this country, but also abroad. He particularly stressed "abroad" because he had seen some remarkable foreign castings of fine appearance, but for the internal condition he could not answer. No doubt was felt, however, but that these could be fully equalled, if not surpassed, by British steel foundries.

The increasing use of steel castings for naval purposes, and particularly for parts exposed to high pressure and superheated steam, dated from about 1923, and engineers and founders were probably better aware of the results of that than the speaker. During the succeeding years large sums must have been expended, whilst certainly much anxiety has been experienced, and there had been a great deal of delay in attempting to produce castings which would meet the specified requirements, and which could be accepted for the exacting services demanded of them.

Specification for Machinery Castings.

The Naval requirements for machinery castings were:—(*a*) The designed dimensions must be adhered to throughout the finished article as closely as possible; (*b*) the material must be everywhere homogeneous and of the specified quality, and must be free from internal cavities and cracks; (*c*) the article must be free from porosity; and (*d*) internal stresses must be reasonably absent.

If we could get castings like that, it would be a very fine business indeed. A detailed analysis has been made of the various types of failure that have come to Admiralty notice through the medium of the overseeing branch, but this did not tell the whole tale, for the founders' rejections must aggregate at least as many as those of the overseers, and probably more. The percentage of rejects in the best practice had been as low as 3 per cent. of the number put forward for inspection; in other cases the rejects might be 10 per cent., or even more. It was evident, however, that a small percentage of rejects might none the less be accompanied by appreciable departures from the designed thickness; this latter point could in general be investigated by the overseer, but might none the less lead to undesirable increases in weight. Many castings that had been accepted showed surface imperfections of an apparently superficial nature. In spite of reassuring statements by the founders that these surface imperfections were but surface imperfections and did not matter, he hoped to illustrate later that so-called "surface imperfections" were certainly not "surface imperfections," and most certainly did matter. Whether all surface imperfections were like that or not one had no means of ascertaining.

Common Failures.

Dr. Pullin would demonstrate the best means available, namely, the X-ray examination. The suitability of the product and the perfection of the technique cannot be judged entirely by the percentage of rejects made as the result of the existing methods of inspection. The general character of the failures reported were:—(1) blowholes; (2) draws, generally at flanges or changes of section, etc. (very few are known in bosses); (3) porosity under pressure tests; (4) contraction cracks; (5) sand inclusions; (6) scabbing; and (7) failure on physical tests. The failures on physical tests were comparatively small, and nearly all the troubles were either draws or blow-holes, porosity of some sort or other. General defects, such as shifting of cores, shortage of metal when pouring, cold shortness, etc., were not included in the foregoing, as these were obvious foundry faults, and, as such, were not germane to the discussion.

The experience with these castings during the past few years had been none too happy, in many cases it having been found impossible to obtain the desired article in cast steel, so that eventually some other material has had to be employed as a substitute. In other cases the thickness had been increased to such an extent that one might as well have used cast iron. In other instances where the product appeared generally sound (apart from minor imperfections) permission has been granted to employ the welding torch or some other means to render the part available for service.

Danger of Laxity in Patching.

This policy of patching was dictated by the eventual urgency of the situation, but it was realised that such a course involved the acceptance of certain risks, and was in any case inimical to the best interests of the foundry trade and of the Admiralty alike, because if patching is permitted to continue, one was not asking anybody to take much trouble over his casting. It has been frequently stated that undue importance was attached to the soundness of castings destined for parts of naval machinery, and that many of those which were rejected could, subject to a little patching, safely be employed for their intended service. There was, however, another point of view which it is proposed to outline.

Steel castings employed for machinery purposes in H.M. Navy differ from those designed for other uses, in that the former were almost invariably subjected to high temperatures and pressures—the first of these factors reduced the strength of the material, while the second entails entire freedom from porosity; cracks and sponginess not only impaired the steam tightness of the finished article, but also gave rise to grave doubts as to its soundness. No responsible person would care to take needless risks with parts the failure of which might cause loss of life and may even endanger the ultimate success of a military operation. That point was so obvious that it was certain to be granted.

Underlying Reasons.

In insisting upon sound castings the engineer-in-chief had, in fact, two main objects in view, namely, maintaining the very high standard of reliability hitherto associated with the machinery of British warships, and, secondly, improving the military qualities of the vessel by reducing the weight of her machinery, which was one of the few ways in which she could enhance her military qualities. Rigid inspection had one further indirect object in view, namely, that of improving the quality of the product, thus enhancing British prestige among the users of machinery all over the world. This was an important service rendered to the manufacturers of the country by those funds of which the Admiralty controlled the expenditure. It was the most important duty put upon the Admiralty to spend the funds not only to produce fine ships, but also to help forward the trade of the country, and if .one did not do one's best to produce the finest articles that were possible, one was failing in one's duty.

The use of the welding torch might possibly be a legitimate method of fairing up prospective jointing surfaces, and was, of course, a valuable aid for removing waster material, but its recognition as a proper tool for any other purposes tended to lower the standard of the product and was detrimental to progress towards perfection of technique. This palliative was open also to the grave objection that, with present methods of inspection, it might be used to cover defects of apparently superficial nature, with possibly disastrous results.

[The lecturer here showed a number of slides which revealed defects which were not shown on the surface.]

Hidden Defects Revealed.

Continuing, Commander Sedgwick said that in the cases shown there was no evidence on the surface of any definite cracks, slight markings being all that appeared of the severe internal defects subsequently discovered by means of

X-rays. These particular castings would have been passed by any inspector, and it was impossible to say how many parts now on service contained similar defects, which might remain unsuspected till they gave rise to eventual failure. Examination of castings by X-ray and by magnetic methods is being rapidly developed —magnetic methods mostly in the United States. He thought it had not been adopted in this country, but X-rays in Dr. Pullin's hands for some 12 years had been carried on, and he would state the progress achieved was unquestionable. After examining a large number of castings, with the results outlined, there must be instituted a method of inspection to indicate what the internal characteristics were. The general adoption of some such method should do much to remove the present uncertainties in the minds of engineers, and should prove economical by saving the heavy expenses incidental to the removal of defective parts on service.

Present Position of Steel Castings.

The existing position with regard to steel castings was: The requirements, for machinery purposes at least, were that definitely sound, homogeneous castings of the thinnest possible scantlings were desired. He insisted that they were not forthcoming; the founders did not appear to be able to meet the demand. These meetings were held with the object of discovering the reason. The logical alternative reasons were:—

(1) *The designer was asking too much of the founder.* If so, why did not the latter protest instead of wasting time and money in attempting the impossible?

(2) *The standard of soundness set by the Admiralty for this service aimed too high.* That may be, but the user had the right to set his own standard, and if it could not be fulfilled, well, he would probably go on to another material and endeavour to obtain his standard fulfilled with that.

(3) *That the founder had not fully explored the possibilities of his art* in this particular

direction. This appeared very likely in view of the extreme excellence of some steel castings that were produced both here and abroad. If it could be done in one case, why not in others? He was at the moment having to examine some very fine malleable and steel castings, and this appeared to be borne out very well. They did not come from this country, but he hoped to compare with them a very fine example of British steel casting, because he wished to know whether the foreign steel castings were as good as British, or better. If they were better, we should probably find a way to make ours as good. If they were not better, and if the demand existed, we should continue with our own as they were.

The technique of the modern chemist and metallurgist was available for the assistance of the practical man, and progress would be needlessly retarded at the cost of eventual economy if these aids were not employed. It has been suggested that founders were too much in the hands of the "rule of thumb" expert, and that modern needs required the adoption of modern methods of control and investigation.

(4) *The product might already be up to the required standard*, as witness the very small percentage of rejects experienced in some cases.

In the face of the difficulties that had sometimes been met in producing sound castings at all, and in view of the unsuspected weaknesses sometimes revealed by complete examination of apparently good castings, he did not think this view could be seriously contended. If, however, it was true that the required standard was regularly attained, then the user's next step was to ask for thinner castings—and he doubted if one would get them under the existing conditions, save at prohibitive expenditure of time and money.

All that was required from the user's point of view was definite evidence regarding the practical limitations which determine the minimum thickness of reliable steel castings suitable for a given purpose. Give that information to the designer and he would then know where he was. It was a very simple matter. Nobody was asking for the impossible. The Admiralty did want the thinnest castings made of steel that the founder could give them, and it was up to the latter to tell us what was the thinnest castings they could produce.

More Co-operation Needed.

A critical examination of the existing situation led one to the opinion that a far better liaison between the foundry and the user, through the intermediary of the designer, was probably the main ingredient of success in this matter. He suggested that the founder and the designer were often unacquainted, and this was often due to the complicated chain of persons between them, the designs frequently being greatly modified after they had left their originator. It was too often the case that foundries accept work known to be almost impossible to carry out in a satisfactory manner; if one foundry did not take the job, then a rival one would, but in either case the waste of time, fuel, material and money appeared to be appalling. Co-operation undoubtedly on national lines was going on in other countries, particularly in countries like Germany, and if we were to compete and not have steel castings bought in Germany, it looked as though something of that sort would have to happen. It was to the general interest to get the very best casting. In the existing state of commercial rivalry between firms it was difficult to suggest any remedy, and if a solution was to be found, it would appear to lie in co-operation on more national lines, using every available modern method of investigation to ensure that the fundamental laws underlying the casting operation were really known.

The products of the foundry trade in this country are often of unsurpassed quality, but no one would deny that this fine standard was by no means invariable. Modern demands were becoming more and more exacting, and the rapid rate of advance of the past century could now be expected; instead, every new step will be made with increasing difficulty and the cost was likely to be more than comparatively small organisations could meet.

In conclusion, the speaker pointed out that this matter was worthy of pursuit quite apart from naval requirements. The steam engine could only hope to compete effectively with the internal-combustion engine by employing steam at the highest possible temperature, and the steel casting was about the only material that one can use for casting in the same line at a reasonable price, so that, if a sound steel casting can be produced, there was no question about the demand. Further than that, the oil engine itself was likely to require such castings in order to reduce weight, so that between the two it appeared as though the founder was in a very happy position. Finally, the user required the thinnest casting possible, and he hoped this meeting would provide evidence as to what were the thinnest castings procurable or what other things the user must not ask the founder to produce. Dr. Pullin would probably enlarge on the question of examination of castings, and would amplify what he had said about how he found these surface markings covering very grave defects.

X-RAY EXAMINATION OF STEEL CASTINGS.

By V. E. Pullin, O.B.E., D.Sc.

The Chairman, in calling upon Dr. Pullin to explain the latest method of investigation on behalf of the engineer to see that his wishes were being fully carried out, said he had been fortunate enough to have had the opportunity of seeing at Woolwich Arsenal this X-ray process under working conditions, and whilst one's first thought was one of sympathy with the steel founder whose products were being submitted to the searching examination of the powerful X-rays, yet, probably, in the long run, nothing was ever to be gained by hiding the truth and, hearing the result of Dr. Pullin's unique investigations on this subject, the gathering would agree that the truth could not be hidden under this system.

Dr. Pullin thought Commander Sedgwick had adequately outlined the Admiralty's need, and he proposed to indicate how the Admiralty and the War Office and the Air Force proposed to examine requirements, or existing supplies. He proposed to indicate what can be done, what their present limits were, what they hoped they would be able to do and what they thought their ultimate practical limits were.

Technical Details of X-ray Work.

X-rays are merely a part of the radiation of a spectrum, and they were the same exactly in nature as ordinary light, but they had a wavelength which was very much less, the average being about 10,000 times shorter than the wave length of ordinary light. Owing to that particular property they could penetrate materials which were opaque to ordinary light. The question of technique arose, and that precluded very largely the practicability of the use of X-rays.

X-rays were absorbed by opaque materials, according to the ordinary exponential equation. $l=l'$[illegible]. The opacity of the material by X-rays was merely defined by its place in the atomic table. Thus, bones were more opaque than flesh, iron was more opaque than wood and brass was more opaque than iron. In the laboratory the penetrative power of X-rays depended upon the shortness of the wave-length or the frequency of radiation, which depended practically upon the voltage which one was able to apply to the terminals of the X-ray tube.

Limiting Conditions.

At the present time one was not able, under the best possible conditions, to produce X-rays at a voltage higher than 300,000. It has been stated that in America, in California, they produced X-rays at 1,000,000 volts. He saw that in the paper and he wrote to the gentleman who did it to tell him how he did it, but he had had no reply yet. (Laughter.) But in England, at any rate, X-rays cannot be produced at any higher voltage than 300,000, and one cannot do that very long because the X-ray tube broke. Such voltage exists, of course, but there were experimental difficulties in the way of producing an X-ray tube that would stand a higher voltage than that. That was part of his research. With a voltage, however, of 300,000, and with suitable technical precautions, one could penetrate five inches of mild steel and could reveal a cavity in it which was about 3 per cent. of its thickness; this, however, was not applicable in the workshop. One was dealing with a set of conditions there that were essentially laboratory conditions. So far as the speaker had been able to accomplish practical examination of metals, one could not extend the voltage more than about 220,000 volts. But that gave a practical penetration of three inches of mild steel and, again, enabled one to see a flaw of about 3 per cent. of the thickness of the material. Experimental evidence went to show that as one increased in voltage one would be able to penetrate thicker metals up to 7 or 8 in. thick. Those figures embraced materials of considerable importance to the services, for example, tubes of guns and certain other forgings that did sometimes contain flaws, although one was told forgings did not.

The Phenomenon of Scattering.

It should not be imagined that one could just bring up the X-ray tube, place the casting in it and press a button and take a picture as one would with a Kodak. One could, but for the phenomenon which always occurs when penetrating opaque materials with X-rays, namely scattering. It was very similar to the phenomenon of scattering ordinary light through a fog and, unfortunately, with X-rays, when the scattering radiation from the surface, was atomic, it affected the photographic plate so that if one increased the scattering very much, as one did with short radiations, one so fogged the plate that one was liable to do away with any useful contrast. The methods adopted to eliminate this scattering and creeping radiation, constituted one of the great difficulties in this work, particularly when dealing with irregularly-shaped castings which had to be dealt with by this method so as to be of practical utility.

De-sensitised Films Used.

One was very often asked whether visual X-ray examination of steel castings was possible. The answer to that is that for very thin materials, materials up to ½ in. in thickness, visual examination for fine cracks and flaws and cavities was possible and practicable. For thicknesses over ½ in. under practical conditions it was not possible. The reason for that was obvious. If one was using the fluorescent screen method of visual examination the action of the rays, if passing through the specimen, had to be instantaneous, whereas, on a photographic film there was an exposure, and the action of the rays passing through the specimen was cumulative. The speaker doubted whether one would be able to increase visual inspection of materials beyond 1 in., but thought in a short time it would be practicable to examine steel materials of 1 in. in thickness visually without any necessity for photography. Another difficulty was that of producing or finding an X-ray dark room in a factory. There had been done a great deal of work on the de-sensitisation of films, and they now used films which had been de-sensitised to ordinary light, whilst at the same time retaining their sensitivity to X-rays. When that was developed a little more they would be able to do photographic work in the factory without any necessity for a dark room.

Practical Considerations.

The next practical question was one of exposure. How long did these exposures take for thick castings? When taking X-ray pictures one always took advantage of the fact that there were certain chemicals which fluoresce under the action of the X-rays. Platino-cyanide, calcium tungstate, and a few other chemical compounds, all fluoresced under the influence of X-rays, so that they used in close contact with the X-ray film one of those screens coated with calcium tungstate or one of these other fluorescent materials and that had the effect of reducing the normal X-ray exposure some 30 or 40 times, so that the actual exposure for, say, 2-in. steel need not be more than 2 or 3 mins., with the proper equipment. That gave a rough idea of what sort of time an X-ray exposure ought to take. Of course, it was not true for the very thick ones—the exposure was very much higher—but for practical conditions such as had been outlined the normal exposure was anything up to five minutes and very rarely any more.

X-rays to Aid Co-operation.

The radiography of specimens by X-ray had now reached the stage where it could be applied practically in the factory, yet he felt that the real use of X-rays from the point of view of the foundry would be not so much as a routine inspection, but in his experience, where it would be useful was when a batch of castings was to be produced. The very first of these should be X-rayed immediately and the foundryman should see the X-ray picture and have it explained to him, and if he saw where the faults were and knew what sort of faults they were, the probability was that while it was fresh in his mind he would be able to modify his technique so that he would get better results. When they had this X-ray examination the designer should be there also to see what the practical effect on his design was. It was there that X-rays would really justify their use. The immediate examination of castings by X-ray had often enabled a foundryman to correct mistakes and immediately to produce good castings.

X-ray Crystal Analysis and Strain Removal.

By using X-rays in another way one was able to see how the atoms of the atomic lattices in metal were ranged and oriented. Now atomic orientation in metal was strain, and he would like to be a bit prophetic at this point. He could examine a casting by one of the methods of crystal analysis and could determine the orientation of the atoms. In other words one could see if strain was present. It could be annealed and a second X-ray crystal analysis picture taken, and then one could state whether the strain had vanished, partly vanished, or whether it was still there. Now it was rather early to speak of these experiments, but some of the results were positively amazing. He thought that the foundryman had no idea as to the value of annealing, until it was shown by X-ray. In the future X-rays would probably be used to examine new designs of castings, and then one would be able to say to the designer perhaps "That would not do; there was too much strain in this part," or "This was a specially weak part in the casting, and it was liable to break or crack ultimately." We were also placed in a position to state to the annealer, "Your annealing which you said was so efficient, might just as well be done in cold water." That sounded exaggerated, but it was not quite so exaggerated after all.

DISCUSSION.

Mr. George Ness said it was rather difficult to discuss the addresses presented, because to him they had come largely as a revelation. He was not a steel foundryman, and his experiences up to then had been very largely with smaller types of castings, probably steam ends of turbines, valves for carrying superheated steam, but not highly superheated steam, not steam at high pressure with high superheating, but what he regarded as good average modern practice in land work particularly. There had been a great deal of common sense in what Commander Sedgwick said with regard to the requirements and to the acting of the steel foundrymen in co-operation with the designer. After seeing the X-ray photographs he felt very largely that any ammunition he had prepared had disappeared, for the simple reason that these X-ray photographs have exhibited definite weaknesses which could not have been really apprehended by ordinary visual examination. Up till then he thought one had been very largely guided in inspection work by visual examination, accompanied, where possible, by ordinary testing methods. His experience in connection with works where he was once a director was that he found that the percentage of rejects so far as he was actually concerned was very small. They had a large number of rather smaller castings made on the Continent, and found that they were excellent, but they were all more or less done by the electrical process. These castings might have been slightly superior to the British castings, but latterly they found that the British castings were becoming almost equally good, and, what was more to the point, they bought them as cheaply as they were getting them from the Continent.

With regard to the larger castings, he did not know so much about the English castings because his works were in Scotland. He had had nothing but splendid material. He had occasionally found a blowhole or two, but very slight. In testing valves, for instance, he regularly applied the paraffin test, anywhere from 1,000 lbs. to 1,500 lbs. to the square inch, and it was a remarkable thing that under the searching effects of paraffin at that high pressure he had a very very small percentage indeed of rejects. It was a peculiar fact, of course, that one did get slight failures under that test where the skin of the casting was broken. That was to say, where one had to subject it to machining, and it was somewhat difficult probably in these castings to trace the course of the leakage; the external leakage might be very far away from the internal defect. He wished to record that in these castings which he had had to deal with they had been excellent, and the rejects had been almost at a minimum, whilst the price was practically the same as those obtained from the Continent.

The X-ray photographs shown gave an insight into the latent unsuspected defects. But he could see very great difficulty in applying some of these tests to many of the current engineering subjects. The possibility of applying them to welding is one that might be approached with some considerable success, particularly where the plates were somewhat thin, and if there were available testing sets of a light portable nature, suitable for plates up to three-quarters or one inch, it might be a very great advantage. Somebody recently asked the speaker if he would like to examine a boiler by means of an X-ray, but he thought even the most ardent boiler inspector would shrink from such a duty. He expressed his thanks to both Commander Sedgwick and Dr. Pullin for the excellent way they had outlined their case, and citizens of this great Empire regard the British Admiralty as having an all-seeing eye and being an omniscient body.

METALLURGY OF STEEL CASTINGS.

By A. M'Cance, D.Sc. (Member).

[The second meeting of the series was presided over by Mr. J. Longden, President, Scottish Branch, I.B.F.]

The subject to be dealt with is a metallurgical one, and is mainly concerned with those physical properties of steel with which the steel founder has to deal in the practice of his art: that is, physical laws governing those happenings which result in some steel castings not showing on the outside what they really are like in the inside. Thus it reduces itself down from that point of view to quite a simple matter, since the main causes of the difficulties in the manufacture of steel castings are concerned with problems of contraction. The subject lends itself to division into three sections. In the first case we have what is termed the liquid contraction: that is, the contraction of the molten metal in the mould down until it reaches its freezing temperature. In the second case there is the freezing contraction, which is the contraction which takes place when the metal passes from the liquid to the solid condition; and finally, in the last stage, there is the cooling contraction, which is that contraction which takes place during the cooling down of the casting from the solid condition at a high temperature to its condition at ordinary temperatures.

Liquid Contraction.

All liquids expand when they are heated, and it is necessary to superheat the steel a certain degree above its melting point or freezing point in order to run the casting, the degree of superheat above the melting point determining the amount of contraction naturally which will take place in the liquid condition. Here, however, steel, as in many other respects, suffers always from disadvantages, because the liquid contraction of steel is rather high. In the case of ordinary mild steel the figure is 0.00039 per deg. C., whereas for cast iron it is only 0.00019 per deg. C. This, of course, proves that steel is much more sensitive to temperature differences than cast iron is, and gives rise correspondingly to greater difficulties. In practical work it may be taken, so far as liquid contraction is concerned, that the colder the steel is run then the less contraction is obtained, always bearing in mind that it is necessary to raise the temperature above its freezing point in order to run the casting.

Solidifying or Freezing Contraction.

Pure iron in passing from the liquid condition at its melting point to the solid condition immediately beneath that, contracts by an amount which is roughly about 5½ per cent. In the case of cast iron the figure is only 3.6 per cent.; but in the case of cast iron there are the modifying expansions which take place later which counteract very largely the effect of this contraction. In steel there is no such alleviating circumstance, and the art of the founder is so to adapt his processes to take charge of this contraction. This contraction can be seen very clearly in the case of the steel ingot, and Fig. 1 shows the section of a rectangular ingot that has been sectioned down the centre, from which it will be seen that solidification takes place from the outside in parallel sheets. Fig. 2 is a diagrammatic representation of what is taking place. On the outside there is the mould surface, and the steel solidifies approximately parallel to it. If it solidified exactly parallel many of our troubles would disappear, but unfortunately it solidifies with an irregular surface, and they finally touch at various points and ultimately leave little contraction cavities which are left to take care of themselves. In the manufacture of steel castings, therefore, this contraction has to be taken care of, and the method of doing that is by fixing a head on the portions where the contraction is likely to take place. These heads, remaining liquid for a longer period than the main body of the casting, allow the liquid metal in them to drain down into the casting underneath. It will be seen, therefore, that any change in section which may take place in a steel casting is likely to give rise to such a contraction cavity. For instance, if a roll section were cast on end it is obvious that the neck and wobbler part would solidify much quicker than the central body, and so all the contraction which takes place would be left as a cavity in the centre of the roll.

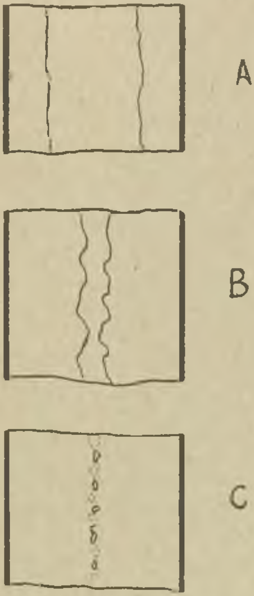


Fig. 1.

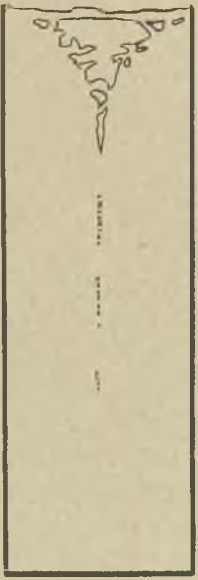


Fig. 2.

It is sometimes supposed that to take care of this contraction all one has to do is to put a head on the top, but unfortunately that is not borne out in practice. For any size of head there is a definite depth of metal only that can be fed by that head, and if that depth is exceeded then it gives rise to unsoundness down the centre. In the case of an ingot such as is shown in Fig. 3, the last portion to solidify is the metal which is moving down from the molten metal, leaving sundry other minor contraction cavities, generally as a V angle to the centre line. Fig. 4 shows three small ingots which the author prepared to illustrate still more clearly this factor. In this case the small ingots were cast in sand, and they were all run from the same charge and at the same time, and it will be noted that the size of head on the smallest body is sufficient to make the ingot completely sound. The same size of head on a slightly larger ingot has left one or two cavities down the centre, and on the still longer ingot it will be seen that there is a considerable area of unsoundness right down the centre, so that there is a definite size of body that can be fed from any definite size of head. This question is of great importance in matters of design, because in the case, say, of two gear wheels with different breadths of rim, one like Fig. 5, which is of comparatively small depth, can be fed without any difficulty, and will result in a completely sound casting, whereas a design with greater depth is too great in this dimension

Fig. 3.

in the normal way to feed, with the result that there is a cavity left at the junction of the last

FIG. 4.

portion which solidified. Some designs are particularly bad in that respect (Fig. 6). A casting of such design is difficult to get completely sound, and the only method by which a steel founder could assure soundness would be to get it redesigned.

The only way in which this contraction can be avoided is to taper the ingot instead of having it parallel. Obviously, since the metal is solidifying in parallel sheets to the outside surface, if a section is tapered it will still solidify parallel, but the contraction space left will be reduced. The amount of taper that is required varies, of course, according to the dimensions of the article in question, but there is a general rule which the author has devised which can be expressed in a curve which gives the amount by which the pipe is raised by differing degrees of taper (Fig. 7). That curve shows how taper reduces the percentage pipe.

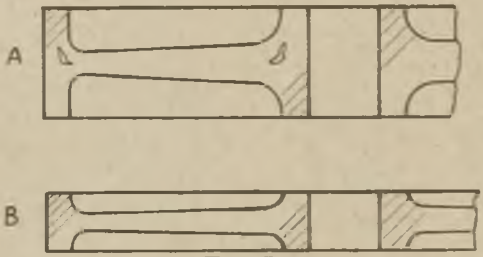
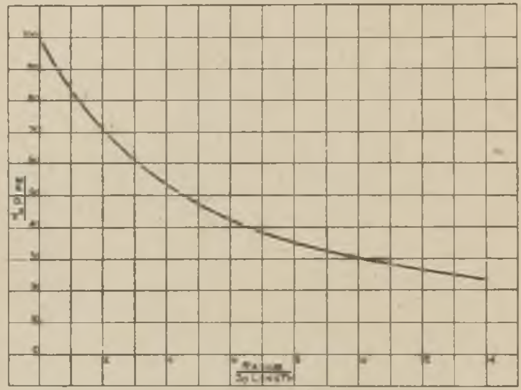


Fig. 5.

The next question which arises is: How does the composition and properties of the metal affect this ability to feed and so prevent those contraction cavities, and to explain that it is necessary to consider what is generally known as a typical freezing diagram? (Fig. 8). In the case of pure iron with the melting point as shown, the amount of the added element is increased, as shown in Fig. 8. It will be obvious that the object of the head being to keep a portion of the casting liquid as long as possible, the longer the time taken from the commencement to the end of the freezing, the better chance it has of feeding, and so it is necessary to know how this freezing range is affected by changes in composition. It can be taken that for any given carbon content this range is mainly affected by the percentage of phosphorus, sulphur and oxygen, while manganese and silicon affect it hardly at all, and so the behaviour of steel made by various processes is really shown up by their content of impurities. In Table I are given some approximate figures which may be taken as average. From this diagram it will be noted that those

FIG. 6.

impurity contents do indicate the properties of the various steels from the steel founder's point of view. It is well known that electric furnace steel is difficult to feed, whereas, on the other hand, Tropenas steel feeds much more readily, and consequently the heads do not require to be so large. There is another factor which is affected by the impurity content, and that is what might be termed the fluidity; that is, fluidity as distinct from viscosity. The viscosity of a liquid is the internal friction which it possesses against movement at a constant temperature. In the case of steel foundry work, what is required is fluidity; that is, the ability to run a given length under cooling conditions, and it will be observed that as that freezing range increases the ability to run a certain distance before solidification is complete under given cooling conditions will depend on the length of that freezing range, and consequently on the content of impurities. Therefore, electric furnace steel as against Tropenas steel will not run so well; it will be stickier, while acid open-hearth steel occupies an intermediate position. The content of impurities, therefore, in those steels is of very great importance, and it is unfortunate that just those factors which give a good steel from the steel-founder's point of view have other disadvantages when it comes to mechanical properties.



FOR ROUND INGOTS IT IS FOUND THAT OTHER SHAPES FOLLOW THE SAME LAW

FIG. 7.

Cooling Contraction.

The mass of metal being entirely solid at a temperature just immediately below the freezing point, and it has to cool down to ordinary temperatures, most metals show a perfectly smooth contraction curve as they cool down from a high temperature to a low temperature, but here again steel is an exception, and it does not contract uniformly. Owing to the presence of the change point, there are abrupt changes in contraction as it is cooling down. Fig. 9 outlines the expansion of pure iron. The change which is taking place in the neighbourhood of 1,400 deg. C. is of a very awkward nature. The casting is held in the sand, which is heating up in contact with the casting, while at the same time the metal is cooling down. The two effects, therefore, are antagonistic, and on reaching a temperature of 1,400 deg. C. there is this abrupt contraction which must throw an added strain on the metal, which it may or may not resist. Here the art of the foundryman again enters if the consequences of this abrupt expansion and contraction are to be obviated. The total contraction of the steel left to itself, proceeding from the melting point down to ordinary temperature, is approximately 2.4 per cent. The patternmaker allows a figure of approximately 1.6 per cent., so that there is 0.8 per cent. in ordinary practice which has to be taken up by the stretch of the metal, and in complicated castings even the 1.6 per cent. allowance for the pattern disappears altogether and no pattern allowance has to be made, which means that the whole of the contraction, amounting to roughly 2.4 per cent., has to be taken up by the stretch of the metal. If the metal can adequately deal with that contraction everything is well, and the casting comes

TABLE I.

Process.	Electric furnace.	Acid O.H.	Bessemer.
Sulphur	0.020	0.045	0.060
Phosphorus	0.020	0.040	0.055
Oxygen	0.025	0.040	0.080
Total	0.065	0.125	0.095

out whole. If, on the other hand, it cannot deal with it, then it has to give way and tear in some

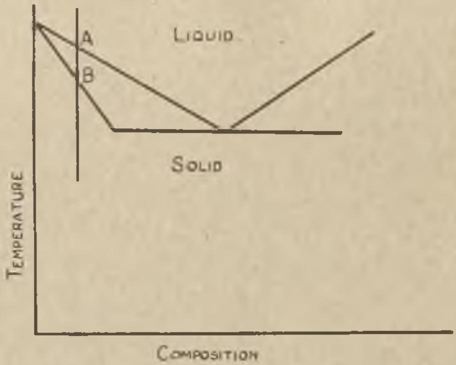


Fig. 8.—Freezing Diagram.

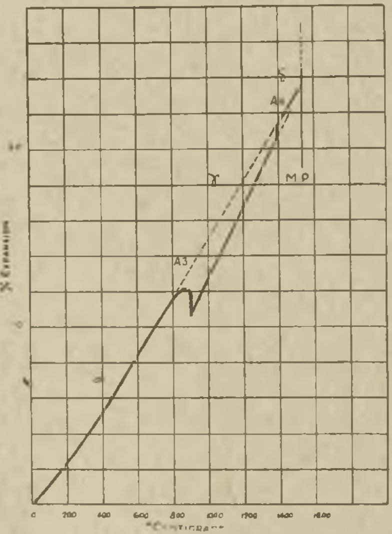


Fig. 9.

place, and in complicated castings this is one of the most difficult features to avoid, especially in a thin casting, because the ratio of the area of metal to the surrounding mass of sand is all against the casting withstanding its own cooling stresses.

What we have been considering is the case of pure iron, but a diagram can be evolved to show how that abrupt contraction varies, or how the delta point, as it is called, varies with content of carbon. (Fig. 10.) This diagram indicates how the change point which takes place at 1,400 deg. C. varies with the carbon, and it will be noted that the temperature at which it takes place rises appreciably with the small content of carbon, until it joins up with the main freezing line, when the contraction disappears altogether. Carbon therefore minimises and diminishes the effects of this contraction, although the variation of this contraction with composition is, unfortunately, not very great. (Fig. 11.) Table II shows the total contraction in a bar which is perfectly free to move in the sand. Many experiments have been recently carried out to find how this cooling contraction varies with different conditions of casting and of moulding. Fig. 12 shows some of the results of Korber and Schnitzkowski. These were obtained by Korber and Schnitzkowski, and the method they employed was to cast plain or flanged bars in green-sand and dry-sand moulds and to measure by means of a suitable instrument the variation in the length of the bar as it cooled, the temperature also being observed separately. In the figure, the numbers refer to the diameter of the bar, used in the experiment,

TABLE II.—*Contraction of Plain Round Bars (Korber and Schnitzkowski).*

Dia. m/m.	Temp. of casting. Deg. C.	Total contraction Per cent.	Contraction to AR_3.	Contraction after AR_3.
20	1,480	2.20	1.19	1.01
30	1,460	2.18	1.21	0.97
40	1,450	2.13	1.06	1.07
50	1,490	2.16	1.20	0.96

and the vertical scale gives the percentage contraction in length. The total contraction which was obtained, even with the bar cast freely in

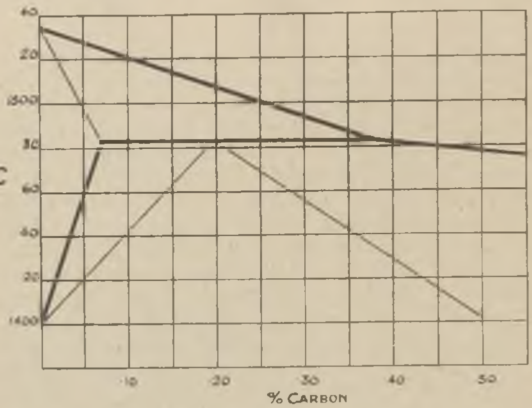


FIG. 10.

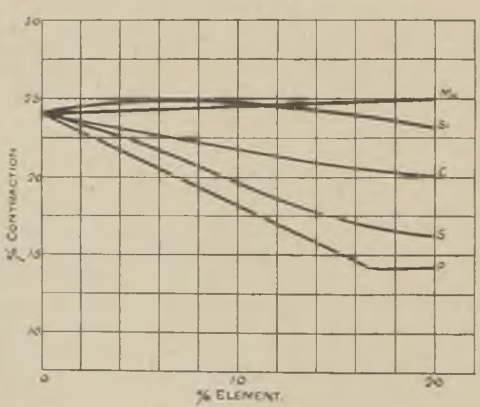


FIG. 11.

green sand, only averaged 2.2 per cent., irrespective of the diameter of the bar. It takes place in practically two equal portions. The portion of immediate interest is that which takes place before the metal really cools, and consequently takes place at a temperature when the iron is weak and least able to stand it. The ability of the steel to withstand this contraction will depend upon its strength, therefore under

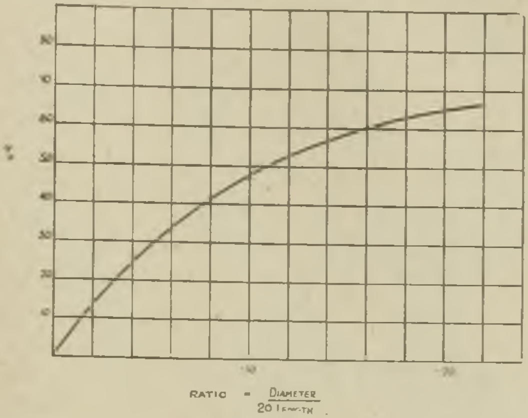


FIG. 12.

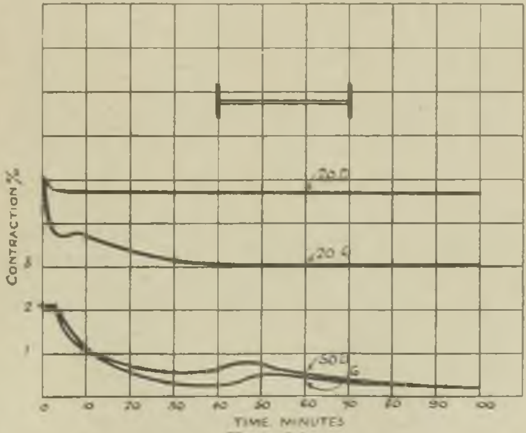


FIG. 13.

ordinary conditions it is independent of the dimensions.

Considering the case (Fig. 13 and Table III) of a small bar with a big flange at the end, it will be seen that in the dry-sand mould hardly any contraction took place at all, only about 0.3 per cent., whereas in the green-sand mould, even with the flanges, practically the full contraction occurred. With larger diameter bars (Fig. 14) there is not such a great difference, although even here there is a difference between the dry-sand-cast bar and the green-sand-cast bar. These results explain the great difficulty there is in casting thin sections, when the contraction which follows after the cooling is not allowed to take place. The contraction occurring at the higher temperatures is of by far the greatest importance, and it is interesting to examine the strength of the steel at such temperatures to ascertain what chance it has of resisting.

TABLE III.—(*Korber and Schnitzkowski*).

Dia. m/m.	Temp. of casting. Deg. C.	Contraction total Per cent.	Before AR_3.	After AR_3.	Mould.
20	1,470	2.03	1.01	1.02	Green.
	1,460	0.34	0.21	0.13	Dry.
30	1,500	2.13	1.12	1.01	G.
	1,470	0.61	0.18	0.43	D.
40	1,480	2.07	1.06	1.01	G.
	1,460	0.89	0.41	0.48	D.
50	1,470	2.19	1.18	1.01	G.
	1,490	1.78	0.89	0.89	D.

Fig. 15 gives the tensile strength of mild steel as the temperature is increased, from which it will be noted that it falls very rapidly until in the neighbourhood of the change point, when it rises, and then falls rapidly again. In the neighbourhood of 1,000 deg. C. the strength is less than 2 tons per sq. in.; in the neighbourhood of 1,300 deg. C. it is less than ½ ton per sq. in., so that in this region, which is the danger zone when metal is cooling down (from 1,500 deg. C. to approximately 1,300 deg. C.), the steel has only a strength of approximately $\frac{1}{4}$ to $\frac{1}{2}$ ton per sq. in. to resist any stress which is produced by the cooling. When this is realised it is surprising that any castings strip whole at all. The author well remembers a casting with which he had difficulty, where the thickness was approximately $1\frac{1}{4}$ in., and unless the core irons were broken within four minutes after casting, tearing took place, showing that the real danger zone so far as hot tears are concerned is in that region

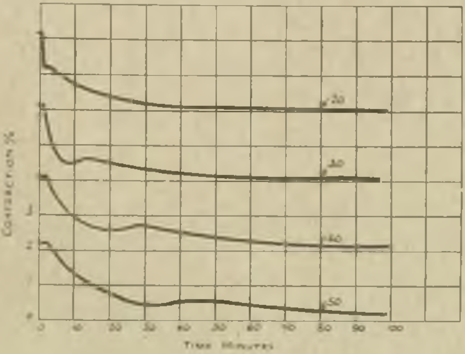


FIG. 14.

immediately below the freezing point down to approximately 1,200 or 1,300 deg. C.

Since the composition affects the total contraction very little one can consider what effect the composition has in resisting those strains, and here one cannot hope for very much assistance, because the increase in strength which the moderate quantities of alloy it is possible to add, give to the steel is inappreciable. There is one detrimental element, however, and that is sulphur. The ability to tear readily is greatly enhanced by a high sulphur content. This, however, is a very complicated question, since the oxygen content is also concerned in it as well.

The difficulties which are produced by the physical actions described, and which have to be allowed for, have to be wholly overcome by the art of the founder. The physical laws are there definitely; they cannot be removed, they have to be circumvented, and it is this which makes the art of steel founding so very difficult, because each individual casting has to be separately considered.

The steel founder has no choice in the physical properties of his metal, but the designer always has some choice in the manner of carrying out his designs. Therefore the designer should consult with the steel founder in the early stages of the design, and not merely after the design is completed, if the best results are to be obtained and satisfactory castings are to be made. Steel castings should be designed *as* steel castings, and not used as one sometimes imagines they are, judging from some blueprints, as a means of developing a love for the fantastic in a drawing-office staff. If the steel founder and designer get together more they will certainly produce a " production job "; that is, a job that will give the maximum amount of saatisfaction with the minimum amount of loss and failure to all concerned.

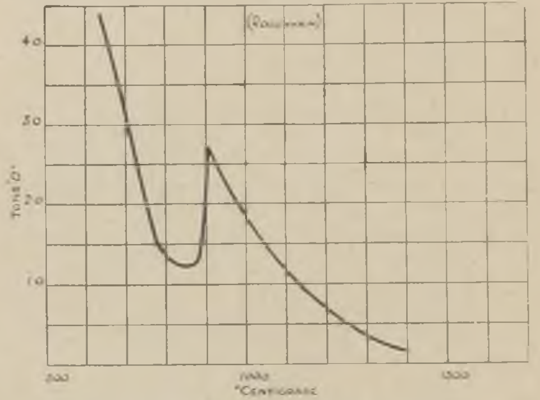


FIG. 15.—STRENGTH OF 0 16 PER CENT. C. STEEL AT HIGH TEMPERATURES.

STEEL CASTINGS FROM THE MOULDER'S VIEWPOINT.

By J. Jefferson, A.R.S.M. (Member).

The tests or experiments made have not been very elaborate, but they were simple, and would convey an idea of some of the difficulties which it is almost impossible to overcome. On the question of faults as considered from the foundryman's point of view, those causing practically all the trouble can be expressed in two words, and that is "drawn" and "torn." These cover the examples put forward by Commander Sedgwick, and also most of those put forward by Dr. Pullin.

Classification of Defects.

The customer generally calls all defects due to holes "blowholes." The complaint would convey more information and would stand a better chance of being rectified in future if the customer stated more definitely the type of defect. The more common faults can be classified as follows, and would probably cover 99 cases out of 100: First, there are mechanical tests which are not to requirements, due to error of manufacture of the steel, low elongation, poor bend, faults in annealing, or the casting insufficiently fed. Then there are blowholes globular in shape, the interior surface being smooth and silvery. They may occur just below the surface, and in bad cases throughout the body of the metal. These are due to faulty steel. There are also blowholes similar to the above, but with the surface tarnished, generally made evident when the skin is broken on machining, these are due probably to damp moulds. Then there are sandholes, with part of the mould broken off or washed from the runner and carried to another part of the mould. These may be at the surface, or just below the surface.

Drawn holes, irregular in shape with rough surface, found in the heavier parts of the casting, are due to insufficient feeding. Then there are " hot pulled " or " torn " holes, shown by what appears to be a crack sometimes so fine that it only appears when taking the finishing cut when the casting is machined. These are due to irregular contraction, or the contraction being interfered with, and take place soon after solidification of the steel.

Briefly, failure of mechanical tests and trouble with blowholes are of comparatively rare occurrence. The engineer will say that the blowhole is not comparatively rare; but the author maintains that failures of mechanical tests are comparatively rare. Twenty-two consecutive tests from the author's test book gave the following results:—The average was 30.3 tons tensile and 31.3 per cent. elongation, whilst what was required was 26 to 35 tons tensile, with 15 to 20 per cent. elongation. The maximum was 31.8 tons tensile and 35 per cent. elongation, while the minimum was 28.2 tons and 29 per cent. elongation. Thus the actual material of the casting causes no trouble. Blowholes due to damp moulds are probably more common, but so long as the human element has to decide when the mould is dry enough and the foreman takes risks to expedite delivery, they are liable to occur. Sandholes are due to carelessness and to bad technique. The engineer cannot help in any of these cases, and it is a question of foundry organisation and technique to reduce them to a minimum. The insufficiently fed and the hot-pulled or torn holes are the real troubles, the others being merely pinpricks. The difficulties arise from certain definite physical properties of the steel, which founders can no more alter than one can prevent sugar from being sweet. The high melting point, say, 1,470 to 1,480 deg. C., plus enough superheat to allow for the running of an intricate casting, may bring the temperature to over 1,600 deg. C. This high temperature is near the refractory limits of some of the components from which the moulding sand is made. If there is a small section of sand surrounded by a comparatively large mass of metal the former becomes semi-fused and is very difficult to remove completely, so that it is generally cheaper to drill from the solid in such cases, while spaces requiring a feather edge of sand should be avoided.

Steel is very weak mechanically soon after solidification, and this is clearly shown when casting ingots. If the side of the mould is touched by the stream of metal and it leaves a small portion overlapping the top of the mould, the other end being attached to the top of the ingot in cooling and contracting, this small section will pull the ingot, although the section of the ingot may be hundreds of times the area of the "ash." The same happens in the mould if the sand is not sufficiently weak to allow free contraction; in this case the casting is pulled, and the more complicated the design the more likely is this to take place.

Another factor is the high coefficient of contraction, which from solidifying point to normal temperature, is about 0.25 in. per linear foot. Sir R. Hadfield, in one of his Papers, mentioned the case of a cylinder which was 7 in. shorter than the mould. Taking this high contraction along with the fact that the steel is very weak soon after solidification, it is easily seen that if there are sudden variations of cross section the casting is liable to be pulled, because the thinner parts will have passed their weak stage and are contracting, while the thicker section is still at the weak stage. Thus there exist weak and strong links being stressed by the casting contracting and overcoming the resistance of the sand, and it is likely to fracture at its weakest spot, that is to say where the thin section joins the thicker. Accordingly, the designer should avoid as much as possible these sudden changes in cross section.

Contraction from the liquid to the solid state is a cause of trouble. Calculating from figures in Berlin's Paper, the author took a cube of 5-in. edge and calculated that in solidifying if there be a thin skin all the way round, the drawn hole would be something less than 2 cub. in. As a matter of fact it was a little over 1 cub. in., the outside, of course, was comparatively good. This, in conjunction with the high solidifying temperature (by that is meant that one does not fill the mould and get it all liquid, for as the mould is filled the sides are beginning to solidify), probably causes the most serious difficulty, especially in complicated designs. If there be a thick section on the casting, unless the shape and position is such that a feeling head can be placed in a suitable position to give a supply of molten metal to the part as it contracts due to changing from liquid to solid, there will be a drawn hole, or, if not showing an actual cavity, there will be a lack of solidity, indicated by low elongation, poor Izod, bad bend, and in severe cases, low tensile tonnage.

Position of Test Bars on Casting.

A plain cylindrical rod would appear to be about as simple a casting to make sound as one could wish, but in reality it is very difficult to cast, and if turned to a test bar will scarcely give a reasonable result. To obtain a good result means a pouring rate suitable to the temperature of the metal and the diameter of the rod. That is practically impossible in a foundry, because, especially in casting small work, there are so many different castings to pour. Sometimes specifications call for such a bar to be attached to the casting, but the mechanical strength of the bar would generally be inferior to the casting. In a case where a structure is strengthened by making it like a T, it is important, if possible, to put the strengthening rib on the side so that a feeding head could be placed on the opposite side, otherwise there will be a weakness along the line represented by the centre of mass where the two plates meet. As a T-shaped casting can be considered as being representative and modifiable, the author utilised it for his experiments. In one case he assumed that the shape of the casting was such that it was impossible to put the head on the back. The only other place to feed it then was as indicated in Fig. 1, and a test bar was taken just bordering on the cavity, and gave 30 tons tensile and 15 per cent. elongation, whereas at A, Fig. 1, away from the centre of mass, it gave 30.4 tons tensile, and 34 per cent. elongation, whilst the works bar gave 31 tons tensile and 33 per cent. elongation. Thus away from the centre of mass one is actually getting a bar as good as it was possible to make from the works bar. The other one where it is possible to get a feeding head in its proper position—that is, a feeding head capable of supplying liquid metal (Fig. 2) as the casting solidified—was 29.5 tons tensile and 25 per cent. elongation. Thus it is necessary in designing an object to place any connecting bars so that there can be proper feeding to the part where there is an extra mass of metal.

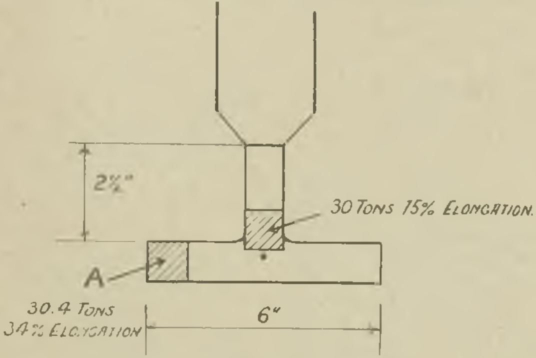


FIG. 1.

In another case (Fig. 3) the author had an unfortunate experience with a series of castings. The castings were made and inspected by bar test. They were 3 ft. long by 6 in. by 4 in. The test bar was put on the bottom, where it registers the best result. No objection was taken to this, and a great number of these links were made; the test called for 26 tons minimum tensile, but the actual tonnage was 31. When the customer got these links he cut one or two up and took a bar from the centre, and he said to us, " You have not given me the correct material." Of course, we said it was inspected and passed, but actually the link gave a higher tensile than 26 tons would have done from that area: that is to say, the bar part was less than the excess we had given over the 26 tons. The question naturally arises, can these castings be made, say, to meet the Admiralty requirements,

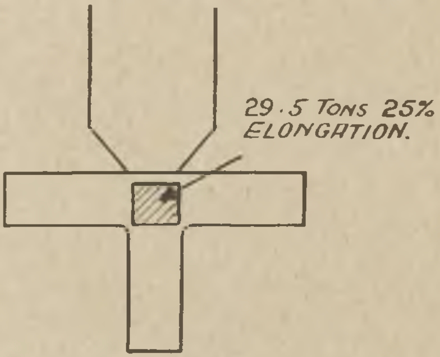


FIG. 2.

that is, the simple castings illustrated? The answer is in the affirmative, but the bar would have to be cast horizontally with a head on its length. If the machining be rated at 2s. 6d., that means that that would give an increase of 70s. per cwt. as an extra which no doubt the authorities would question. Similarly there would have been an increase of 10s. per cwt. in the link. The T-piece could have been made satisfactorily by thickening it down to the centre of the mass and feeding that way, which would have increased the price of this small casting by 12s. per cwt.

The author agrees that steel is the most likely to give the best results for the modern requirements of the engineer, but metallurgists do not know definitely the effect of high temperatures and pressures on steel, so that the factor of safety has necessarily to be high. The effect is probably cumulative, and when such is the case it is very difficult to predict what the eventual result will be. Perhaps members of the engineering department of Glasgow Technical College or University can say what is being done in this line and when definite results are likely to be forthcoming.

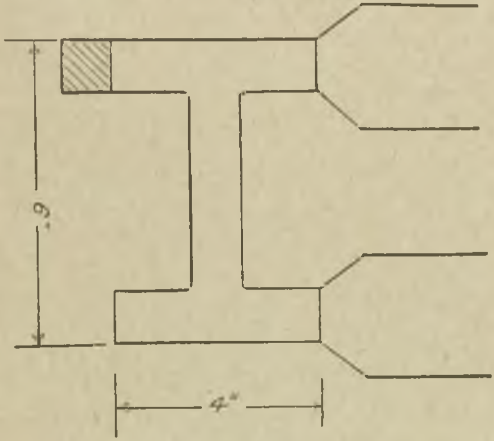


Fig. 3.

Loosely-Worded Specification.

Regarding the requirements for naval machinery castings, the author has extracted what he considers the important adjectives, namely, "everywhere homogeneous," "specified quality," "free from internal cavities," "cracks," "porosity," "internal stresses," and, as he mentioned before, "cheap." The adjective "cheap," to the steel founder just now, is like rubbing salt into an open wound, and from the examples given it will be seen that the price for these conditions must necessarily be higher. It may appear good business to reduce the weight of a casting, but the economy is not so real as one would expect if sold by the cwt. One is apt to overlook the fact that, for example, on a steel casting at 40s. per cwt., one is reducing a part represented by about 8s., and increasing the rate per cwt. on the remaining 32s. As Commander Sedgwick pointed out, the value of decreasing the non-combatant part of a battleship now is of a value which cannot be measured in terms of money. The thickness of standard valves and pipes has been arrived at by trial and error over a long period, and the thickness of comparatively small diameter fittings is, for casting purposes, much greater than that required to resist the stress. No doubt founders could run a much thinner metal, but the thickness has to be such that it will withstand the bursting action of the core as the metal contracts. The amount of reduction on these and other castings can only be found by experiments, and to cover the cost of these, Commander Sedgwick's suggestion that these might be done on a co-operative principle seems to be one solution. Such a series of experiments, for valves alone, could easily run into £1,000, and for 20 to 30 firms each to spend that amount on the same type of research would be folly. As there is no such organisation, there would be some difficulty in putting the suggestion into practice. It is suggested that such experiments could best be carried out at Woolwich, were the X-ray apparatus is available.

On the question of homogeneous castings, it is impossible to make a complicated casting homogeneous in the strict sense of the word, and it is suggested instead that no part of the casting should give tests inferior to the specification. If the specification calls for 26 tons tensile and 20 per cent. elongation, and different parts of the casting give 30 tons tensile and 30 per cent. elongation, and 28 tons tensile and 20 per cent. elongation, it would seem to be unfair to reject it, but one could not say it was homogeneous. In reference to the making of hollow cylindrical castings homogeneous, sufficient care has not been given in trying to make the sand outside more conducting than the core. In the case of round, hollow ingots cast in an iron mould, they can be made solid without feeding heads, due to the outer skin contracting quicker than the inner, thus making up for the difference in volume between the liquid and the solid.

Summary.

(1) The dimensions in the design must be adhered to throughout, as closely as possible.

This is quite a reasonable requirement.

(2) The casting must be completely homogeneous.

This cannot be guaranteed in complicated designs, the attainment of the specific quality gives practically no trouble, most customers are already receiving this. The requirement that the material must be free from internal cavities can be fulfilled if the design is suitable, that is to say, if it is of such a nature that founders can take precautions to prevent cavities. Freedom from cracks can generally be achieved.

(3) The article must be free from porosity.

This requirement is usually complied with.

(4) Internal stresses must be reasonably absent.

The founder cannot do more than attempt to correct by annealing. If this does not remove the inequalities, then the problem is one for the designer.

(5) The next requirement is "cheapness."

It is difficult to make castings cheaper consistent with quality. The term "cheap," however, is a relative one, and if Commander Sedgwick means by "cheap" a reasonable profit over cost of production, then the author agrees with him.

(6) Reduction of thickness.

As previously indicated, experimental work would be beneficial in this connection, and it is suggested that such experiments should be carried out at Woolwich.

Mr. Lindsay Foster said that they had now had the second of a very interesting series of meetings which undoubtedly offered such a wide field of thought as between quite distinct bodies, the Institution of Mechanical Engineers and the Institute of British Foundrymen. It has been rather interesting to see how both of these speakers have emphasised the fact that the industry is in nearly every case between two stools; and to achieve the desired result and to get good steel castings means that one has more or less to reconcile the irreconcilable. Both speakers have emphasised that the practice in the steel foundry to-day, despite the much vaunted claims of science, is still faulty. In conclusion, he proposed a vote of thanks to the lecturers.

GENERAL DISCUSSION.

The third and last meeting of the series was devoted to the discussion of the various Papers, and Mr. James Richardson, B.Sc., again presided.

In opening the discussion, the Chairman said he had noted six points that occurred to him as having arisen out of those Papers. Possibly, however, his stating these six points may be coloured from the point of view of the engineer or of the user of steel castings:—(1) What prospect has the engineer of more reliable steel castings, more particularly to meet the higher requirements as indicated by Engineer-Commander Sedgwick, and the more detailed and closer examination as foreshadowed by Dr. Pullin? (2) What prospect is there of thinner steel castings, also to be reliable, because if engineers can rely on thinner steel castings being reliable, then undoubtedly there is an unlimited market for steel castings to replace iron castings in all those branches of engineering where weight is of some importance? (3) Is the X-ray evidence put forward by Dr. Pullin, for the first time to his knowledge, accepted by the steel-founding industry? (4) Can the composition of this steel not be varied to suit the particular type of casting to be produced? He put this forward in ignorance of the metallurgical aspect of the production of sound steel castings, but he did know that for different types of ships different types of engines had to be designed, just as for different maladies different medicines had to be taken. Possibly various compositions of steel could be used to produce satisfactory results and to meet the varying degrees of complication. (5) It cannot be without interest to the steel-founding industry to know to what extent X-ray analysis will be specified by those authorities who were responsible for the purchase of large quantities of steel castings per annum. (6) Lastly, how is the engineer best to co-operate with the steel-founding industry? Should there not be brought into being some central authority, some clearing-house as it were, to deal with the various problems with which the founder and the engineer are beset?

Steel Castings can Show Properties Equal to Foreign.

MR. J. S. BROWN said the Papers which had been presented to this conference formed a very valuable summary of the position of steel castings in British industry. It had been shown that there was an increasing demand for such parts in modern power plants, and that progress in the development of these power plants was being restricted by certain limitations in the founders' art. In reply to this the steel makers had explained the exact nature of their present difficulties, classified as lying in the characteristics of the steel during cooling in the mould, in the destruction of the refractories forming that mould, and in the ever-present question of costs. While it was not possible to make suggestions which would remove limitations, it remained necessary to point out that the representatives of the users had raised little objection to increased costs; and the evidence they had submitted of excessive wasters discloses in itself that a fair return could be earned on any increased care which would insure that the moulding costs only arose once for each casting.

To encourage developments in this direction it might be of some service to the steel founder again to review the qualities in his product which the user found of value: and the following was a resume of that position. The steel casting took the place of both cast iron and gun-metal on entering the range of the higher steam temperatures in boiler work; it appeared in the pistons and cylinder heads of the Diesel engine; and it had a wide and increasing scope in all situations where the weight was important. Its merits in the high-temperature field arose from a definite superiority in its strength qualities; and the Department of Scientific and Industrial Research had recently published detailed reports on tests of a series of cast steels showing tensile, creep and other qualities which are almost identical with the corresponding forged steels of similar carbon content.* From this position the user would be willing to substitute steel castings in almost every position where forged steel is being used, and would find immense advantage in the flexibility of form given with the casting; and if he did not proceed fully in this direction it was because of experience that the actual castings fell below the standard of the small test-pieces on which the above tests were made.

Continental Competition and the Electric Furnace.

There was another side to the question of the quality of steel castings in the fact that certain Continental foundries were able to maintain a position in the markets of this country; and in the case of motor vehicle items, such as axle casings and wheels, this market continued in spite of the 33 per cent. import duty. There was no use in disguising the fact that Britain was an importing country, rather than exporting. This showed that the Continental founder can offer a product which better met the requirements in certain directions.

Does this arise from certain differences in technique such as the Continental use of electric

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* Engineering 'Research Report, Nos. 1 and 2, May and July, 1927

melting? It had been stated that the electric furnace may actually increase the difficulties due to the charge being too pure; but this could not be a complete explanation, for the purity could be adjusted in a downward direction with great ease. And, further, the firm of Leyland Motors, Limited, have installed their own electric steel-melting furnaces, and experience a brisk demand for their surplus capacity from other branches of the engineering industry.

Reviewing the position as a whole, it would appear that this country had some leeway to make up in the progressive development of casting in steel. The user had been pressing the founder to this end since 1885, when the Institution of Naval Architects had a Paper on Cast Steel Crankshafts; but these crankshafts had not yet arrived, and one was led to ask whether there was not scope for some intensive research into all the problems; what detailed analysis is present practice being subjected to in the light of Continental results?

This would doubtless involve a considerable financial expenditure, but the industry could expect to be supported by the Government research organisations. Indeed, this position was already arising, for the latest Report of the work at the National Physical Laboratory showed that they are investigating gas inclusions in steel castings, and that they were using electric melting in preparing the steel. It would be of great service for the industry to encourage this work; to see that its scope included the actual difficulties met with in practice, and to broadcast the final conclusions as fixing definite limits to the sections and proportions which can be obtained with success.

An Inspector's Views.

Mr. J. L. Adam said it was largely against his own convictions that he joined in the discussion, because he represented an inspection department, and, while he found defective castings, he was rarely in a position to say how they should be avoided. One of the things he liked in Dr.

Pullin's lecture was his reference to the service which might be rendered by the use of the X-ray in examining the first few specimens of a large batch of castings, and so discovering a method of remedying any defects which might appear. He had the same trouble as the Admiralty, only to a different degree, probably due to the fact that he had more latitude in the matter of weight, but he had trouble where conditions approximated to those of the Admiralty, as, for instance, in hollow castings of comparatively low scantlings, such as steam pistons of the box-pattern.

Steel Castings for the Merchant Marine.

Engineer-Commander Sedgwick did not deal with ship castings, but to some extent these are even more troublesome in merchant service than are engine castings. Larger masses of material were dealt with having more rapid changes of section, and, as a consequence, steel castings for sternframes of the "U" or trough section earned a doubtful reputation, and he was not sure that in some minds the doubtful did not still remain. In particular this applied to castings forming the heel of sternframes where the section changed from a "U" or trough-shaped form with two arms into the solid mass formed by the shoe of the sternframe. All Mr. Jefferson's remarks on the necessity for avoiding rapid changes of section are no doubt perfectly true, but in ships of the ordinary design for merchant service it was a little difficult to see how such castings could be avoided, and this applied also to the design of spectacle brackets.

Futility of the Hammering Test.

In the ordinary specification relating to steel ship castings, the pious opinion was given that steel castings, where intended to be used for forgings, should be so designed as to avoid abrupt changes in sectional area. Each casting must be thoroughly annealed and subjected to percussive and hammering tests, as well as tests for tensile strength, ductility, etc. It was also stipulated that the test-pieces were to form part of the actual casting submitted for approval, and are to be subjected to similar and simultaneous annealing. If he understood Mr. Jefferson correctly, despite such precautions the results obtained from the test-piece may give little or no indication of the actual strength of the casting. Engineers had all experienced cases where the tensile tests from a casting had been perfectly satisfactory, and yet when the casting (in the particular case in mind, it was a heavy fore-foot casting) was dropped through an angle of 45 deg. it broke through the "U" section. He would appreciate some information as to the value of hammering tests. The usual specification in regard to ship castings required that they should be slung clear of the ground and well hammered all over with a heavy sledge hammer. So far, at least in recent years, he had not been able to obtain particulars of any casting being rejected as the result of this hammering test, although rejection of castings on account of defects, mostly understood to be due to "draw," were common enough.

A great deal had been said about defects found under testing conditions, and various tests had been described. If such information was to be of any use for the purpose of these discussions it could only be by an analysis of the results of the tests which would show the why and the wherefor of any defects, because many engineers could find a defect and not be able to say how it could be avoided.

Co-operation as Basis for Improvements.

Mr. W. E. Lewis said that Engineer-Commander Sedgwick had put forward the point of view in favour with the Admiralty, and probably mercantile and marine engineers as well. Undoubtedly, however good steel castings were at present, there was room for improvement, and any possible improvement would be the result of the co-operation initiated by this Joint Meeting. If we could find some method by which defects could be traced and localised, many of the difficulties confronting both engineers and steel founders would disappear. Referring to the chairman's Point No. 6, how was this improvement to be obtained? The secret of the whole business was co-operation. Everyone of the speakers mentioned that, and only by cooperation between the departments interested in the production of steel castings could the most efficent results be obtained.

Dr. Pullin had shown that it was possible now to have an apparatus by which the interior of a steel casting could be examined. The problems that were facing the industry recalled the problems that were facing the users and the makers of steel chains and cables before the passing of the Cable and Chain Act. Users were not satisfied with the product, but the users and the makers got together and a specification was drawn up, various centres (the Proving Houses) were established to assist the maintenance of this standard, with the result that in a very short time afterwards the quality of British chain cables became second to none in the whole world. He suggested that the Admiralty, as the biggest users of steel castings, might do something in that line themselves. It was impossible to ask the steel founder to erect X-ray apparatus in his foundry, but would it not be possible to establish X-ray centres, in Glasgow, say, and in other large industrial centres, to which the founder could send his casting and have it examined by an expert and a report thereon prepared and sent to him? That would then form a basis by which both makers and users could get together. Another matter in regard to which co-operation is very necessary, is between the designer and the founder. The third person to whom cooperation was most important is the independent patternmaker. The last was the most important of all, because he had to transform the engineer's wishes on paper into something concrete for the foundrymen to work upon, and he knew from bitter experience how great the need was for this co-operation. He had had patterns sent into the foundry when he was engaged in the business from which it was really impossible without a great deal of modification to make a decent casting. The more the metallurgist and the steel founder co-operated the better would be the results reflected in the product.

Finally, the founder should co-operate with all the others, so that the results of their work should not be lost. Unless care is taken in the foundry, the efforts of all the others, the designer, the patternmaker, and the metallurgist are absolutely thrown away, and he thought there was no part of the work where that neglect receives more drastic retribution than in steel founding; and from experience with castings he had found that the greater number of replacements that he had was due to such faults as sand holes, etc. If these faults could be eliminated, and according to Mr. Jefferson's Paper they could be eliminated, then 50 per cent. of the engineer's troubles would disappear, and the people whose duty it was to attend to the castings would find that the other 50 per cent. would disappear.

Mr. T. M. Service limited his remarks to the Paper given by Commander Sedgwick, for the reason that he dealt with the Admiralty views which were the result of large experience. Further, in the case of Admiralty castings for high pressure purposes, no patching, either by welding or other means, was permitted, consequently the castings as cast must be perfect both superficially and internally. Commander Sedgwick in the early part of his Paper, outlined the Admiralty requirements, and, at a later stage, showed how the steel founder failed to meet the specification, and gave seven types of failures as illustrations. At a still later stage in his Paper, Commander Sedgwick pointed out the Admiralty desired to help the steel casting industry, and by their stringent supervision tried to improve the quality, and as a result reduced the weight of the various parts in naval ships.

He, the speaker, had condensed the Admiralty requirements into three main issues and proposed to analyse these and show how the Admiralty assisted, or otherwise, in attaining their ideals. The three points were:—(1) Quality of material; (2) reduction in weight; (3) homogeneity.

Admiralty Specification Deemed to be Low.

As to the quality of material, it was interesting to note the following specifications:—

Admiralty:—*Ultimate tensile strength*, 26 to 35 tons per sq. in.; *elongation* on 3 in., 15 per cent.; and *bend*, 60 to 90 deg. on 1 in. sq. bend.

Lloyd's and B.E.S.:—*Ultimate tensile strength*, 26 to 35 tons per sq. in.; *elongation* on 3 in., 20 per cent.; *bend*, 120 deg. on bend, 1 in. × ¾ in.

In the case of two valves, the walls were only ¾ in. thick and the walls comprised the greatest area. The founder had to cast a test-bar sufficiently large to obtain a 1 in. × 1 in. bar for bending purposes. He had been under the impression that the object of testing was to obtain the average physical properties of the bulk of the material and this could be more nearly met by test bars of the dimensions given under Lloyd's and B.E.S. specification.

If the Admiralty required the highest quality of steel, would Commander Sedgwick explain why the Admiralty Specification was the lowest of all the British Surveys?

Lightweight Valves and Heavy Brackets Exhibited.

As to reduction in weight he exhibited models of two valves, one 10½ in. and the other 11½ in. The weight of the first, without brackets, was 7 cwts., and the weight of the brackets was 1¾ cwts. The second valve, without brackets, weighed 10½ cwts., and the brackets weighed 2½ cwts. That meant, in order to attach the valves to the ship's structure, a further additional 20 per cent. in weight was required. The thickness of the valve walls, which were exposed to high-temperature high-pressure steam was ¾ in., while the thickness of the brackets which were required to attach the valve to the ship's structure was as follows:—

10½ in. *valve* ... Supports ⅞ in. and base 1⅛ in.
11½ in. *valve* ... Supports ⅞ in., base 1⅛ in.
thickened in places to 1⅜ in.

If the Admiralty were serious in their attempt to reduce weight, why should the important part of the casting be sacrificed? Surely it was within the skill of the designer so to design the valve that the important parts should not be harmfully reduced but the major reduction in weight carried out on the less important.

Homogeneity of Steel Castings.

Designers do not seem to appreciate the physical changes which take place in steel when cooling from the fluid to the solid. In addition to lineal contraction there was also volume contraction, and accompanying this volume contraction there were also the chemical changes which, with certain compounds, lead to heterogeneity, the degree of which depended on the mass and speed of cooling.

That the above laws were not understood by designers was illustrated in the $10\frac{1}{2}$-in. valve, where two $7\frac{7}{8}$-in. brackets met at a point on the $\frac{3}{4}$-in. wall, with the result that an area of retarded cooling is produced which becomes a potential source of hot tearing. In addition to the danger mentioned there was also the possible danger of an internal weakness, due to the fact that the surrounding metal was solid before volume contraction in this area was finished. By an alternative in design this difficulty could be minimised.

If one examined the valves internally, one found a circular valve seat which, with machining allowance, has a cross-section of 2 ins. × 2 ins. = 4 sq. ins. This seat was connected to the valve opening by a $\frac{3}{4}$-in. thick wall. It was obvious that the $\frac{3}{4}$-in. wall would be solid before the volume contraction was completed in the valve seat and consequently a contraction cavity would occur.

These remarks were based on the two models submitted, but many more Admiralty designs could be discussed and shown to have equally bad features. He was aware that some of the defects mentioned could be minimised by the use of chills, a point on which he had not touched, but one must remember that the Admiralty ask for castings free from defects externally and internally, and chills in many cases set up defects equally as serious as the ones mentioned, and as welding or other forms of repairing were not allowed, the castings, even if chills had been used, would be equally unserviceable. The steel founder was to blame in the respect that he had blindly accepted designs without question, while he should, instead, have pointed out the objectionable features. As a case in point, his firm took a very strong stand in the case of an Admiralty design, and had it altered to bring it within manufacturing capability and accessibility for inspection, with the result that satisfactory castings, both from the Admiralty and founder's point of view, have been produced.

Steel Gearing for Sugar Machinery.

Mr. A. A. Arnold said that one of the many uses for steel castings in the construction of sugar machinery was for the heavy spur wheels and pinions used for the reduction gearing driving the sugar mills, and for pinions on the mill rollers themselves. The teeth of such gears were now universally made as steel castings, either with machine-moulded cast teeth or machine-cut teeth, and it was not only on account of its strength that steel should be used, but for its wear-resisting properties. The service in the case of pinions on mill rollers was most strenuous, amounting, in some cases, to estimated pressures of, say, 2,000 lbs. per in. width of tooth face, or possibly more, and under very difficult conditions, because the centres between the shafts might change slightly in the course of working, due to increased openings between the rollers. The tooth speeds were low, being between 20 and 40 ft. per min., but the service in many cases was continuous throughout a whole week. The reduction gearing, however, had fixed centres between shafts, also low tooth speeds, the first motion being in the neighbourhood of 300 ft. per min., with tooth pressures up to 1,600 or 2,000 lbs. per in. of width, and the second motion about 100 ft. per min. with tooth pressures up to as much as 3,000 or 4,000 lbs. per in. of width. There were, of course, cases of much higher tooth speeds, with machine-cut teeth, and the present tendency is in that direction. Steel gears with machine-moulded teeth, after a service of nearly 20 years (five to six months' season per year), have shown very little signs of wear, which indicates that both strength and wear-resisting requirements had been satisfied. The defects to which such castings may be subject is more apparent than real, but in some cases one would like to see smoother surfaces, especially for the contact surfaces of the teeth in machine-moulded wheels and pinions.

Resistance to Wear.

Further, castings made by steel founders of the highest reputation were sometimes very ragged along the edges of the wheel arms as though the metal were sluggish in the mould. Regarding resistance to wear, he had, on the other hand, seen many cases of machine-cut cast-steel gears working under similar conditions of service at the low tooth speeds already given, and in some cases actually alongside the machine-moulded gears on adjacent sugar mills in the same factory; the machine-cut gears had shown signs of distress by the teeth edges spreading sidewise, indicating that the material was somewhat soft, possibly due to the cast surface being removed and exposing the internal metal which might have been of a softer character. Some pinions had been, in a short time, so much worn in this manner that they had to be reversed on their shafts so as to present the opposite face of the teeth as the driving side. There was usually nothing objectionable in this procedure except the expenditure of time, which was important in a sugar factory, and the labour of doing so. When this spreading out takes place, obviously the contour of the teeth becomes altered and imperfect, under which conditions rapid wear must take place. In one case in point, the first motion gears were stated to require entire replacement every season after working about six months. It was only fair to state that in all the cases mentioned the machine-cut steel wheels and pinions were supplied by manufacturers in the United States and not from this country. He would not say that this was the reason of the want of durability, perhaps others could say.

One defect, if it may be called such, was that some steel founders, and only some of them, remove core prints from the patterns and omit cores so that hollow parts are cast apparently solid and additional machining was therefore necessary. It saved the inconvenience of badly-cored castings, but incidentally it reduced the anxiety of the steel-founders of the risk of misplaced and displaced cores and saved them the necessity of exercising care while increasing their weight output and the cost of the casting to the machinery manufacturer. It also produces " fuzzy " places or hollows in the interior, such as Mr. Jefferson had outlined. Cores of small cross-section may be fused up, it is true, but it was not to these that he referred. Was the designer to be blamed or not for defects arising from this cause?

As a matter of interest he would like to raise the question of the strength specification for steel castings. It would be remembered that in the days gone by, for wrought steel it was specified that the tensile strength should not be less than so many tons per sq. in. and not more than so many tons per sq. in. with a certain minimum elongation in a certain length. In most standard specifications this style seems to have disappeared and the tensile strength is required to be between certain limits or to have a minimum value with a corresponding minimum elongation. There were, however, exceptions, as in the case of crank webs for marine engines if made of cast steel.

Both Lloyd's and the Board of Trade rules state that the tensile strength must *not exceed* 32 tons, and further the sum of the tensile strength in tons per sq. in. and corresponding elongation on a standard test piece shall not be less than 50 per cent. From this it would seem that steel castings of the highest tensile strength, with suitable elongation for all grades A, B and C which were in accordance with the British Engineering Standards Association specification for marine purposes, were unsuitable, because their tensile strength exceeds the figure already stated. Should the inspector reject such castings for this purpose, even supposing that the obtained tensile strength of 35 tons was reckoned only 32 (the limit) when added to an elongation of 20 per cent. making a sum of 52 against the 50 required, that was to say, was steel of 32 tons and 20 per cent. elongation suitable and steel of 35 tons and the same elongation—20 per cent.—considered unsuitable, and if so what was the reason? Commercially it was not possible to have tensile and other tests made for all castings, how, then, was the engineer to know when the castings supplied have been satisfactorily annealed?

He was surprised to learn from Commander Sedgwick's Paper that steel castings, for superheated steam, were first used by the Admiralty in 1923, as 20 years before that there was occasion to put in a stop valve for superheated steam which was specified to be of gun-metal, because the Admiralty always had gun-metal stop valves. The consulting engineers to the Admiralty (it being a land job) were requested to allow a stop valve with cast steel body to be supplied instead, and that was done.

Views of a Locomotive Engineer.

Mr. C. H. Robinson said the subject of steel castings was one of great interest to locomotive engineers. A considerable proportion of the weight of the present-day locomotive was composed of steel castings, which amount to from 15 to 20 tons, in the case of standard gauge express engines, such as the L.M. & S.R. "Royal Scot" and L. & N.E.R. "Pacific" classes. This figure tended to increase to the elimination of heavier iron castings, which were being substituted by steel of lighter sections, and of plate and angle stretchers which were not so rigid. In this country the plate frame was universal, but in the U.S.A. the bar frame held the field. The latter was always made of steel castings in that country, but where used on Dominion or foreign railways, which were controlled by British boards and engineers, there seemed to be a diffidence to use this material, and it was almost universally specified that they must be ripped out of solid rolled steel slabs. A pair of bar frames for a medium-sized locomotive weighed about 10 tons in the finished condition.

Some few years ago some very heavy engines of the bar-frame type were built in this country for South Australia, and the frames were cast in America. Whether this was a question of price or diffidence to undertake the work on the part of home founders, he did not know, but it was not very inspiring to see such work going abroad. Recently inquiries were circulated for some heavy locomotives for another Australian railway, and it was specified that the frames and stretchers should be "cast in one." The whole structure was designed as a "box section," and the total weight of the casting, a very complicated one, was 16 tons. These were actually specified to be cast in the United States.

Steel Castings from the Machine Shop.

Considering steel castings from the machine-shop point of view, he had noticed a considerable difference in the quality of home as against continental castings. The continental casting was usually "milder" and seldom suffered from two defects, serious from the machine-shop aspect, which were frequently missing in home castings, namely, "hard spots," and "sand inclusions." The "hard spots," which occurred in segregated patches were a serious drawback, as a reasonable cutting speed was impossible owing to the liability of breaking the tool, and they often had to be chipped out with a sharp-pointed chisel, causing a great waste of time. "Sand inclusions" were also the cause of serious delays, as the tools were blunted and had to be removed frequently for regrinding. These two defects prevented the use of milling processes, owing to the risk of ruining expensive cutters. Judging from machine-tool makers' catalogues and articles in the technical Press, which boom the successes of the milling machine in America for finishing steel castings with wonderful production times, one imagined that castings free from these defects must be the general production in that country.

He had noticed that the contraction allowance on patterns for continental foundries was very much greater, sometimes almost double, that required in this country. It would be interesting if Dr. M'Cance could enlarge upon this.

Failures of steel castings in locomotive operation were, in so far as his experience went, infrequent. He had known of one or two cases of stretchers cracking, but these appeared to have been "hot tears," which had not come through the skin, until submitted to stresses in service. He once inquired of a friend, who was chief mechanical engineer of a railway which possessed a large number of locomotives, whether he had had any experience of a cast-steel wheel centre failing in service, and the reply was "never." This was certainly to the credit of the steel founder, as he imagined that a wheel centre, with its heavy boss and spokes tapering into a comparatively light rim, must be the very worst type of casting to make good, judging from the remarks made by Mr. Jefferson.

He regretted that none of the Papers had dealt in any way with alloy steels. Judging from the technical Press relative to locomotives, they were being much used and discussed in the United States, particularly for bar frames and heavy stretcher castings. It would be interesting to know the effects of the various alloying constituents, and to what extent they were being used in this country.

MR. FRANK HUDSON said that the experience of Glenfield and Kennedy with steel castings, in hydraulic engineering, was not altogether a happy one, especially in light valve castings having relatively thin sections. On the other hand they had little to complain about in the heavier work, and quite recently some 54-in. valves went through the shops without any defects in the castings coming to light during machining operations or under hydraulic test. In light valve castings, however, they usually returned at least 50 per cent. of the castings received to the foundryman as scrap or for some attention, such as welding, etc.

Value of Statistics.

He drew attention to Fig. A, which gave a sectional drawing of a 3-in. cast-steel valve, and typical of the general run of light castings. The greatest number of defects existed as porosity in the top flange which one soon found out when drilling flange bolt holes, followed by blow- or sand-holes on the valve faces, and lastly hard spots on the valve faces. Mr. Jefferson suggested that it would be very helpful for the steel founder, when castings were found defective by the customer, to have the correct information as to the actual cause of the defect rather than the general term "blowholes." This information to be of any value must of necessity be determined by those responsible for the manufacture of the casting. At the same time he would like to see all foundries make a better analysis of defective castings. Admittedly they can all say what the percentage of defective castings was for the last financial year, but how many could say that out of this percentage they had had so many defective to shrinkage cavities, so many defective to hot-tears, etc.

From personal knowledge of one firm who kept careful statistics they now found that their greatest machine-shop-rejects were due to shrinkage holes, followed by dirt and slag inclusions, then hot-cracks. The actual percentage of bad castings due to shrinkholes was 36 per cent. of total machine-shop rejects. This confirmed Dr. M'Cance's remarks, and at the same time gave added emphasis to the need of very intimate co-operation between the designer and founder. In this question of design uneven distribution of metal and improper filleting produced castings which were an eye-sore to the engineer.

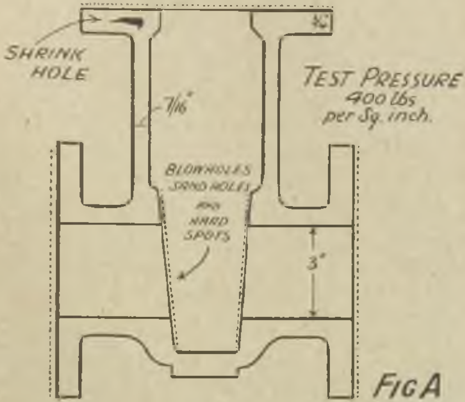
SHRINK HOLE
3/4"
7/16"
TEST PRESSURE
400 lbs
per Sq. inch.
BLOWHOLES
SAND HOLES
AND
HARD
SPOTS
3"

FIG A

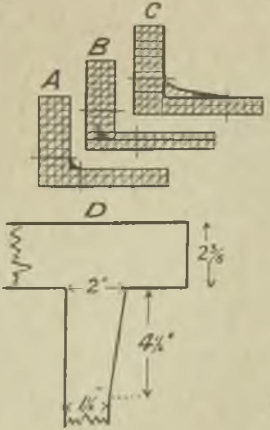
C
B
A
D
2 5/8
2"
4 1/2"
1 1/4"
1

FIG B

The porosity found in the top flanges of the light steel valve shown in Fig. A was due to this. In the heavy valves, although the change of section was just as pronounced, his firm so far had not been bothered with porosity or shrink-holes, due to intelligent placing of suitable fillets as shown in Fig. B. The fillets shown at " a " and " b " proved unsatisfactory, whilst " c " was in general use for their heavy valves. " d " was the actual section of a 54-in. valve where the flanges join the body and show the fillet. No cavity had ever been found when drilling flange bolt holes. This, to his mind, showed the advantages to be gained by co-operation between the designer and founder, whilst at the same time it should be particularly noticed that in many cases this co-operation would result in the production of sound castings without a radical alteration of design.

Commander Sedgwick would no doubt be interested to learn that it would appear from his experience that the lighter or thinner the casting then the greater the number of rejects in the machine shops. He was more or less in agreement with the engineers' requirements, as outlined by Commander Sedgwick, but suggested that surface finish was also of importance for obtaining better steel castings. It seemed to him that mould surface played only a minor part in this matter, and the roughness of some steel castings was mainly due to the viscous nature of molten steel.

In conclusion he drew the engineer's attention to the price question. It would appear that it was not quite appreciated that, apart from the actual value of the founder's art, over 200 tons of material and tackle must be used and handled in the average steel foundry to produce one ton of castings. This could not be done for nothing, and no doubt left the steel founder very little surplus to play with.

Elastic and Plastic Strains.

Mr. G. F. Gillott, B.Met., said that for the past year he had been engaged in research work on steel castings at the Research Department, Woolwich. Dr. Pullin had given an illuminating account of X-ray methods applied to the examination of steel castings. A great advantage of this system was of course that it was rapid, accurate, and did not injure the castings. As Dr. Pullin had explained, interpretation of the X-radiographs requires considerable experience. As a rule, cracks, excepting the finest, were fairly readily identified, but with cavities some difficulty occurred. The radiologist usually described these as "blowholes." For many purposes such a general description was quite adequate, but to the metallurgist, a more exact knowledge of the nature of these voids was essential. At present it was necessary for this purpose to supplement the indications of the X-radiographs by a critical metallurgical examination of the sectioned casting. This unfortunately meant destroying the casting and took some time.

Another point worthy of mention in connection with X-ray examination was the question of strain in castings. If this was "plastic" it was harmless, provided that it had not been so great as to develop flaws in the metal. If, however, it was "elastic," this implied the existence of stresses in various parts of the casting, balancing each other, and possibly concentrated in some of the angular sections. These "elastic" strains might be serious since they may be stressing the casting in the direction in which it will be stressed in service and so diminishing the factor of safety. It would be of great assistance if radiologists could discriminate between strain accompanied by stress (*i.e.*, "elastic" strain) and strain with no remanent stress (*i.e.*, "plastic" strain).

He thanked Dr. M'Cance for drawing attention to the loose use of the term "blowhole." Blowholes caused by gases evolved by the metal could generally be put down to steel of poor quality or insufficiently deoxidised, a comparatively rare complaint in the modern steel foundry. This point deserved mention in view of the fact that some research workers had described gases in steel as a "casting defect." It is rather a "steel-making" defect. The majority of serious voids were not blowholes, but shrinkage cavities. These could usually be avoided by casting with the heavier sections uppermost and by providing large feeding heads over the heavy sections. Unfortunately, as Mr. Jefferson had pointed out, the additional expense necessary to ensure soundness was considerable, and on that account many foundries were obliged to take the risk of "draws."

Strength of Elevated Temperatures.

However, these, and other defects, were of a comparatively minor nature compared with cracks. These were of a most persistent nature, and difficult to repair satisfactorily. Most cracks might be described as "pulls" or "hot tears." As the steel was cooling down from the molten state, the contraction stresses were gradually increasing in magnitude. At the same time the steel was becoming stronger, so that the matter resolved itself into a race between the two factors. There were two possible methods of attacking the problem: First, by reducing or releasing the stresses before they become dangerous, and second, by increasing the strength of the steel at high temperatures, as for example, by careful attention to its purity, or by the use of alloying elements such as nickel or chromium. The latter method also had the effect of greatly improving the mechanical properties of the finished castings. No doubt much remained to be investigated in the way of providing moulds and cores which yielded readily on the cooling of the metal, but which possessed the initial mechanical strength and refractoriness to withstand the pressure and erosion of the molten steel. To eliminate the hot-tear, some means must be found to decrease the contraction stress, or increase the strength (or both), so that at any temperature during cooling the steel has adequate strength and ductility to deal with the stress which was being imposed on it.

In conclusion, he remarked that his thanks were due to Dr. R. H. Greaves, of the Research Department, Woolwich, for permission to take part in the discussion.

Mr. Jack Currie said that as a foundryman, his remarks were necessarily directed towards the author of the first Paper. It was rather a difficult matter to criticise, as Commander Sedgwick had clearly stated what he wanted, and surely if he was prepared to pay for it he would get it, if it was at all possible; but he himself was rather afraid that in a few isolated cases it was the impossible Commander Sedgwick had demanded. It was rather disconcerting to the steel-founder to hear from the authorised representative of the Admiralty that the quality of British steel castings was not quite up to the high standard required.

Dr. M'Cance and Mr. Jefferson both came to the common conclusion that more co-operation must exist between designer and founder, and Mr. Currie suggested one line of thought that such co-operation might follow. In cases where intricate castings were required, difficult to mould and feed properly and the only beneficial property seemed to be one of cost, he thought that the idea of making a composite casting should be considered. By composite, he meant the making of the casting in two or more pieces and building up to produce the finished article. In many cases this might not be possible, but in some it would be quite feasible, and although increased cost might be incurred, increased quality would certainly be the result.

Commander Sedgwick did not mention much in his Paper regarding alloy-steel castings, and to his mind such castings represented the answer to the engineer's demand for steel of improved quality, as by the proper application of alloying elements it was possible to obtain increased physical properties. Alloy steel, however, could not be considered a panacea for all the troubles that arise in the use of steel castings, and owing to the difficulties in manufacture and increased service such castings necessarily demanded a higher price than was asked for ordinary steel castings.

Unification of Standards Desirable.

Mr. Currie, continuing, said that much trouble and expense would be avoided if there was a co-ordination of specifications, as at present it seemed to the founder, at least, ridiculous that two castings of the same pattern for the same purpose should be made to entirely different specifications, thus causing increased trouble to the manufacturer with no increased service to the user. This might seem a minor point, but if a foundry had to cater in the same day for material to meet specifications such as 26/32, 28/32, 30/37, 35/40 and 38 tons min. per sq. in., the trouble entailed could be partly realised. Surely a standard steel of, say, 34/36 tons per sq. in., with a minimum elongation of 15 per cent., would meet the case for all purposes, and at the same time make it possible to cast intricate castings, which when required in the softer qualities of steel were almost impossible to produce without flaws appearing in some place or other.

He would also have liked to have heard Commander Sedgwick pass an opinion on the quality of castings obtained from the various processes by which steel castings were now commonly made, or at least the three mentioned by Dr. M'Cance, namely, the electric, acid open-hearth and converter. He understood that whilst the Admiralty were prepared to accept general castings from any of these processes, they would not allow the converter process to be used in the production of castings which had to withstand fluid pressure. This was rather difficult to understand, as by taking proper precautions steel could be produced by the converter process capable of complying with any test requirement. It was fluid enough to run the thinnest types of castings, and whilst the impurities, as shown by Dr. M'Cance, were as a rule higher than in the other two processes, this had the advantage of nullifying to a certain extent the evil effect of fluid contraction, although it had to be admitted at the same time increasing the tendency of the material to develop flaws during solid contraction. The only point to his mind which might rule out the converter process was that the human element entered into it to a greater extent than was the case in either the electric or open-hearth furnaces, but he did not think that this, in face of the results obtained by this type of furnace, should debar a steel-founder from manufacturing material which was well within his scope.

Regarding the limit of thinness asked for, this is rather a difficult and dangerous question to answer, as thinness could only be taken in conjunction with something else, and must be relative to the size and shape of the casting desired. Mr. Currie said that he had diverged in some of his points from the actual Paper, but as they were things in which he was very interested, he would like to hear Commander Sedgwick's opinion on these matters.

Limitations in Co-operative Activities.

Mr. Walter West (Leyland) said that it was well to recognise that there were limitations which beset the designer as well as the foundryman, a fact that accentuated the great need for a closer working between the two. The designer, of the desirable type of mind, was only too anxious to assist when the anticipated difficulties created by the design had been pointed out. In like manner, it was also essential that the patternmaker should also join in the discussion. Co-operative effort on a large scale would be of immense value to investigate many phenomena which affected the broad principles of steel founding, but something deeper than any work which a national body of research workers could effect was urgently needed. In the first place, it would not be possible for a national association to look into with precision, problems which arose with every different pattern. Here, was called for that personal initiative from the foundry management which would take him to the user, after very careful consideration of the work to be carried out, and boldly state any difficulties which presented themselves. A man inspired with such enthusiasm would strike the right note for a frank, amicable discussion with the most conservative of designers. This method of attack would produce direct results, which no national effort could possibly accomplish, and it would be an assembly of such individuals, who, being in immediate touch with the needs of the Admiralty or the engineering trade in general, could advise and direct the activities of the proposed association without unnecessary loss of time or money.

It was misleading for foundries to put their entire hope in such an association, and in their own circle of activity they, themselves, should therefore display a similar spirit of co-operation with their customers.

Assuming that every step had been taken to produce a design to the satisfaction of designer and founder, and that such had been correctly interpreted by the patternmaker to give the easiest and most effectual method of production from the view of coring up the mould, immediate release of the casting after pouring, and commercial profit, the result then depended to a large extent upon the foundry technique. That such was not simply confined to the moulder was easily proved. Solidity or homogeneity of a casting—having already assumed that the question of design was settled—depended primarily upon the disposition and size of feeding heads. Other factors, such as the method of running and the size of the runners, had a great influence over the results, but the fluid pressure exerted by an ample number of liquid-steel reservoirs could not be replaced by any of the expedients which were so often adopted in the foundry. Further to this, in spite of much excellent research attention which the manufacturer of steel had been given, it had to be admitted that this work had been directed more towards the making of steel ingots than steel for castings. There was much yet to learn, and for a national association to take up such a question would be of great assistance.

Properties of Electric Steel.

Broadly speaking, there were three processes of manufacture—open-hearth, the converter and the electrical furnace, each of which would produce steel of identical chemical composition, but with what difference in physical behaviour during solidification, only those who had a wide experience or had worked the three methods could describe. That steel had certain definite physical properties which founders could not alter was correct as a broad statement, but, for example, in the electric furnace, where an unlimited amount of heat energy was available, the conditions, on the face of matters, would appear to be admirable for the production of thin section castings. The truth, however, was that this flexibility of operation was a source of danger in disguise, for steel produced with degrees of super-heat, changed in its physical behaviour during the period of solidification. Experience showed, without the theoretical explanation to give the reason, that such steel has inherent tearing or cracking properties, and no matter to what temperature the metal might be cooled the same phenomenon was observed. This was sufficient evidence to the practical mind that the thickness of the section was not only limited by the possibility of running the metal to every extremity of the mould, but also by the degree of super-heat which could be given to the molten steel.

Furthermore, they, as founders, had not exploited all the possibilities in the manufacture of steel for high-pressure steam castings. The physical characteristics of molten steel were not entirely derived from the chemical composition, but could be affected by the manner in which the molten bath was treated during the refining period. Experiments had shown that by an unusual method of "killing" or finishing the metal—a difference in the behaviour and consistency could be obtained. While definite information could not, as yet, be given with sufficient surety for general broadcast, the following test results obtained would indicate that the steel differs sufficiently from the usual as to warrant the conclusion that further knowledge could still be obtained from research on these lines:—

	C. P. cent.	Y.P. Tons.	M.S. Tons.	E. P. cent.	R.A. P. cent.	Brinell No.
A8073	0.30	28.5	40.4	22.5	31.5	170
A8093	0.27	27.3	41.0	21.5	30.0	187
A8079	0.26	28.4	39.8	23.5	38.5	170

Ignoring the test results here given, the cream-like appearance of the steel made in this manner at the normal temperature of casting in foundry practice called for distinct notice. The behaviour also during solidification in the mould more than indicated that if the shrinkage, is as great as the usual run of steel of similar composition, the liquid metal had a life sufficiently long to cater well for it.

Oil-Sand Cores and Hot Cracks.

The extensive use of brackets in foundries to prevent cracks occurring in steel castings indicated that sufficient attention was not paid to the material used in the making of the internal sand cores. Here, consideration could well be given to the use of oil-sand cores in place of those made in naturally-bonded sand. Limitations accompany such a suggestion, in view of weight and size of the casting required, but there was little doubt now left in the minds of those manufacturers who had adopted such mixtures, that hot cracks were thereby greatly reduced in number.

In conclusion, Mr. West said that the suggestion regarding an advisory committee, composed of engineers and foundrymen, for the purpose of discussing the question of steel castings, was greatly to be recommended, and was anxiously awaited by progressive members.

Pointers in Relation to Competition.

Mr. D. Sharpe thought for the type of castings being discussed there were two types of steel founders—one good and one bad. The bad steel founder who turned out steel castings with the main aim of profits should not give consideration to the manufacture of the high-duty castings called for under discussion, but should leave them to the steel founder who could be classed as good for this type of work. The so-called bad steel founder might be quite competent to deal with the class of casting which was his normal product, probably better and cheaper than the man making the good quality of steel casting. Occasionally, however, whilst passing through periods of dull trade the lower grade founder was tempted to venture into the high-quality market, send in a quotation which was so attractive to the buyer that he jumped at it. The net result was trouble all round. He was putting forward this point of view in the belief that it would be helpful to the discussion.

One other point he brought forward was in regard to thin section steel castings. He had dealt with in his experience a very wide range of thin sections, in this country, in Belgium, and in the United States, and he believed that the real difference between these competitors and the average British firm was the process, the Belgian and German makers producing a green-sand casting while British founders still remained firm for a dry-sand casting. They were, however, gradually developing the green-sand casting, and of the good steel founders here many were able to get green-sand castings equal to those produced on the Continent. With regard to a remark made about the electric furnace, this was limited to the smaller marine-engine casting, and could not in its present stage deal with large hull castings.

A great part of the discussion was related to what might be called pipe-line work, high-pressure and high-service castings. The electric furnace had a great advantage in producing such castings. Defects in steel castings had been enlarged upon, but he thought it would be very helpful to a future discussion of the same kind if the engineers, on the other hand, would make a careful tabulation of the defects occurring at their plants, and make a list of headings, including blow holes, slag, and sand inclusions, tears and draws, and support that with a percentage scale with which to shock the steel founder. He was able to trace in his own experience of about 25 years in steel founding the improvement that had been made in steel castings over that period, and he believed that if the average engineer nowadays was to secure a casting like the average sent out 25 years ago there would be a revolution. The improvement has been going on steadily from year to year, and he thought that from a good steel founder one could obtain high-grade castings of any reasonable design.

Inarticulate Founders Create Trouble.

Dr. J. W. Donaldson wrote:—The four Papers on steel castings were of considerable importance and demonstrated the difficulties of steel founding. Engineer-Commander Sedgwick had given quite definitely the Admiralty requirements for steel castings, and then put forward four possible reasons why those requirements were not being met.

As regards the first of these, whether the designer was asking too much of the founder, the designer, as a rule only asked what the founder stated he was quite prepared to give. If the designer asked too much the founder should refuse to attempt those designs, and the designer would be forced to meet the founders' requirements. Founders seldom did this, and the designers' conclusion was that moulders did not know till they tried whether a particular design could be cast successfully or otherwise. If the moulders did not know it could not be expected that the designers should know.

It was agreed that there were frequently designs that could be simplified or improved, and it was equally true that the suggestions of founders would be met, if at all possible, but the time for this was before the castings were attempted. There were designs, however, so intricate that the founders should refuse to make them in cast steel, and engineers should be asked to accept them in cast iron, and would find them more satisfactory, especially if the higher grades of cast irons now available were adopted.

Regarding the second and third reasons, the standard of soundness set by the Admiralty was one with which engineers generally would agree, as the standard must necessarily be high, if such castings were to serve their engineering purpose. While Dr. M'Cance and Mr. Jefferson's Papers showed that some founders at least had done their best to perfect the art of steel founding, Dr. M'Cance's Paper, in the first instance, left an impression that the difficulties of steel founding were so very great that success can only be achieved in the simplest castings. Mr. Jefferson's Paper was, however, a complementary one and corrected such an impression to some extent, but it was hoped that founders would supply facts to remove this impression altogether.

The fourth reason that steel castings were already up to the required standard would not be endorsed by users in general. The percentage of defective castings passing through the average engineering works was still too high to give confidence, and many engineers looked with the greatest suspicion on steel castings, and this suspicion should be allayed as much as possible. Commander Sedgwick deprecated the patching of unsound castings, and he (Dr. Donaldson) agreed with him, as welding was not only a palliative, but was too often used to cover up defects, which, if seen in the first instance by the user, would lead to the immediate rejection of the casting.

Dr. Pullin's Paper on the X-ray examination of steel castings opened up a new field of testing of considerable interest to the metallurgist, and gave an insight into the possibilities of this method of testing for castings of all types and materials. His remarks about crystal analysis and strain removal were extremely interesting, and, when developed, would form a very valuable addition to the present mechanical and metallographic methods of testing for satisfactory annealing.

In dealing with cooling conditions Dr. M'Cance stated that in castings of complicated design the usual pattern allowance of 1.6 per cent. contraction disappears. Did he mean that the patternmaker could not make such an allowance owing to design, or that the allowance was made but could not be taken advantage of owing to the physical conditions of the molten metal when cooling?

Quality and Price Considerations.

Mr. Jefferson stated that satisfactory steel castings could be made, but at prices which he indicated may be higher than those generally quoted. If that was so, why was it that satisfactory castings can be obtained from foreign sources and at prices averaging 40 per cent. less than those obtained at home. A recent example which came to his (Dr. Donaldson's) notice was of a cast steel stern frame where the Continental price was one-third of the lowest British price—that is, 66 per cent. less—and where a sound and satisfactory casting was supplied at this price.

It was also stated by Dr. M'Cance and Mr. Jefferson that if the design of castings were improved more satisfactory castings would result, and general agreement would be expressed in a larger amount of real co-operation between the designer and the founder. One felt, however, that in addition to the four Papers read a fifth one from the designer's point of view was necessary to complete the series.

Definite Improvement in Technique Recorded.

Mr. Robert Scott wrote:—Commander Sedgwick's Paper introduced such a vast field for discussion that it appeared to him the best way would be to attempt to discuss the one or two special points which particularly interested him or applied to any special knowledge of the trade. (1) The designer asked too much of the founder, and (2) that the founder had not fully explored the possibilities of his art. The founder was unable to say whether he could meet the design or not without actually attempting to produce the casting called for. This was the only way at present that the founder had of furthering his research work and advancing his technique. He had also the spur behind him to attempt those new designs by the knowledge that if he did not his competitors would. Speaking of founders' experiences, they were daily producing castings which six or seven years ago they would have refused as being impossible to make, and they felt that they were improving their technique every month. They could assure Commander Sedgwick that they are not standing still, but were using every effort to improve their productions.

The *soundness* insisted upon by the Admiralty must necessarily be high, but small defects in the casting, which did not affect strength and utility of casting, should receive reasonable consideration, as no one could expect perfection, and especially 100 per cent. perfection.

As regards *minimum thickness*, it was thought that the present sections asked for were the minimum, and in some cases under it (considering the number of foundry rejections), but no doubt any steel founder would undertake to attempt much thinner sections for the Admiralty on a time and line basis. In the present financial position it was almost impossible for any steel founder to undertake research work for the Admiralty unless on such a basis, as, after all, a steel foundry was a commercial undertaking.

With regard to Dr. M'Cance's and Mr. Jefferson's Papers, being confrères, the majority of these contentions is naturally agreed with, and especially with one remark by Mr. Jefferson that the Admiralty need not expect good steel castings to be cheap.

[*After the Symposium a joint Committee was appointed to summarise the findings with a view to forming a basis for further discussions. This summary is detailed in the following pages.*]

This conference extended over a series of evenings during the winter of 1928-29, and was brought together by the joint action of the Scottish branches of the Institution of Mechanical Engineers and the Institute of British Foundrymen. The scope of the conference was extended to include the interests of the users of the castings, and also of the inspection societies, in addition to the more intimate interests which connect the founder who produces the castings and the engineer to whom they are supplied.

The conference recognised that the production of castings in steel is more difficult than in the more common engineering materials, but it directed attention to a number of cases where the percentage of wasters was unduly high, and it was concerned to learn that the experience with steel castings in the Naval Service was such as admitted the position to be summarised as follows, by Commander Sedgwick:—

"The experience with these castings in the Naval Service has been none too happy, in many cases it has been impossible to obtain the desired article in cast steel, so that eventually some other material has had to be employed as a substitute. In other cases the thickness has been increased to such an extent that one might as well have used cast iron."

Continuing, Commander Sedgwick suggested that there were four logical alternative reasons for this position:—

(1) *The designer was asking too much from the founder.* If so, why did not the latter protest instead of wasting time and money in attempting the impossible?

(2) *The standard of soundness set by the Admiralty for this service aimed too high.* That may be, but the user had the right to set his own standard, and if it could not be fulfilled, then he would probably go on to another material and endeavour to have his standard fulfilled with that.

(3) *That the founder had not fully explored the possibilities of his art* in this particular

direction. This appeared very likely in view of the extreme excellence of some steel castings that were produced both here and abroad. If it could be done in one case, why not in others?

(4) *The product might already be up to the required standard*, as witness the very small percentage of rejects experienced in some cases.

At an early point in the proceedings Dr. Pullin described the use of X-ray methods for tracing hidden defects in the castings, and he was able to present a series of examples which showed conclusively that hidden defects of important proportions could be found in certain types of castings.

The case for the founder was presented by Dr. M'Cance and Mr. Jefferson, who described the exact nature of the difficulties they were called on to work under, due to the properties shown by the steel during the time it is fluid, and again whilst it is cooling. It was stated that practically all the defects are traceable to questions of gating and feeding the moulds so as to overcome shrinkage and contraction: but that in some cases the designer asks for parts which do not allow any satisfactory system of feeding. The questions involved in the casting of thin sections were discussed. The general trend of the discussion is reviewed in the following statement under the eight separate headings, as below:—

(1) Commercial interest of cast steel; (2) general requirements and typical defects; (3) production of the casting; (4) thin sections; (5) specifications; (6) tracing hidden faults; (7) conclusions, and (8) further action.

(1) Commercial Interest of Cast Steel.

The mechanical qualities of cast steel compare closely with the forged material of similar chemical composition; the tensile strength at elevated temperatures, and other properties of the two materials have been quoted in the Reports issued by the Department of Scientific and Industrial Research—Engineering Research Reports Nos. 1 and 2 of May and July, 1927. In view of these qualities the user would be willing to substitute steel castings in almost every position where forged steel is being used, and would find immense advantages in the flexibility of form given with the casting.

(2) General Requirements and Typical Defects.

The general requirements in steel castings were summarised by Commander Sedgwick, and he also indicated the nature of the usual run of faults which came under the notice of the Naval Inspection Service.

The Naval requirements for machinery castings were:—(*a*) The designed dimensions must be adhered to throughout the finished article as closely as possible; (*b*) the material must be everywhere homogeneous and of the specified quality, and must be free from internal cavities and cracks; (*c*) the article must be free from porosity, and (*d*) internal stresses must be reasonably absent.

Further, the Naval Inspection Service have reported defects of the following general types:—(1) Blowholes; (2) draws, generally at flanges, or changes in sections (very few are known in bosses); (3) porosity under pressure tests; (4) contraction cracks; (5) sand inclusions; (6) scabbing, and (7) failure in physical tests (comparatively few).

The foundrymen took the view that their real troubles were covered by the two words "drawn" and "torn," and these are the result of insufficient feeding or the effects of certain physical properties of the steel which the founder is unable to alter and which have to be overcome by his experience and art. The foundrymen also drew attention to the general use of the term "blowhole" to describe almost every kind of defect. It was explained that blowholes proper are a comparatively rare occurrence, and when they do occur it is due to the failure of the human element in the foundry. Sand-holes and sand-inclusions come under the same category.

(3) Production of the Casting.

The pouring temperature of molten steel approaches closely on the fusing temperature of the moulding sands and causes certain limitations in the methods of moulding. In addition the contraction allowances are about twice that required for cast iron, that is, the contraction while in the liquid state is twice that of cast iron, and again, during freezing it is again twice that of cast iron, and, finally, during cooling the case of cast iron is favourably assisted by modifying expansions, which are not met with in cast steel. Thus the characteristics of the steel, during solidification and subsequent cooling, made it impossible to avoid a tendency towards local weakness at all changes in the sectional thickness of the casting: the thicker section cooling more slowly, and being then damaged by the other parts drawing away the material from the heart of the thick portion. In practice this detrimental influence dictates the position in which the part will be moulded, and in the more complicated castings it leads to the provision of additional heads to feed the thick portions.

This tendency to draw is so very real that it is almost impossible to promise that a casting will be of entirely uniform composition; the Izod values and tensile elongation tending to become reduced at all changes in the section. It was pointed out that even in the case of a simple 1-in. test-bar the core-material would be superior with a side head on the bar, instead of the usual end feeding head; but, in practice, it is almost impossible to work out an ideal system of feeding the more complicated castings, and each casting has to be separately considered.

The extent of the porous material in a simple rectangular billet casting was given by Dr. M'Cance in a graph; this showed that 50 per cent. might have to be cropped from a billet two diameters in length. Thus, in order to secure sound material in a casting it is necessary to provide large gates and headers, and it is only by working in this direction that the moulder can improve his product. As the cost of these extra heads had to be included in the price of the casting, it would seem that the skill of the moulder lies in deciding which of the desirable heads can be omitted without leading the purchaser to find reason to reject the casting as being defective.

(4) Thin Sections.

Experiences were quoted where a design had to be increased in thickness before a satisfactory casting could be obtained, and in some cases the thickness became so great that the part might as well have been made in cast iron. Here the defect showed as a hot-tear, where the restrictions imposed by the mould caused internal stresses during the early part of cooling, when the solidifying steel has such a low strength and ductility that the stresses were relieved by fracture. These fractures may become difficult to locate in the finished casting, as they close again with the cooling of the heavier sections. Here the founders took the view that all progress towards thinner sections was a matter of experiment, and that much could be done by the breaking of the core-irons shortly after pouring the steel. Evidently it is largely a matter of obtaining a softer material for use in the moulds, and there would appear to be scope for investigating the remark that the Continental foundries are able to use about twice the allowance for contraction which obtains in this country.

(5) Specifications.

The founder finds in the case of castings whose forms lend themselves to the moulding process, that there is no difficulty in running a steel of relatively high-tensile strength, and he, therefore, regards it as confusing to be asked to work to such a series of specifications as are quoted below, where there is a considerable amount of overlapping between the different tensile strengths. Further, the view was expressed that there can be no sound reason behind the rejection of a casting on the ground that it is too strong, where the tensile strength falls slightly above the upper limit and all the other properties fall within the specification.

Range of Specifications:—

(*a*) 26-32 tons per sq. in.
(*b*) 28-32 tons per sq. in.
(*c*) 30-37 tons per sq. in.
(*d*) 35-40 tons per sq. in.
38 minimum.

Here it was suggested that 34/36 tons minimum, with 15 per cent. elongation, would provide a suitable standard specification which would meet all the requirments of the above range.

Again, the specifications of the Admiralty and of Lloyd's show the same strength but differ in the other particulars.

	Admiralty.	Lloyd's.
Tensile, ultimate tons ..	26/35	26/35
Elongation on 3 inches ..	15 per cent.	20 per cent.
Bend	60/90 deg. on 1 in.	120 deg. on 1 in. × ¾ in.

(6) Tracing Faults in Castings.

The source of the faults in the castings arises from a failure to obtain solid material, due to voids, porosity and tears; and while, in the past, it has been usual to pass the castings on the basis of an external inspection, and possibly a further water-test, it has now been found that new methods of inspection bring out further concealed defects of which there is no evidence on the surface. The search for these internal discontinuities makes use of the X-ray methods brought forward by Dr. Pullin, and of another method which discloses changes in the electro-magnetic properties of the part in the vicinity of a local fault. In the case of neither method can it be said that the process of inspection lends itself to routine use in a foundry, but they have given results of considerable practical importance and their use must be expected to extend in the future. On this subject the founder pointed out that while the methods disclose additional defects, these defects are located in positions where they were most likely to occur, and the inspection methods cannot lead to any important change in moulding practice.

(7) Conclusions.

The founder was agreed that castings could be made to Admiralty requirements; but in the more complicated forms the cost would be much higher than that of routine castings.

The founder finds that he has little or no choice in the physical properties of his metal and he feels that the designer, who always has some choice in the nature of his design, does not fully appreciate that point.

It was suggested that the designer and founder should co-operate at the design stage so that the experience of the latter might lead to the design being free from the more prominent difficulties in moulding, while being equally serviceable for its duty; also that the technique of the chemist and metallurgist should be utilised by both designer and founder.

It was suggested that this co-operation could be attained by the formation of a consultative committee consisting of engineers, foundrymen and metallurgists, such a committee to be of local connection rather than of national standing.

(8) Further Action.

The following points brought forward by Mr. Richardson would appear to provide a basis for any future discussion:—

(1) What prospect is there in obtaining steel castings to meet the requirements put forward by the Admiralty that will pass the inspection described?

(2) Can thinner steel castings be produced that are sufficiently reliable to be used in place of iron castings?

(3) Could the varying degrees of complication in castings be met by varying the composition of the steel?

(4) How can the engineer best co-operate with the founder? Should there be some central authority or clearing-house to deal with the various problems with which the engineer and founder are beset?

REPLY TO DISCUSSION.

By Dr. M'Cance.

Dr. M'Cance wrote that he considered the general discussion which the Papers had aroused had been valuable and enabled anyone who wished to take a comprehensive view of the situation to see more clearly the direction in which progress was tending and to recognise the factors in steel castings manufacture which were not yet under complete control. But he did not think that it was justifiable to take any despondent view of the present position. It would probably always be the case that the demands of engineers were slightly ahead of the practice of production, since it was a simple matter to increase one's demand but a relatively slow business to increase practical proficiency. But steel founders would welcome all the assistance that could be obtained from the new research methods of Dr. Pullin and were in his debt for the pioneer work he was doing. He hoped that his results as they became available would be given wide publicity.

In the discussion Mr. Adam had raised the question of the value of the hammer test, and he (Dr. M'Cance) thought that for present castings it was of no value at all. A casting would require to be exceedingly bad to fail under the hammer test, and in the detection of unsoundness it was so uncertain in its indications that it was of little use. After all, the chief trouble with steel castings was not the detection of major unsoundness but the detection in otherwise good castings for *specially severe service* of areas of secondary unsoundness which were often of very small extent and which could not readily be seen, and in most cases could not be seen at all by a usual examination from the surface. It was not a case, as some people seemed to think, of the majority of present-day steel castings being bad, but of discussion of the best methods for producing difficult steel castings where the necessities of design restricted the application of known physical laws. That distinction was of great importance and should be borne in mind.

Mr. Robinson had raised an interesting subject in his statement that the contraction allowance for Continental foundries was greater than was usual in this country. This was an indication that their moulds were less rigid and interfered less with the natural contraction of the steel either through the use of green sand or better-prepared dry sand. There should consequently be a greater freedom for hot tears, which arose from this cause. He was glad that the conclusions reached by Mr. Gillot as the result of his work at Woolwich corroborated the point of view put forward in his Paper. Seeing that on fundamental questions there was agreement, the chances of satisfactory developments from the research work in progress was most hopeful.

He regretted if he gave Dr. Donaldson the impression that successful steel castings could only be made in the simplest types, for that was far from the truth and was not his opinion.

The uncertainty of the contraction in certain difficult castings arose from the conditions that owing to design it was not possible to make the mould sufficiently collapsible so that the casting had to stretch in cooling down. Exactly how much contraction and how much stretch to allow for could only be decided by making a casting. Yet this question had to be decided by the patternmaker long before the casting had reached the foundry stage. This illustrates merely one of the uncertainties which made the application of rigid scientific principles to foundry work so difficult.

London Branch.

ALUMINIUM-SILICON ALLOYS.*

By R. B. Deeley, B.Sc., A.R.S.M.

The value of the aluminium-silicon alloys for use in modern engineering and manufacture, particularly as compared with the other light alloys of aluminium, is a subject which, though touched upon by a number of writers, has not received any very detailed attention. This may not perhaps be so surprising as it seems at first sight, when one considers that it was less than forty years ago that the Hall press reduced the cost of production of aluminium sufficiently to enable the metal to enter into commercial competition with the old-established metals, iron, copper, zinc, lead and tin.

In this comparatively short space of time the use of aluminium has increased so rapidly that in 1927 the world consumption was 200,000 tons, making it the fourth in order of importance as regards world production of the non-ferrous metals.

Though the metal was first isolated in 1824 by Oersted, the quantities obtained were not sufficient for a study of the properties of alloys, nor was there much object in doing so on account of the cost of the metal. The production, by Deville in 1854, of large quantities of aluminium by means of sodium cheaply obtained by Bunsen's new process, made possible a study of the alloys of the metal, and although some attention was given to the Al-rich alloys, most investigations seem to have had the object of determining the effect of small quantities of aluminium on established metals and alloys.

The electrolytic process discovered by Hall in 1886, and universally employed in the manufacture of aluminium, so reduced the price that serious attention was paid to aluminium-base alloys. The properties of alloys with copper, copper and manganese, zinc, and copper and zinc

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* Slightly abridged.

formed the subjects of reports to the Alloys-Research Committee of the Institution of Mechanical Engineers, and, of course, a great amount of work was carried out during the war, but the general view of the aluminium-silicon alloys, at any rate of those with any substantial percentage of silicon, was that they were weak, brittle and liable to gas-holes and large cavities.[1] This view, which was perfectly correct in the circumstances, held until Pacz, in 1920, invented the treatment, now called *modification*, which so materially improves the properties of the alloys that they may be said to be the strongest of all the aluminium casting alloys for use in the cast state without subsequent treatment.

Modifying Treatment.

This treatment, for which Pacz was granted British Letters Patent No. 158,827, consists of treating the aluminium-silicon alloys, containing from 5 to 20 per cent. of silicon, in the molten state, before casting with an alkaline fluoride or a mixture containing an alkaline fluoride with an alkaline chloride, or even a substance which under this treatment would yield an alkaline fluoride.

Pacz stated in his Patent that aluminium-silicon alloys when produced by melting the metals together, and without the treatment which he described, had a strength when cast of from 6½ to 8 tons per sq. in. and an elongation of ½ to 1¼ per cent. The extraordinary changes brought about in the alloys when treated by his process may be realised from the fact that the alloys so treated would, he stated, have a tensile strength of 10½ to 14 tons per sq. in., with an elongation of 3½ to 11 per cent. He remarked that the fracture of the untreated alloy was very coarse, dark and crystalline, while that of the treated alloy was fine-grained, light and dense. He also mentioned that the shrinkage on cooling of the treated-alloy was less than that of any other aluminium-alloy.

Several subsequent treatment-agents have been devised and patented both in this country and abroad, and among these are the alkali metals, particularly potassium, sodium and calcium and other materials, chief among which are the alkali oxides, hydrates, peroxides and sodamide.[2] All these processes are entirely satisfactory, and when properly used will produce similar results, but the most convenient and economical process to employ at the present moment is the use of metallic sodium, which is relatively cheap, very efficient, and, if suitable precautions be taken, can be stored for long periods in safety and without fear of deterioration.

Fig. 1 shows the microstructure of the 12 per cent. silicon alloy made by melting the constituents together, and also of the same alloy when modified. In both these micro-sections only two constituents are visible, the white ground mass being practically pure aluminium, while the silicon is present as the black constituent. It will be seen that in the unmodified alloy the general structure is very coarse, and that the silicon is present either in the form of long needle-shaped crystals, or as large polygonal crystals. In the modified alloy, however, the silicon occurs as very small curly particles. It will be seen from Fig. 2 that the effect of modification on the appearance of the fracture is very similar to the effect on the internal structure of the alloy.

Theories of Modification.

There have been many theories advanced to explain the mechanism of this phenomenon called modification, and one of the earliest was that modification was due to the removal of aluminium oxide by the fluxing action of the modifying agent. This theory, however, would not seem to be sound, for several materials which are known to dissolve aluminium oxide (in particular sodium bisulphate) do not act as modifiers. It has been suggested also that the aluminium-silicon alloys can exist in two states, the one stable and the other metastable, but since the aluminium-silicon alloy system shows a complete absence of metastable constituents,

UNMODIFIED. MODIFIED.

FIG. 1.—MICROSTRUCTURE OF SAND-CAST 12 PER CENT SILICON ALLOY, MODIFIED AND UNMODIFIED, × 100. CONSTITUENTS:—SILICON, BLACK; ALUMINIUM, WHITE. UNMODIFIED ALLOY ALMOST OF EUTECTIC COMPOSITION; MODIFIED CONTAINS EXCESS ALUMINIUM.

and as no allotropes of aluminium have so far been discovered, this theory does not appear to be tenable. That modification is due to a ternary alloy being formed with sodium has been suggested, but this also is considered unlikely as certain sodium compounds which are known to be reduced by molten aluminium do not produce modification.

That modification consists essentially of a peculiar type of refinement of crystal size, particularly of the silicon crystals, is completely proved by the results of Jeffries'[3] investigations with the X-ray spectrometer, when he found that the diffraction pattern obtained either with the modified or with the unmodified alloy was the same and was that corresponding to a mixture of silicon and aluminium crystals.

UNMODIFIED. MODIFIED.

FIG. 2.—FRACTURE STRUCTURES OF 1-INCH DIAMETER SAND-CAST BARS OF MODIFIED AND UNMODIFIED 12 PER CENT. SILICON ALLOY. NOTE COARSENESS OF UNMODIFIED AND CLOSENESS OF MODIFIED. (COMPARE FIG. 1 OF THE MICROSTRUCTURE.) FULL SIZE.

There are three other theories which have been advanced to explain the phenomenon of modification, and, since two of these are based on the colloid theory, it may be advisable to recall some of the properties of a colloid. Now, when one substance is dissolved in another to form a truly homogeneous solution it is generally understood that the largest particle of either substance present in the liquid is a molecule—that is to say, the liquid solution consists of an intimate mixture of molecules of the two substances. Crystals are large numbers of molecules arranged in a definite formation, and, if a true solution as defined above be subjected to some influence which reduces the solubility of the dissolved substance in the solvent, groups of molecules will associate together and form crystals of a size visible to the naked eye or at least to a microscope. It is known also that certain solutions can exist in a state known as colloidal when the dissolved substance may be present in the form of groups of molecules which are not visible even to the ordinary microscope. Such a colloidal solution is very sensitive to additions of certain other substances which in colloid chemistry are known as protectors and coagulants—protectors tending to protect or stabilise the colloid state by preventing further molecules joining the groups already formed and thus preventing growth to and deposition as crystals; coagulants accelerating the growth of the colloid particles.

The first of the three theories is that advanced by the Staff of the Research Bureau of the Aluminium Company of America,[4] who consider that when the modifier is added to an aluminium-silicon melt it disperses in particles of colloid dimensions, and, as the melt cools, impedes the normal growth of the silicon particles. In the second theory, which is from the same source, it is suggested that the alkali metal used as a modifier is absorbed as a film at the surface of the particles of silicon as they form in the liquid, thereby impeding their growth.

The third theory, and the one which most closely fits the facts, is that developed by Dr. Gwyer and his colleagues of the Research Laboratories of the British Aluminium Company.[5] In this theory it is suggested that the aluminium-silicon alloys, on cooling from a temperature well above their melting point, and, therefore, in a state of true solution, pass through the colloidal state, and are susceptible to the influence of substances which may act either as protectors or coagulants. The various known modifiers act, they suggest as colloid protectors, causing more or less complete stabilisation of the colloid state whereby that state tends to persist after solidification. As regards coagulants, they have found that sodium chloride brings about complete reversion of the modified alloy to the normal state. It follows from this theory that the best results would only be obtained of the correct quantity of modifier or protector were used. This is, in fact, what happens in practice, for it is found that on adding progressively increasing quantities of modifier to the normal alloy, the properties are improved up to a certain percentage addition, after which there is a gradual deterioration.

The persistence of the colloid state after solidification, or, in other words, modification, may be brought about without the use of a chemical modifier by means of ultra-rapid chilling, such as quenching from the molten state into iced brine. Such an exceedingly rapid rate of cooling is not possible in ordinary practice, especially in the case of sand castings, and it is therefore necessary to modify the alloy chemically. The chilling effect of an ordinary chill mould is insufficient to bring about complete modification, as will be seen from Fig. 3, in which it may be noted that the silicon particles, though small, have the characteristic needle-shaped formation of the normal or unmodified alloy.

In further testing their theory, Gwyer and Phillips[5] have found that it is possible to modify and coagulate other alloys, particularly those of aluminium and copper, aluminium and manganese, aluminium and iron, aluminium and nickel, and antimony and copper.

Constitution of the Alloys.

The normal alloys were first studied by Fraenkel[6] in 1908, and later by Roberts[7] in 1914, and by Rosenhain, Archbutt, and Hanson in the 11th Report of the Alloys Research Committee of the Institution of Mechanical Engineers.[1] The modified system has been studied by Gwyer and Phillips[5] in this country and by the Research Bureau of the Aluminium Company of America in the United States.[4]

Both when modified and unmodified, the alloys form a simple eutectiferous series with very slight solubility of silicon in colid aluminium. In the normal series the all eutectic-alloy contains 11.7 per cent. silicon and freezes at 577 deg. C. In the modified alloys, however, it is found that modification, besides refining the structure, also depresses the freezing point and increases the silicon-content of the all-eutectic alloy. The

FIG. 3.—MICROSTRUCTURE OF 12 PER CENT. SILICON CAST IN IRON CHILL WITHOUT MODIFICATION, SHOWING INCOMPLETE REFINEMENT OF SILICON PARTICLES WHICH, THOUGH SMALL, ARE NEEDLE-SHAPED. (× 100.)

freezing point of the modified alloys may be as low as 561 deg. C., but the composition of the all-eutectic modified-alloy is greatly influenced by the rate of cooling, and Gwyer and Phillips have found the all-eutectic structure present in a rapidly-chilled modified alloy containing as much as 15 per cent. silicon. It will be appreciated, therefore, that any equilibrium diagram given for the modified alloys will only hold for a particular rate of cooling. Fig. 4 gives both the modified and unmodified alloys plotted on the same diagram. It is taken from Gwyer and Phillips' Paper, and it will be seen that for the particular rate of cooling employed—8 to 10 deg. C. per minute—the composition of the all-eutectic alloy is 12.85 per cent. silicon. Fig. 5 is taken from a Paper[4] by Archer and Kempf

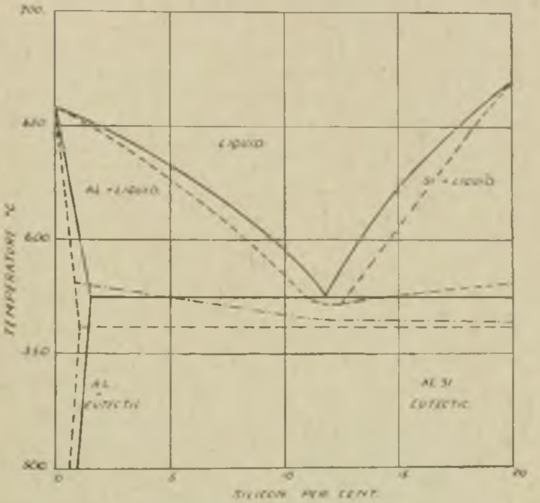

Fig. 4.—Equilibrium Diagram for Modified and Unmodified Alloys — Gwyer and Phillips. (Rate of Cooling 8-10 deg. C. per minute. Unmodified—Full Lines: Modified—Dotted Lines.)

of the Aluminium Company of America, published in March, 1926, to the American Institute of Mining and Metallurgical Engineers. The rate of cooling is more rapid, and approximates to that of alloy cast in a sand-mould. It will be seen that in this case the composition of the all-eutectic modified alloy is approximately 14 per cent. silicon.

From the point of view of microstructure, the alloys are, therefore, divisible into three groups, as follows:—

(1) Those with less than 11.7 per cent. silicon, which, both in the normal and in the modified state, consist of dendrites of primary aluminium in eutectic ground mass; (2) those alloys whose compositions lie between those of the normal and modified all-eutectic alloys. These contain from 11.7 to approximately 14 per cent. silicon, and when unmodified consist of primary silicon crystals in a ground-mass of normal eutectic. When modified, however, they consist of dendrites of primary-aluminium in a ground-mass of modified eutectic; and (3) in this group are the alloys containing more silicon than the all-eutectic modified alloy, and whether modified or normal they consist of primary-silicon crystals in a eutectic ground-mass.

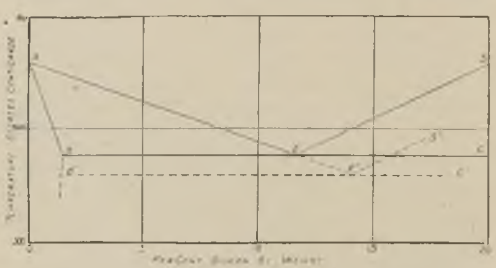

FIG. 5.—EQUILIBRIUM DIAGRAM FOR MODIFIED AND UNMODIFIED ALLOYS—ARCHER AND KEMPF. (RATE OF COOLING EQUAL TO SAND CASTING. UNMODIFIED — FULL LINES: MODIFIED—DOTTED LINES.)

Practical Consideration of the Modification Process.

The process of modification, which consists essentially of adding the modifier to the metal, and allowing the metal to stand for a certain period of time, without any stirring, before casting is carried out, contains a number of variables which are not met with in the casting of other metals and alloys. The actual temperature at which casting is to be carried out is fixed as in the case of any metal or alloy by the size and general shape of the casting, particularly by the thickness and the extent of the thinnest section of the casting.

The temperature at which casting must be carried out, automatically fixes the temperature at which modification must be applied to the melt, and also the time period. Among the most influential variables which are peculiar to the casting of modified aluminium-silicon alloys, are:—

(1) The quantity of silicon in the alloy to be modified; (2) the quantity of modifier used; (3) the time allowed to elapse between modification and casting; and (4) the thickness of section of the casting cast.

Considering firstly the quantity of silicon present in the alloy to be modified, though the commercially-useful alloys contain anything from 3 to 20 per cent. silicon, those having the best combination of properties, contain from 10 to 14 per cent. Archer and Kempf[4] have shown that the amount of modifier required varies with the silicon content of the alloy, increasing as the silicon increases.

It is impossible to give any details as to exact quantities, for the class of work being done, the particular modifier used and a number of other factors cause great variaitons in the amount of modifier required.

With regard to the quantity of modifier used with any particular silicon content, it appears quite general that the amount of modifier and the time period are closely inter-dependent, and that if the amount of modifier be increased the time period must also be increased and *vice-versa.* From this it would seem that in order to obtain the optimum properties in an aluminium-silicon alloy, the alloy must be cast at just that particular moment after modification has been carried out, when the sodium or other modifier left in the alloy has reached a definite percentage. This is largely a speculation on the author's part, but it seems to be borne out in actual practice.

In order to reduce the variables as much as possible, it is perhaps best to work with an alloy of uniform composition, to use always a standard proportion of modifier to melt treated, and to vary only the time period and modification and casting temperatures as may be required by the greatest and smallest thicknesses or sections, and the general size of the job in hand.

Assuming, therefore, that a standard quantity of modifier be used, and the time period be varied, it will be found in practice that if the pouring be carried out too soon after the modifier has been applied to the melt, the casting will contain many gas holes, and the maximum properties will not be obtained. Fig. 6 shows the microstructure of a casting made in alloy containing 12 per cent. silicon, which was cast before the necessary time between modification and casting had elapsed. It will be noted that full refinement of the silicon particles of the eutectic has not been obtained.

After the correct time period has elapsed, the alloy tends to revert from the modified to the normal state, and a casting cast from alloy which has been standing too long after modification has been carried out will show patches which have reverted to the normal state, the amount and size of these patches depending on the time which has elapsed since the correct casting time. The ultimate result of allowing alloy to stand for a long time after modification is, of course, that the alloy reverts to the fully normal condition. Fig. 7 shows the microstructure of a sand casting which was cast too long after modification had been carried out. It will be seen that in the particular field shown there is a large area of aluminium containing large crystals of massive silicon. The use of too much modifier causes colonisation of the eutectic and local reversion as may be seen from Fig. 8. The effect on the mechanical properties is to reduce considerably the elongation.

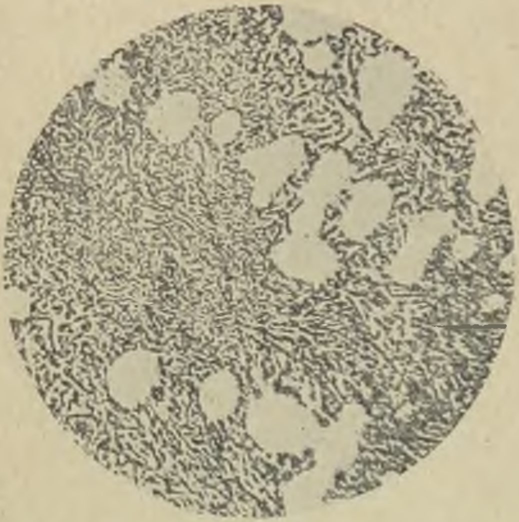

Fig. 6.—Microstructure of Sand-Cast 12 per cent. Silicon Alloy, Cast too Soon After Modification, showing Incomplete Refinement of Silicon Particles. (× 100.)

The Choice of Alloy.

Fig. 9 shows graphically the tensile strength and elongation of the normal and the modified alloys, as determined by Archer and Kempf[4] on test-bars cast to size in sand moulds. It will be seen from this that, with the particular rate of cooling used, the strongest alloy in the modified system and the one with highest elongation is that containing 14 per cent. silicon, and, at first sight, it would appear that, in order to obtain optimum properties, this alloy would be the best to select. It must be remembered, however, that the figures from which these curves were constructed were obtained on test-bars cast under carefully controlled conditions. All the variables occurring in carrying out such tests as these were varied until the best conditions were found for each alloy tested, and the values indicated represent, therefore, results which can only be obtained with such very careful control as was used by Messrs. Archer and Kempf, and cannot always be anticipated in practice. Even the most scientifically-controlled modern foundry cannot expect in production to copy the results obtained in the laboratory, and, therefore, must be allowed some latitude or "safety factor" in applying the processes devised in the laboratory.

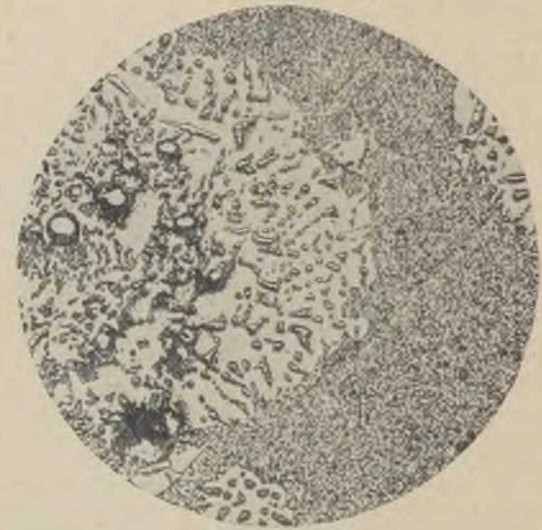

Fig. 7.—Microsection of Sand-Cast 12 per cent. Silicon Alloys, Cast too Long After Modification, showing Area of Reversion to Unmodified State. (× 100.)

The 14 per cent. silicon alloy is a "borderline" alloy. It contains such an amount of silicon that under the best possible operating conditions a sand casting made from it will have the all-eutectic structure. There is a grave risk, however, when using this alloy that, if the operating conditions are not precisely correct, primary-silicon crystals will separate from the melt and will cause a very serious drop in the elongation.

FIG. 8.—MICROSECTION OF SAND-CAST 12 PER CENT. SILICON ALLOY, MODIFIED WITH TOO MUCH MODIFIER; SHOWING COLONISATION OF EUTECTIC. (× 100.)

It is customary, therefore, to use an alloy containing not more than 13 per cent. of silicon.

Effect of Impurities.

The most common impurity found in these alloys is, of course, iron, and its effect on the properties of the alloy is not so apparent in chill castings as in sand castings. In sand castings it is safe to allow the iron to rise to a value between 0.6 and 0.7 per cent., but the exact figure cannot be given, as it depends on the rate of cooling. If the iron content rises above the latter value, a new constituent, consisting of silicon, aluminium, and iron, will separate out as large flat plates, and these cause planes of weakness and discontinuity in the alloy, greatly reducing the tensile strength and elongation. Fig. 10 shows the microstructure of a sand-cast alloy containing 12 per cent. silicon and 0.72 per cent. iron. Fig. 11 shows the fracture structure of the same alloy.

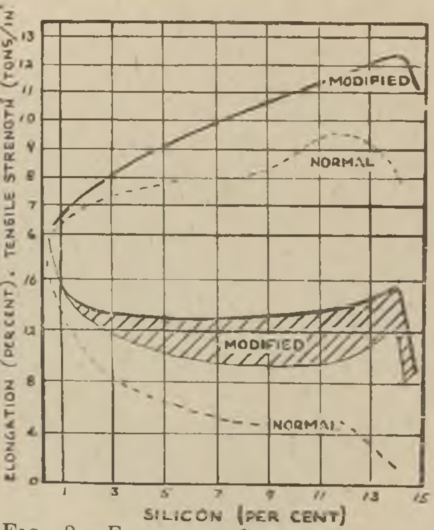

Fig. 9.—Effect of Silicon Content on Tensile Strength and Elongation of Modified and Unmodified Aluminium - Silicon Alloys (Archer and Kempf).

This example has been chosen because it shows what may happen in an ordinary foundry if the iron content is allowed to increase slightly. The effect of allowing the iron content to rise to higher values is, of course, to increase the amount and size of these iron-rich plates. Figs. 12 and 13 show respectively the micro- and fracture-structures of an alloy containing 2.28 per cent. iron and 12 per cent. silicon. Such an alloy is extremely brittle.

Fig. 10.—Microstructure of Sand-Cast 12 per cent. Silicon Alloy Containing 0.72 per cent. Iron. Iron Constituent shows as Long White Lines. (× 100.)

Specifications.

The specifications issued by the D.T.D. Air Ministry and by the Admiralty are shown in Table I. It is interesting to note how pure an alloy is demanded by the Air Ministry, for it will be noted that in their specification the total amount of metallic impurities other than iron and manganese must not exceed 0.1 per cent.

The effect of other metals on the properties of the modified 13 per cent. alloy has been closely investigated by Welter[8], and the results he obtained show clearly how extremely sensitive these alloys are to the effect of very small quantities of added metals. The scope of the present Paper does not, unfortunately, permit of a reproduction of all the curves he obtained showing the effect of increasing quantities of the added metal on the tensile strength and elongation of the modified 13 per cent. silicon alloy, but the results may be briefly summarised by stating that, in general, progressively increasing additions of other metals cause a gradual decline in tensile strength and a rapid decrease in elongation. Table II shows the amount of each of a number of other metals, which, when present separately, will cause a reduction of 50 per cent. in the elongation of the modified alloys. It will be noted that, with the exception of zinc and manganese, the presence of a few tenths of 1 per cent. of any of the other metals shown in the table will ruin one of the most valuable characteristics of the modified silicon alloys—their

Fig. 11.—Fracture Structure of Sand-Cast 12 per cent. Silicon Alloy Containing 0.72 per cent. Iron. Note the Flat, Bright Plates of Iron-Rich Constituent in the Alloy.
]

FIG. 12.—MICROSTRUCTURE OF SAND-CAST 12 PER CENT. SILICON ALLOY CONTAINING 2.28 PER CENT. IRON, SHOWING SECTION OF LARGE PLATES OF IRON-RICH CONSTITUENT. (×100.)

FIG. 13.—FRACTURE STRUCTURES OF SAND-CAST 12 PER CENT. SILICON ALLOY, CONTAINING (LEFT) 2.28 PER CENT. IRON, (RIGHT) 0.30 PER CENT. IRON, SHOWING FLAT BRIGHT PLATES OF IRON-RICH CONSTITUENT IN THE ALLOY CONTAINING 2.28 PER CENT. IRON.

ductility, and it will be appreciated that the strictest laboratory control must be kept on the chemical composition of the alloy, and that the utmost care must be exercised in the foundry to ensure that no scrap from castings in other alloys becomes mixed with runners, risers, etc., which are to be permitted.

Peculiar Foundry Characteristics.

The commercial aluminium-silicon alloys are one of the very few all-eutectic alloys ordinarily used, for, with the exception of the iron-carbon eutectic cast iron, the lead-tin eutectic or "tinman's solder," and possibly also the eutectic cadmium-zinc solder, all other alloys consist mainly of solid solutions, or only contain a small amount of eutectic. It is to this fact that the superior foundry properties of these alloys as compared with the other aluminium alloys is mainly attributable. The freezing ranges of a number of aluminium alloys in common use are shown in Table III, from which will be seen how

Table I.—*Air Ministry and Admiralty Specifications for Aluminium-Silicon Alloy Castings.*

		Air Ministry. D.T.D. 25.	Admiralty DNC/M/ 1 and 1A.
Composition :			
		Per cent.	Per cent.
Si	Between	10–14	9–14
Fe	Not more than	0.75	0.6
Mn	,, ,, ,,	0.5	0.5
Other metallic impurities (not more than)		0.1 total	0.1 each.
Mechanical Test.—(On test pieces turned from 1 in. chill cast bars) :—			
Ultimate strength not less than		12 tons/sq. in.	11 tons/sq. in.*
Elongation strength not less than		7 per cent. on 2 in.	6 per cent. on 2 in.*

* Test bars may be cast in sand moulds when only 9 tons/sq. in. and 5 per cent. are required on test.

small is the freezing range of the aluminium-silicon alloys and how large is that of the other alloys. The effect of this on the behaviour of the alloy in the mould, and, therefore, on the properties of the casting produced, is very important, and not always appreciated by those who attempt to work in these alloys. As was recently remarked by Mortimer[9], there is no other alloy as liable to provide pitfalls for the inexperienced and unwary, and this has been corroborated by at least one subsequent publication.

In considering the foundry properties, it will perhaps be best to commence with the design of the mould, for it is here that will be noted some of the more radical differences of the silicon from the other aluminium alloys.

TABLE II.—*Effect of Impurities on Modified Aluminum-Silicon Alloys.*

Element.	Amount to reduce elong. by 50 per cent.
Calcium	0.2
Magnesium	0.3
Copper	0.4
Zinc	4.5
Tin	0.3
Antimony	0.4
Manganese	1.0
Titanium	0.2

When a mould has been filled with molten metal, and the mould is extracting heat from the metal and radiating it away, freezing commences at the surface where the metal is in contact with the mould. As heat is progressively lost, the skin of solid metal which first formed at that surface gradually grows in thickness as more and more metal solidifies on it until the whole thickness of the casting is solid. In the case of alloys with a large freezing range, the primary constituent which freezes at the higher temperature deposits first at the outer surface in the form of dendrites at right-angles to the surface. As cooling proceeds, the dendrites increase in length and in multiplicity of branches, and in the spaces between these branches those constituents which freeze at lower temperatures solidify as their freezing points are reached.

The dendrites are liable to trap small bubbles of gas, and also totally to enclose small quantities of lower-freezing constituents, which, on freezing, may contract so much that a void is left. The large numbers of small holes thus formed in other alloys are not found in the silicon alloys, which, since they are almost of eutectic composition, have no dendrites, and in which freezing takes place by a continuous wall of completely-solid metal growing inwards from the mould surface until all the alloy is frozen.

TABLE III.—*Freezing Ranges of Aluminium Alloys.*

Alloy.	Primary Freezing Point. Deg. C.	Final Freezing Point. Deg. C.	Range. Deg. C.
12 per cent. Si Mod ..	572	564	8
12 per cent. Si Unmod...	579	577	2
Y. Alloy (4 per cent. Cu 2 per cent. Ni 1.5 per cent. Mg.) ..	630	493	137
L.8 (12 per cent. Cu) .	622	545	77
L.11 (7 per cent. Cu 1 per cent. Sn) ..	630	540	90
L.5 (13 per cent. Zn 3 per cent. Cu) ..	610	490	120

The design of the mould with regard to the position, size, and number of runners and risers and the size of the gates is in accordance with general foundry practice, with the exceptions indicated below. The fluidity of the aluminium-silicon alloys, even at temperatures but slightly above the freezing point, is so very much greater than that of any other aluminium alloy that runners can be cut down to a minimum that would be impossible in any of the other alloys, and, in fact, it is often customary, even with castings weighing as much as 5 to 6 cwts. with very thin sections, to use only one runner. In passing, it may be remarked that the great fluidity of these alloys makes possible the satisfactory running of very large castings of very thin section, which could not otherwise be cast in an aluminium alloy.

Table IV shows the thermal expansion, crystallisation shrinkage, and total contraction for a number of aluminium alloys, and it will be noted that, while the thermal expansion is almost the lowest, the total contraction of the silicon alloy is the smallest of all the alloys included in the table. The point of most importance, however, is that the crystallisation shrinkage of the silicon alloy is about one-half (3.8 per cent. compared with from 6 to 7 per cent.) that of the other alloys, and it is due to this in particular that silicon-alloy castings, if made in a properly-designed mould, are free from the shrinkage cavities found in castings of other alloys. It must not be forgotten, however, that since the alloys freeze over a very small range of temperature, this shrinkage occurs almost at one instant, and, if suitable steps are not taken to counteract it as it occurs, the cavities formed may be much larger than with the other alloys. An excellent

TABLE IV.—*Thermal Expansion, Shrinkage, and Contraction of Aluminium Alloys.*

Alloy.	Alpax Modified Aluminium Silicon.	L.5 13 per cent. Zn 3 per cent. Cu.	L.8 12 per Cu	L.11 7 per cent. Cu 1 per cent. Sn.	Y.
Thermal Expansion (Linear per 1 deg. C.) $\times 10^{-4}$ ..	0.222	0.255	0.264	0.246	0.220
Crystallisation shrinkage ..	3.8%	6—7%	6—7%	6—7%	6—7%
Contraction	1 in 96	1 in 78	1 in 79	1 in 83	1 in 77
,, (per cent.)	1.042	1.282	1.266	1.205	1.299

example of the great care required in designing the mould, and how unsuitable for silicon alloys is a mould which is eminently suited to other alloys, was given by Archbutt, Grogan and Jenkin in their recent Paper[10] to the Institute of Metals on the "Die-Casting of Aluminium Alloys." The die they used at the commencement of their research was designed for ordinary aluminium alloys, and was totally unsuited for the silicon alloys, castings of which, made in the die, contained large cavities.

There is one other most important foundry characteristic of these alloys, and that is their almost complete freedom from hot shortness.

In the above-mentioned Paper by Archbutt and his colleagues they recorded the results they had obtained for the impact strength of aluminium alloys at temperatures near their melting points, and Table V shows some comparative values taken from the curves given in that Paper. In the first column is shown the temperature fall below the melting point of each alloy that must take place before the alloys require 10.9 ft.-lbs. to fracture the particular sized specimen used. It will be seen that the 12 per cent. silicon alloy attains this strength at 3 deg. C. below the melting point, as compared with 11 deg. C.—nearly four times as much—for "Y" alloy, while the fall for 2 L.5 is 45 deg. C.

TABLE V.—*Hot Shortness of Aluminium Alloys near their Melting Points.*

Alloy.	Temperature fall in deg. C. before energy to fracture is 10.9 ft.-lbs.	Energy in ft.-lbs. to fracture at 5 deg. C. below melting point.
12 per cent. Silicon ..	3	10.9
Y Alloy	11	4.7
8 per cent. Copper Alloy	24	0.7
2 L.5	45	0.5

It will now be appreciated that these alloys have peculiarly superior foundry properties as compared with other aluminium alloys. They are very fluid, and large castings of very thin section can be satisfactorily run, and when cast they are not liable to foundry cracks. It is for these reasons in particular, and also, but to a less extent, to their freedom from shrinkage cavities, that they are the only possible alloys for the manufacture of satisfactory castings of the type exemplified by railway-carriage doors.

Physical Properties.

The commercially useful silicon alloys contain from about 9 to 14 per cent. of silicon, and the optimum properties of strength and ductility are obtained with alloys containing from 12 to 13 per cent. silicon. In considering the physical and other properties of cast modified aluminium-silicon alloys, the values given are, therefore, in all cases those obtained from castings containing 12 to 13 per cent. silicon, unless otherwise stated.

The physical properties of the silicon alloys exhibit a number of peculiar characteristics, which, in different ways, show these alloys to be superior to other aluminium casting alloys for use in the cast state, and in considering these properties it is perhaps best to consider first the purely physical properties of the alloys.

Conductivity—Thermal and Electrical.

The thermal and electrical conductivities of aluminium and its alloys have recently been re-determined both at ordinary and at elevated temperatures by Griffiths and Schofield[11], and values taken from their Paper are given in Table VI. It will be noted that the thermal conductivity of the aluminium-silicon alloys is higher than that of any other aluminium alloy, and is, in fact, 75 per cent. of that of pure aluminium and 45 per cent. of that of copper. This appears at a first glance to be an adverse criticism, but, when it is remembered that the modified silicon alloy has a much greater strength than pure aluminium, it will be found that the heat conducted by the pure metal and by the silicon alloy through sections of equal strength is almost equal, and since this statement is based on a comparison of the strength of cast alloy with wrought pure metal, it would seem that there are large untouched fields of application for the modified silicon alloys. Though it is not possible to make the same comparison in the case of copper, it may be said that modified aluminium-silicon alloys have many points in their favour in their possible supersession of pure aluminium for replacing copper articles in such industries as food and chemical manufacture, where resistance to corrosion and certainty that material will not be absorbed from the containing or treatment vessels is of the greatest importance.

TABLE VI.—*Thermal and Electrical Conductivities of Aluminium Alloys.*

Alloy.	Thermal conductivity Cal/cm./sec.	Electrical conductivity reciprocal microhms/cm.^{3}
Aluminium-Silicon Modified	0.41	0.25
Y Alloy (4Cu 2Ni 1½Mg) ..	0.40	0.26
2 L.8 (12 Cu)	0.38	0.23
3 L.11 (7 Cu 1 Sn) ..	0.39	—
2 L.5 (13 Zn 3 Cu) ..	0.32	0.20
Pure Aluminium	0.55	0.35
Copper	0.92	0.59

The electrical conductivity, it will be observed from Table VI, is almost the highest of any of the ordinary aluminium alloys, being slightly less than that of Y alloy, and considerably higher than that of 2 L.5 (13 per cent. Zn, 3 per cent. Cu alloy), and bears a similar relation to that of pure aluminium and copper as in the case of the thermal conductivity. Table VII gives a comparison of the relative cross-sections of conductors of aluminium and its alloys and copper, when the conductors have the same resistance, together with the relative weights of such conductors. Although the cross-section of aluminium and aluminium-alloy conductors must be larger than a copper conductor of the same resistance, a considerable saving in weight can be effected by the use of these light metals—aluminium affording a weight saving of 48 per cent., and aluminium-silicon alloy 28 per cent. This again suggests another possible field of application for these alloys, for, although they are greatly used in a number of pieces or parts of electrical apparatus where lightness and resistance to corrosion are of primary importance, aluminium-silicon alloy castings, so far as the author is aware, have not been used primarily for their current-carrying capacity. It would appear from the above tables and calculations that there must be a large number of parts where lightness together with strength and good conductivity are essential characteristics.

TABLE VII.—*Comparative Conductivities of Aluminium and its Alloys and Copper.*

Material.	Resistivity Microhms/cm.^{3}	Specific gravity.	Relative cross sectional areas of conductors for same resistance.	Relative weights of conductors for same resistance.	
				Al=1	Cu=1
Copper	1.69	8.9	1.0	1.94	1.0
Aluminium ..	2.85	2.72	1.69	1.0	0.52
Al-Si Alloy ..	4.0	2.66	2.37	1.37	0.72
Y Alloy ..	3.8	2.79	2.25	1.37	0.72
2 L.8 (12 Cu) ..	4.4	2.88	2.60	1.63	0.84
2 L.5 (13 Zn 3 Cu)	5.0	3.0	2.96	1.94	1.0

Mechanical Properties.

In the consideration of the mechanical properties of castings in general, it is essential that some reliable standard be used for the comparison of one alloy with another, and, with this end in view, the British Engineering Standards Association specify that castings of aluminium alloys shall be represented by test-pieces turned from 1-in. diameter chill-cast bars. The results of tests obtained from such bars give an indication of the quality of the material in the casting, and, if the castings are made under uniformly good conditions, bear a definite relation to the actual strength of the alloy in the casting. With the ordinary aluminium alloys, the increase in tensile properties due to the grain-refinement produced by chilling is fairly definite for each alloy, but in the case of the silicon alloys, that increase is far greater in the unmodified than in the modified alloys. This is due to the fact that casting the unmodified alloy in a chill mould causes partial modification to take place in addition to the normal grain-refinement to be expected from the increased rate of cooling. It will be seen from Table VIII, which gives the tensile properties of sand and chill bars of unmodified and modified alloy that the relation existing between the sand and chill bars in modified alloy is much closer than that existing in the unmodified alloy. It will be noted also that, although the tensile values for the chill bars, both modified and unmodified, are not very different from each other, the modified sand castings are at least 50 per cent. stronger than the unmodified. It will be appreciated, therefore, how misleading the chill test-bar can be as an indication of the quality of the alloy in a sand casting in silicon alloy.

TABLE VIII.—*Tensile Strength and Elongation of Sand Cast and Chill-Cast Bars of 12½ per cent. Silicon Alloy—Modified and Unmodified.*

State.		M.S. tons per sq. in.	E. Per cent.	Ratio : Chill to Sand.	
				M.S.	E.
Unmodified	Chill cast	12–13	8	1.7	2.7
	Sand cast	7	up to 3	1.9	
Modified . .	Chill cast	13–15	10–20	1.1	1.6
	Sand cast	10–12	6 and upwards	1.5	3.3

In Table IX are shown average values for the mechanical properties of 12 per cent. modified silicon alloy for the four B.E.S.A. aluminium casting alloys, Y, 2.L.5, 2.L.8 and 3.L.11, and in order to make a true comparison, values for sand as well as chill test-bars are included.*

Considering chill castings first, it will be noted that the elastic limit and yield stress of the silicon alloy are comparable with those of the other alloys, except Y, while the fatigue range is superior to all other alloys except heat-treated Y. It is when the ultimate stress, elongation and impact strength are compared with the other alloys that the superior properties of the modified silicon-alloy become evident, for the ultimate strength is almost equal to that of Y alloy as cast, and superior to that of all the other alloys, while the elongation and impact strength are almost double those of L.5, which are the highest of the other alloys. In the case of sand castings, it will be noted that the silicon alloy is stronger in every way than L.5, L.8 and L.11, and its ultimate strength is equal to that of Y alloy, while, though the yield stress is slightly lower, the elongation is many times greater than that of Y.

With regard to the possibility of improving the mechanical properties of the modified silicon-alloys by heat-treatment, it will be realised that but little increase of properties can be expected since the solubility of silicon in aluminium is about 1.2 per cent. at the eutectic temperature, and decreases rapidly to 0.2 per cent. at 450 deg., remaining at this value right down to room temperatures. Archer, Kempf and Hobbs[12] have shown that the tensile strength and elongation of modified sand castings can be increased by about one-tenth by quenching in water after heating for a time at about 15 deg. C. below the melting point, but, as they point out, such heat treatment is not commercially applicable.

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* The author is indebted to Mr. S. L. Archbutt for some of these figures which he found difficulty in obtaining, particularly for sand-cast Y alloy.

TABLE IX.—*Properties of 1-in. Diameter Cast Bars of Aluminium Alloys.*

Alloy.	E.L. Tons/in.^{2}	Y.P.S. Tons/in.^{2}	U.S. Tons/in.^{2}	E. Per cent. in 2 in.	Brinell Hard.	Izod Impact. Ft.-lb.	Fatigue Range. Tons/in.^{2}
			CHILL CAST BARS.				
12 per cent. Silicon Modified . .	2.0	7.3	13.5	11	65	7.0	±3.8
Y Alloy (4 per cent. Cu, 2 per cent. Ni, 1½ per cent. Mg.)							
as cast	5.6	11	14	1.5	85	—	—
Heat Treated	7.0	16	20	3.0	105	3.6	±7.0
2 L.5	2.8	4.5	13	5	70	4	±3.5
2 L.8	2.2	7	11	1	80	0.6	±3
3 L.11	3	8	10	3	60	1.4	±3.6
			SAND CAST BARS.				
12 per cent. Silicon Modified . .	2.0	7.0	11	8	52	5.0	±4.5
Y Alloy (4 per cent. Cu, 2 per cent. Ni, 1½ per cent. Mg)							
as cast	—	9.0	11	0.5	80	—	—
Heat Treated	—	—	16	1.5	100	—	—
2L.5	1.8	4.5	10.5	4	65	3.0	—
2L.8	1.8	—	9	1	75	0.6	—
3L.11	—	—	7	2	50	—	—

Welter[11] has shown that small additions of copper increase the dynamic properties of the modified alloy without serious effect on the tensile strength or elongation, in particular the resistance to repeated impact and to alternating stresses is considerably improved. Another improvement effected by the addition of a small amount of copper is the machinability which in the pure alloy is perfectly satisfactory if the correct form of tool be used, but is liable to cause a certain amount of trouble to the inexperienced if the correct form of tool is not used.

The tensile strength and elongation of chill-cast bars at elevated temperatures have been studied by Tapsell [13], who found that the tensile strength decreased steadily to 4 tons per sq. in. at 350 deg. C., while the elongation was unaffected at temperatures below 250 deg. C., after which a rapid increase took place.

It would at first sight appear that the modified silicon-alloy is not so suitable as Y alloy for use at high temperatures of the order of 200 to 250 deg. C. It must be clearly understood, however, that all the results so far published for the strength of these alloys at high elevated temperatures have been obtained from test-pieces tested at the ordinary speed in the testing machine under the so-called "rapid loading test." Since most parts working at elevated temperatures usually have to withstand stresses continuously for long periods of time, it would appear that a better idea of the usefulness of the aluminium alloys at high temperatures could be obtained by a comparison of the maximum stresses which at any temperature they would withstand for an indefinite period of time—or, in other words, the limiting creep stresses at various temperatures. It would, therefore, seem advisable to omit further consideration of this point until the limiting creep stresses at various temperatures for the various alloys have been determined.

Chemical Properties—Corrosion Resistance.

Corrosion of aluminium alloys in general, and particularly those containing substantial amounts of copper or zinc, is due to the formation of local electrolytic-cells between individual crystals of differing electrochemical potential with the corroding-medium acting as electrolyte. The silicon-alloy being composed solely of aluminium and silicon, with the exception of a minute amount of iron which occurs as an unavoidable impurity, is not subject to the formation of these cells, and is, in fact, very similar to pure aluminium as regards its resistance to corrosion.

The alloy has been found in practice very resistant to atmospheric corrosion and large numbers of castings have given several years' satisfactory service, under conditions of atmospheric corrosion varying from those found in a smoky town to those on board ship. It is impossible to give precise details of the corrosion-resistance of aluminium-silicon alloys compared with other alloys since conditions of service vary so widely, but in order to obtain some idea of the comparative rates of corrosion, the author has suspended from a frame on the roof of his works, a number of cast plates of various alloys. Fig. 14 shows the way in which " Alpax " (the 12 per cent. modified silicon alloy) and 2.L.8 increase in weight week by week, and it will be seen that the L.8 plate corrodes at roughly three times the speed of " Alpax." In order that the figure should not become too complicated, only these two curves have been plotted. The results obtained, however, show clearly that whether chill- or sand-cast, whether " as cast " or polished, and whether or no it contains 0.8 per cent. copper, " Alpax " corrodes at a very much lower rate than L.8, L.5, and an alloy containing 5 per cent. copper and 3.5 per cent. zinc.

With regard to other types of corrosion, it has been found that the modified silicon alloys are very resistant to sea water when erosion is not very marked. A test casting suspended half-way between high- and low-water marks in the Clyde for six months was only slightly coated

—not pitted—while the iron plates to which it was bolted had almost completely disintegrated. The silicon-alloy, from a corrosion point of view, behaves in very much the same way as pure aluminium, and is very suited for making many articles which can be cast in one piece, but which would be difficult to build up from sheet.

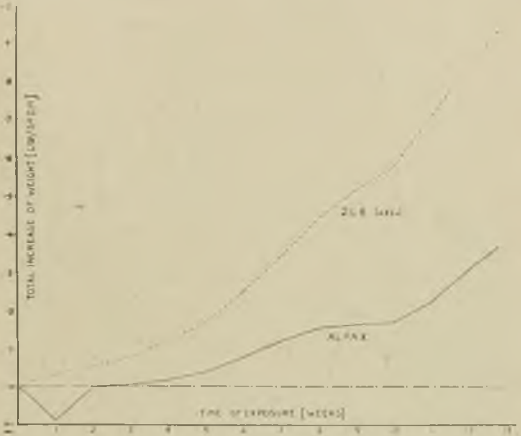

Fig. 14.—Corrosion of Aluminium-Silicon and Aluminium - Copper Alloys. Weight-Increment-Time Curves.

On account of this, large numbers of parts have been made for apparatus for use in the food industry—refrigerators, autoclaves, etc., and in other industries where lightness, strength, and resistance to corrosion are essential.

DISCUSSION.

The Chairman (Mr. W. B. Lake, J.P.), inviting discussion, paid a tribute to Mr. Deeley for his very carefully prepared and informative Paper, which, he added, reflected great credit upon the Institute of Metals and the Institute of British Foundrymen.

Difficulties with Pattern Plates.

Mr. C. H. Kain, referring to modification, said he gathered that the modified condition did not persist after re-melting, even if the heat consisted wholly of re-melt. He asked if, in the casting of aluminium-silicon alloys, there was a lag between the metal and the mould. His company had experienced some little difficulty in making a certain small casting of this alloy. The casting was perfectly simple, being a plate, 12 in. by 3 in., and about $\frac{1}{4}$ in. thick, with a boss running across it. When they had made such plates a large sink had occurred near the boss, due to shrinkage, and this difficulty was not overcome, although the plates had been cast in every possible manner, and at temperatures varying from 570 to 710 deg. C. Subsequently, similar plates were bought from an aluminium-founder, and, although there was a shrink near the boss and in the boss itself, the outsides of the plates conformed perfectly to the dimensions of the mould. This seemed to suggest that the castings adhered to the sides of the mould, and that some sort of lag obtained under certain conditions of temperature and casting. He asked for Mr. Deeley's views on that problem.

Professor T. Turner (Past-President, Institute of Metals) voiced the thanks of the members of the London Local Section of the Institute of Metals to the London Branch of the Institute of British Foundrymen for having invited them to attend the meeting, and added that they had been very glad to come. He congratulated Mr. Deeley, not only upon the choice of matter he had presented to the meeting, but also upon the form of presentation. Some years ago Dr. Voce had carried out experiments in his laboratory on the problem of modification, and, so far as he could judge, the statements made by Mr. Deeley in his Paper were in accordance with their experience. The development of the application of the aluminium-silicon alloys was very interesting. He had had no idea—although, perhaps, one ought to expect it—that carriage doors and other castings of relatively large size and of such thin section had been made with these alloys.

Resisting Acid Attack.

Mr. W. T. Hobkirk asked Mr. Deeley for information as to the ability of the aluminium-silicon alloys to withstand the attack of acids which might be present in water. This was interesting from the point of view of the production of radiators for export. Radiators are made of aluminium in this country, but he pointed out that the water supplied here is, practically speaking, pure, whereas the water used in radiators exported to other countries might not be so pure.

Inadequate Nomenclature.

Mr. J. D. Grogan said that the whole question of modification was extraordinarily interesting, and it was also extremely humiliating to the ordinary scientist, because it was analogous, he considered, to what an insurance man would call an " act of God." In the present state of knowledge, no scientist could really explain it satisfactorily, but perhaps that was all to the good, because it made them realise that they are not yet on the road to knowing everything. The use of the term " grain refining " in connection with modification was rather dangerous, he suggested, because metallurgists generally spoke of grains as meaning " crystal grains." The term " grain refining " suggested that the crystals, instead of being large, became small on modification, but that was not altogether the case; it was quite possible that the size of the crystals was reduced, but the reduction was not really very much. It was the eutectic structure inside the grain that was refined. If someone could suggest another phrase to describe this phenomenon, the danger of misunderstanding would be avoided. Another excellent quality of the silicon-aluminium alloy, and one which Mr. Deeley had not mentioned, was that, when it was cast in metal moulds with a suitable dressing, it had a fine surface finish. On the other hand, Mr. Deeley had emphasised the pitfalls into which novices had fallen when founding aluminium-silicon alloys, and it could not be stressed too often that the founding of them presented special difficulties to founders who approached the task with a knowledge of the ordinary aluminium alloy castings. One must have a knowledge of the difficulties and of the methods to be applied to overcome them.

Remelting Necessitates Remodifying.

Mr. Deeley, discussing the difficulties experienced by Mr. Kain in the casting of aluminium-silicon alloy plates, said he imagined that there must have been something wrong with the design of the moulds, and that the runners and risers were not arranged to feed the castings properly.

Mr. Kain said he did not think that was the cause of the trouble, because castings which were correct and castings which were not correct were all made in exactly similar moulds, and, as far as he knew, under the same conditions.

Mr. Deeley asked if the same metal was used in each case.

Mr. Kain replied that, so far as he knew, it was.

Mr. Deeley asked if the metal were modified.

Mr. Kain said that the metal he had used was not modified; whether or not the metal used by the aluminium founders who had made some of the plates was modified he did not know. Although there was a very large shrink in the heavier section of the good castings, in the thinner sections adjoining the heavier section the castings conformed exactly to the shape of the mould. In the castings he had made the thickness was less than that of the mould.

Mr. Deeley said it was rather difficult for him to help without seeing the castings and without knowing definitely whether or not the alloy was modified. Replying to the question as to the effect of the modifier after re-melting, he said it had not the same effect after re-melting as it had previously; the alloy must be modified each time.

Replying to Mr. Hobkirk, he said it was difficult to say how the aluminium-silicon alloys would withstand the action of acids unless one knew the exact conditions, but the silicon alloys were less liable to corrosion in general than were the alloys containing copper and zinc. Erosion, of course, had a great influence in the removal of material.

Like Mr. Grogan, he had had difficulty in expressing the effect of modification, and the only term he could think of was "grain-refining," applying it in the wider sense. After all, the phenomenon was a type of grain refining, but he admitted that there was great liability to confusion with the meaning of the term as generally understood, *i.e.*, the refining of the whole crystal. The finish of the silicon alloys as a general rule was particularly good.

Vote of Thanks.

Dr. S. W. Smith proposed a vote of thanks to Mr. Deeley for his Paper, and also took the opportunity of endorsing Professor Turner's expression of appreciation, on behalf of the members of the Institute of Metals, of the invitation to attend the meeting, and of the great pleasure it gave them to be present. Mr. Deeley's Paper was one of profound interest to all concerned with the casting of metals, and the development of the aluminium-silicon alloys was perhaps one of the most remarkable developments in connection with alloys in recent years. A remarkable feature was that the particular range of alloys dealt with by Mr. Deeley was in the neighbourhood of the eutectic, for, in the past, the eutectic range had been regarded as one to be avoided. The remarkable fluidity of the metal was another important factor which made it possible to produce castings of thin section. An outstanding feature of the process of so-called "modification" was the extraordinary way in which the silicon was finally dispersed in the solid metal. A great deal of significance attached, he thought. to the work carried out by Dr. Gayler, at the National Physical Laboratory, on the effect of

" under-cooling " of aluminium-silicon and other aluminium alloys, and he felt sure that, had time permitted, Mr. Deeley would have referred to this work. Dr. Gayler had shown that the solubility curves produced by super-cooling the " normal " alloys were practically identical with the solubility curves produced by the " modified " alloys. It seemed, therefore, as though the process of " modification " resulted in " catching " the alloy, as it were, in an under-cooled condition and returning it in that condition, because Dr. Gayler had found that it was impossible to under-cool these " modified " alloys. Very little knowledge of the mechanism of the phenomenon was yet available, but he had no doubt that in a very short time we should understand the process of modification, which should be of great significance not only in relation to these particular aluminium-silicon alloys, but also in relation to a wide range of other alloys.

Co-operation Stressed.

Mr. H. C. Dews (seconding the vote of thanks) said the meeting had listened to a most admirable presentation of a mass of very suitably correlated data. Mr. Deeley, bearing in mind the character of the meeting he was to address, had managed to incorporate into his lecture a very suitable blend of theory and practice. It was popularly supposed that the members of the Institute of Metals were immersed in theory, and that the foundrymen were wallowing in practice. Those who were members of both bodies would agree that such a conception was an entirely unsuitable representation of the aims of the two bodies. Those who, like himself, found it necessary to keep in touch with the activities of both bodies were very gravely disappointed to find that their London meetings were being held on the same evening in each month throughout the present session, and he—supported by a number of those who belonged to both bodies—would have no hesitation in condemning very seriously any movement which sought to separate the interests of the two. As a member of the Council of the London Branch of the Institute of British Foundrymen, he would do his best to ensure that such a catastrophe as had occurred this session would be avoided.

The vote of thanks was carried with acclamation.

Mr. Deeley, in a brief response, apologised for having omitted to refer to the work of Dr. Gayler, but, as Dr. Smith had suggested, the omission was due to the necessary limitation of the time at his disposal.

The Chairman, referring to Mr. Dews' remarks as to the necessity for avoiding the holding of meetings of the two bodies concurrently, said that both Dr. Smith and himself appreciated its importance, and had already pledged themselves on behalf of their respective Councils, to do all in their power to prevent clashing of meetings in the future.

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Birmingham, Coventry and West Midlands Branch.

ALLOY CAST IRON.

By Professor D. Hanson, D.Sc. (Member).

During the past two years researches on alloy cast iron have been carried out in the author's laboratory, both on the theoretical and practical aspects of alloy cast iron; in the more practical of these researches we have been fortunate in securing the co-operation of a number of foundries in which large scale trials have been carried out based on laboratory investigations, and in this way it has been possible to obtain valuable data indicating some of the improvements that can be achieved in cast iron by the suitable use of alloys.

As in the case of the development of special steels, so in the evolution of alloy irons nickel as an alloying element has been the first to receive serious attention. The reasons for this are now quite evident; in the first place nickel is an element that can be readily added to cast iron without modifying the existing methods of manufacture; it is readily absorbed, provided certain quite simple precautions are taken; it is not liable to segregate, nor do losses of nickel occur during the addition, nor on remelting. Moreover, the large amount of attention now being given to nickel cast irons is justified by the promising results that have already been obtained both in the laboratory and the foundry, and, indeed, nickel is now regarded in most of the more advanced foundries as an essential item in their metal stock, and is being used regularly to achieve results that would be difficult or impossible to obtain without it.

The association of nickel with chromium has produced many notable advances in metallic alloys, both in steels and in non-ferrous alloys, and it is not perhaps surprising to find the same pair of metals in useful association in cast iron. Developments in this direction appear likely to be no less important than those of the simpler nickel cast irons.

Experience has already shown that the indiscriminate use of alloy metals in cast iron, without a proper appreciation of the character of the base iron and the action of the alloy, is likely to lead to disappointing results. This is in no way surprising; the development of alloy steels, especially in the early days of nickel steels, was accompanied by just such a period of difficulty before scientific alloying became general. The author can well remember numerous instances in which the injudicious use of alloy steel has led to disappointing results, failures and breakages, solely because the principles involved in the manufacture and use of such steels were imperfectly understood. Happily such instances are now rare, but we must inevitably pass through a similar stage before we can emerge successfully into the age of alloy cast irons. It would, perhaps, be more correct to state that we are now in the transitional period, for, thanks to our better scientific knowledge of metals and alloys, and to the many researches on this subject already carried out, not only in this country, but also abroad, especially in America, Germany and France, we have made very definite progress towards an understanding of the principles involved in making alloy cast iron.

Nickel in Cast Iron.

Before passing on to a consideration of the practical results of alloying, it will be as well to examine the fundamental actions involved, and since nickel enters into practically all the alloys that we shall consider here, and its action has already been fully investigated, it will be appropriate to devote some time to examining the effect of this element on the constituents of cast iron, and the accompanying changes in properties.

Cast iron can be considered as a complex alloy of iron and carbon in which the carbon can exist in two forms, iron carbide and graphite, the exact balance between these two depending partly on the composition of the iron and partly on the thermal history (this was amplified in a recent article by A. B. Everest*); in certain special cases it may consist wholly of one form or the other. Now, of all the elements normally found in cast iron, the one that exerts the predominating effect in determining the character of the material is silicon, and as a first approximation we may regard cast iron as an alloy of iron, carbon and silicon. The other elements—phosphorus, manganese and sulphur—cannot be ignored in practice, and consideration of their importance in alloy irons will be given later on. We can, however, produce in iron-carbon-silicon alloys the principal characteristics of the cast irons. Starting with this simplification, Dr. A. B. Everest and the author have carried out investigations of the action of nickel on this system, and a consideration of these results will give a good general picture of the nature of the action of this metal on cast iron. That this is the case is amply confirmed by numerous experiments by the author and others on commercial irons.

A series of alloys was made by adding silicon and nickel to an iron-carbon alloy containing approximately 3.5 per cent. C, and the now well-known step-bar castings were made in each alloy; each step of these castings was examined by determining (*a*) its hardness and (*b*) its microstructure, and the results may be conveniently represented in diagrammatic form. Some typical hardness results are given in Figs. 1 and 2, representing respectively the effect of nickel on alloys containing no silicon and 1.2 per cent. silicon. For simplicity only two curves have been drawn on each diagram, corresponding to the ⅛-in. and 1-in. sections of the castings; diagrams representing intermediate sections have an intermediate form.

The curves in Fig. 1 are perhaps the most interesting; the ⅛-in. section, which is, of course, quite white in the original iron, is hardened con-

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* "Foundry Trade Journal," Vol. 39, p. 223.

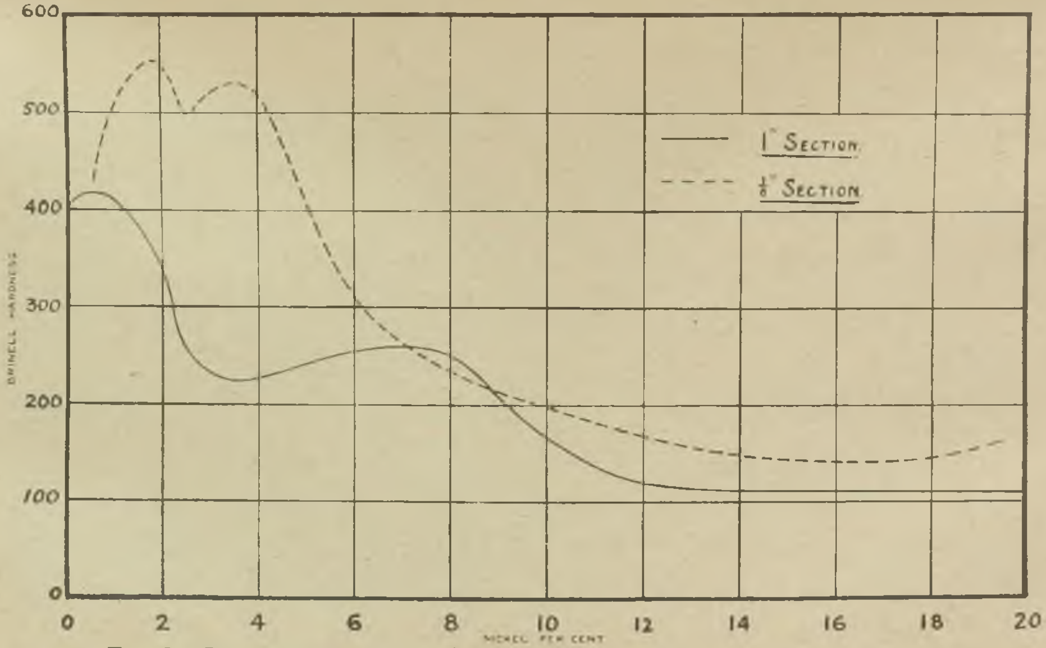

FIG. 1.—BRINELL HARDNESS OF ALLOYS AS CAST. SERIES 0. INITIAL SILICON, NIL.

siderably by additions of nickel up to 2 per cent., due, as microscopic examination reveals, to the direct hardening of the cementite-pearlite constituents, which remain substantially unaltered in nature. When, however, the nickel content exceeds 2 per cent., a softening occurs, due to the graphitising action of nickel in the iron carbide, which, for lower percentages had not been detected on this section owing to the rapid chilling; as still more nickel is added this softening is followed by a hardening, due to the transformation of the pearlitic matrix, first into sorbite and then into martensite. During this period the softening effect due to carbide decomposition and the hardening due to martensite formation may occur simultaneously, due to the rapid chilling action which retains carbide while inducing martensite formation. The rise in hardness is then followed by a fall, caused by the appearance of austenite, until, with high nickel additions (say 16-20 per cent. of this iron), the material consists entirely of graphite and austenite.

The diagram for the 1-in. section is similar in type; it contains two peaks, but they are less intense, and extend over a wider range of composition. This is due solely to the difference in chilling effect resulting from the different section of the metal. The slower rate of cooling favours graphite formation, thus reducing the amount of nickel required to commence graphitisation, and lowering the intensity of its hardening action on white iron, *i.e.*, it depresses the first peak and causes it to occur at lower nickel concentrations; at the same time, the intensity of the matrix hardening is reduced, so that more nickel is required to produce martensitic structures, and, since graphitisation is facilitated, this martensite is formed in a matrix lower in carbon; *i.e.*, the second peak is depressed and occurs at higher nickel contents.

Thus we can recognise four main effects due to nickel:—(*a*) It hardens white iron (when the iron is of such a character that the cementite is stable); (*b*) it decomposes iron carbide, giving graphite; (*c*) it hardens the matrix, converting pearlite into sorbite or martensite; and (*d*) with high nickel, a soft austenitic grey iron is formed.

Fig. 2 shows similar diagrams for an iron containing 1.2 per cent. silicon. Here we observe that the first " peak " is absent, and that the first effect of nickel is to reduce the hardness. This is amply accounted for by the micro-structures, which show that the silicon prevented the formation of the austenitic-cementite eutectic except in the thinnest sections, and the graphitising effect of the nickel additions became immediately effective. Practically all the commercial grey irons are of this type, though many of the commercial white irons fall within the type of **Fig. 1.**

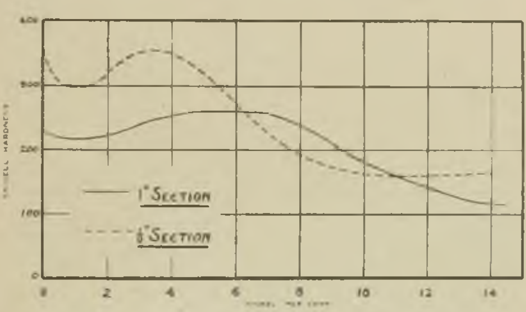

Fig. 2.—Brinell Hardness of Alloys as Cast. Initial Silicon, 1.2 per cent.

Thus we see that the general effect of nickel can be represented by a characteristic curve, the effect of chill being to compress the changes into a smaller range of nickel additions.

Fig. 3 shows diagrammatically the structures of 1-in. sections of step-bar castings containing varying silicon and nickel, and amplifies the information given in Figs. 1 and 2.

Comparison of Effects of Nickel and Silicon.

Nickel, like silicon, promotes the formation of graphite; it is, in fact, quite possible to produce a grey iron with nickel, in the complete absence of silicon. But a consideration of the action of silicon at once reveals important differences in their behaviour. The first effect of silicon on a pure iron-carbon alloy is to harden the austenite cementite constituents as Turner has shown, but this effect only occurs in irons outside the normal grey iron range. This is succeeded by a softening action, due to graphite formation, which is continued so long as any carbide remains in the iron; silicon not only causes the decomposition of eutectic and pro-eutectoid cementite, but removes the eutectoid carbide (pearlite) as well, so that a high silicon grey iron, in moderate or heavy sections (and, indeed, sometimes in thin sections) may consist entirely of ferrite and graphite. Silicon is not only a carbide softener, but a matrix softener as well, whereas nickel softens the carbide formed above the eutectoid range, while its graphitising action below this point is very mild and its hardening effect through sorbite formation is considerable. It is therefore a matrix hardener.

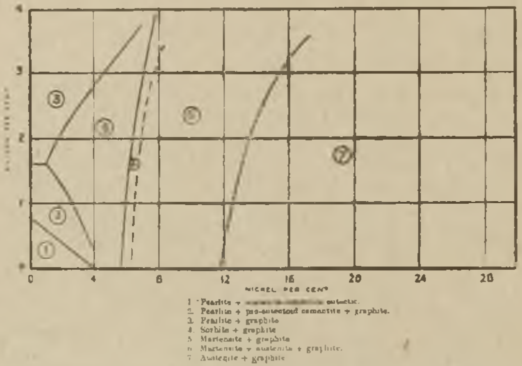

FIG. 3.—CONSTITUTION OF NICKEL-SILICON-IRON ALLOYS WITH 3.5 PER CENT. CARBON. AS CAST. 1-IN. SECTION.

Above the critical range nickel and silicon may be said to supplement one another, but below this range nickel restrains the action of silicon in decomposing pearlite, and maintains a structure free from ferrite, while its own matrix hardening through sorbite formation is definitely in the opposite direction to the effect of silicon.

The Scientific Use of Alloy Additions.

From the foregoing it can readily be seen that the effect of a nickel addition will depend on the nature of the base iron and conditions of casting.

For example, an iron that is liable to chill will be softened in the chilled parts by adding a little nickel; an iron containing a wholly pearlitic matrix will, in general, be hardened, through pearlite refinement or sorbite formation; but an iron possessing an open grain and much free ferrite will in general be less affected, since the free carbides are already completely decomposed and the matrix possesses little pearlite upon which the nickel can act.

It may be, however, that in one and the same casting entirely different structures will exist; heavy sections may be grey while the thinner sections are chilled. Chilling can, of course, be prevented by raising the silicon content, but not without the risk of producing too open a grain, and too soft a matrix in the thicker parts. It is in such a case that the characteristic properties of nickel can be utilised with great advantage, since by a suitable addition the chilled portions may be softened by a break-up of the carbide, while the pearlitic grey portions are refined and hardened. The nickel acts differently on the different parts, softening the hard portions and hardening the soft portions, thus producing a casting of more uniform hardness.

Nickel, therefore, must be used with due regard to the character of the iron, the nature of the casting and the effect that it is desired to produce—the indiscriminate use of this, or any other alloy addition, may well give unsatisfactory results, but used in the light of the general behaviour outlined above, it can effect improvements in the product otherwise unobtainable.

Effects of Nickel on the Properties of Cast Iron.

We may now consider the effects of nickel on industrial irons, and we shall devote our attentions mainly to high-grade grey irons, dealing first with irons low in phosphorus.

Chill and Hard Spots.

Nickel, in common with silicon, assists graphite formation, and is therefore effective in reducing chill and eliminating hard spots. This is well illustrated in Fig. 4, which represents fractures of fins of equal section cast in a high-grade automobile-cylinder iron; they contain 0.0, 1.12 and 1.84 per cent. of nickel respectively, and the elimination of chill and mottling is well illustrated. This is confirmed by many other instances in the writer's experience, and it is even possible to turn a white iron grey even when the silicon is very low, as is shown in Fig. 5, although higher nickel additions are here necessary.

According to Houston[1] two parts of nickel are equivalent to one part of silicon in eliminating chill. Experiments in the writer's laboratory are in agreement with this figure for some of the high-grade engineering irons, but in some cases rather more nickel may be required, especially in certain low-silicon mixtures of high-chilling tendency.

The reduction of chill and hard spots may be effected by silicon more cheaply than by nickel, but not without depreciation of the general physical properties of the casting through opening of the grain, and greater porosity and shrinkage, whereas, as will be shown later, nickel may be used to give simultaneously reduction of chill and increase in hardness and strength. But even where nickel is used solely with a view to the elimination of chill and without regard to the composition or properties of the grey portions of a casting, it is without appreciable deleterious effect on these portions.

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[1] D. M. Houston. Proc. American Society for Steel Treating, Jan., 1928. Vol. xiii, No. 1, p. 105.

Table I, which refers to the castings illustrated in Fig. 4, shows the elimination of chill by nickel without appreciably altering the properties of the grey portions. This could not be effected by silicon. The tests refer to standard I.B.F. " M " bars cast 1.2 in. in diameter, tested on a span of 18 ins.

TABLE I.—*Mechanical Tests on* 1.2 *in. Diameter Bars.*
T.C., 3.30; Si, 2.08; Mn, 0.96; S, 0.10; P, 0.18.

Nickel—per cent. ..	—	1.12	1.84
Ratio G.C./T.C. ..	81.5	81.4	81.2
Transverse—			
Max. stress-cwt. ..	25.36	26.68	24.58
Modulus of rupture. Tons per sq. in. ..	33.65	35.38	32.60
Tensile—			
Max stress. Tons per sq. in.	12.74	13.22	13.25
Chill: on ⅛-in. step ..	0.33	0.04	nil

Grain.

The effect of nickel on the grain (graphite structure) varies with the nickel added, and the nature of the iron. Small additions of nickel up to about 2 to 3 per cent. refine the grain of ordinary engineering irons, but above this amount the structure may become coarser. This effect has been repeatedly observed in Everest's and the author's experiments[2], and is substantially in agreement with the works of Wickenden and Vanick.[3] In irons that are already open in grain through too high silicon content, little refinement generally is effected.

In order to obtain the maximum effect of nickel in this direction it is necessary to reduce the silicon content. It is well recognised that increasing silicon opens the grain of the iron. If therefore when nickel is added the silicon is

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[2] Everest. Turner & Hanson. J.I.S.I. 1922, Vol. cxvi, p. 125, Everest & Hanson, J.I.S.I. 1928, Vol. cxvii, p. 358.

[3] Wickenden & Vanick, American Foundrymen's Assoc. 1925, Vol. xxxiii, p. 347.

reduced in the right proportion to maintain equal chilling properties, much greater grain refinement can be effected. This is, of course, the rational way to use nickel, and the author's experiments on cylinder irons, in which this adjustment was made, amply confirm the refining action of nickel used in this way.

NICKEL 0 1 2 PER CENT.

FIG. 4.

Hardness.

The effect of nickel may be considered under two headings, (*a*) general effect, and (*b*) use of nickel to equalise hardness.

(*a*) It has already been shown that nickel may increase or decrease hardness according to the nature of the iron to which it is added. In regard to grey irons, there are two principal effects:—(1) Softening of the hard spots, such as chilled or mottled edges and free carbide (pro-eutectoid cementite), and (2) matrix-hardening through pearlite refinement and sorbite formation. The first of these effects has been dealt with in discussing chill, and will be referred to again in dealing with wear and machineability. The second effect is amply illustrated by Brinell hardness results, of which a number of examples are given in this Paper. It is usually readily detected even in irons in which the silicon content

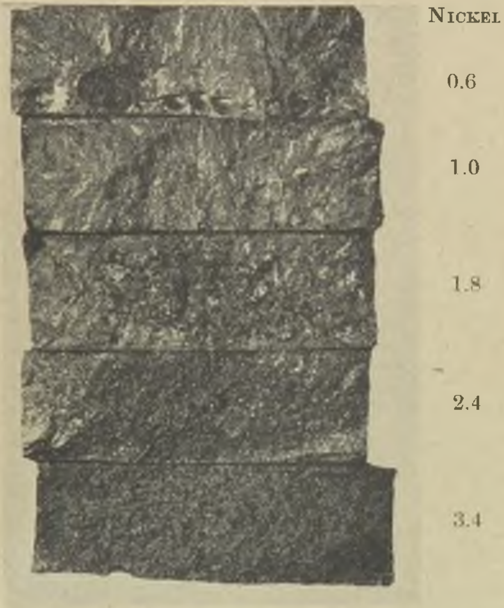

FIG. 5.

is not adjusted to the amount of nickel added, as in the first three series of Table II, but is most effective when the appropriate adjustment in silicon is made. Comparison of the above figures with those of the other castings given in the same table, in which the silicon was reduced to give irons of similar chilling tendency, at once reveals the great improvement effected, while the iron remains completely grey up to quite high Brinell numbers—in fact, machineable grey irons, having Brinell numbers exceeding 250 have regularly been obtained.

(*b*) *Equalising Hardness in Varying Sections.* —One of the most useful qualities of nickel is its equalising effect on the structure and properties of castings of variable section. As a rule, castings with thin sections, made in ordinary cast iron, must contain sufficient silicon to prevent the formation of chilled edges; but if they also contain heavy sections, the silicon will open the grain of the iron, with the accompanying reduction in strength, and liability to porosity and shrinkage. It is in such an instance that the dual action of nickel on the iron can be utilised with great advantage. The heavy sections can be refined by reducing the silicon by the appropriate amount, while chilling of the thinner parts, edges and corners, which would otherwise accompany this silicon reduction, is prevented by the addition of a suitable amount of nickel, which, while preventing the formation of unmachineable white iron in thin parts, will exert a sorbitising action generally on the matrix. Fig. 6 illustrates this effect in diagrammatic form; the diagrams represent the results of step-bar tests, the hardness of the different sections and the amount of chill being shown; on the heavy sections is also included the results of standard transverse tests and tensile tests on 1.2-in bars; the metal was melted in crucibles and cast into green-sand moulds, and contained 3.15 per cent. carbon; 1.15 per cent. silicon; 0.4 per cent. manganese; 0.30 per cent. phosphorus; and 0.05 per cent. sulphur.

The Effect of Nickel on Strength.

Castings of high strength, for which the demand is increasing, require a close-grained structure accompanied by a strong pearlitic or sorbitic matrix. The application of the principles of composition balance already described contributes to the solution of this problem. Irons possessing the highest strength must always contain sorbitising elements; nickel (and, as we shall see, chromium) has the required strengthening action, whereas silicon has not. The substitution of some silicon by the equivalent amount of nickel is therefore a logical solution of this problem, and here it is important to recognise that nickel addition to an iron of moderate or poor mechanical properties without simultaneous reduction of silicon cannot have a marked effect on strength since sorbitising without grain refinement may increase hardness and reduce chill, but will not greatly affect strength, since the refining action of nickel alone, on irons with normal or high silicon, though definite, is not sufficient to produce great improvement in strength. Silicon adjustment is here essential. Failure to appreciate this fundamental principle has been responsible for much unnecessary disappointment in the use of nickel.

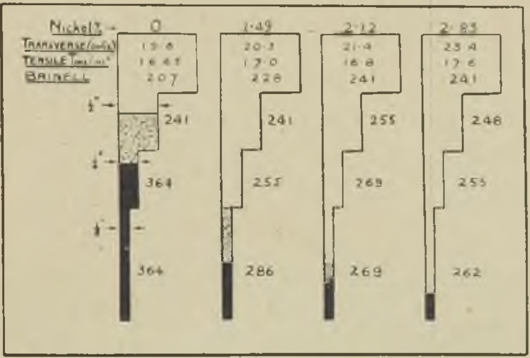

Fig. 6.—Step Bar Castings in Iron Containing T.C. 3.15; Si 1.15; Mn 0.4; S 0.05; and P 0.30 per cent.

The experiments tabulated in Table II, made on an automobile-cylinder iron, were carried out by Everest and the author with a view to obtaining harder and stronger irons of similar chilling tendency to the unalloyed iron. The improvements in strength obtained are very substantial,

TABLE II.—*Effect of Nickel on Strength and Hardness.*

Material: Automobile Cylinder Iron, T.C., 3.2–3.3 per cent.; Mn, 0.9 per cent.; S., 0.10 per cent.; P, 0.18 per cent.

Ni. Per cent.	Si. Per cent.	Transverse tests.[4]		Tensile strength.[5] Tons/sq. in.	Brinell numbers (step bar).			
		Load, cwt.	Mod. of rupture, Tons/sq. in.		1 in.	½ in.	¼ in.	⅛ in.
0.0	2.0	25.36	33.65	12.74	192	192	229	229
0.7	2.0	25.52	33.87	13.09	197	199	229	235
1.12	2.0	26.68	35.38	13.22	199	210	229	235
0.0[6]	1.3	—	—	—	228	250	364	340
0.93[6]	1.29	26.6	35.3	16.84	212	228	242	251
1.84[6]	1.35	28.0	37.4	16.70	225	241	251	286
1.22	1.42	29.46	39.0	18.5	226	232	273	292
1.12	1.44	28.43	37.6	20.5	228	230	250	386

[4] Transverse Tests on standard I.B.F. "M" Bars.

[5] Tensile Tests, pieces cast 1.2 in. diameter and tested 0.9 in.

[6] Carbon rose to 3.40 per cent. in these irons.

from 12.74 tons per sq. in. without alloy, to over 20 tons per sq. in., with only 1.12 per cent. of nickel (replacing 0.56 per cent. silicon—replacement ratio Ni/Si = 2/1). While the irons remained practically equal in regard to chill, the hardness of all sections was substantially improved, and completely grey sections having hardness values close to 300 were obtained, while some large omnibus engine blocks were cast in this alloy iron to give cylinder bores with a Brinell hardness of 215 without machining difficulties through chill on the thinner sections.

Effect of Nickel on Machineability.

In discussing the question of machineability of cast iron we have to take into account the peculiar properties of the material. Cast iron can contain a great variety of constituents and structures varying from hard and white iron, containing much free carbide to a dead soft material consisting essentially of ferrite and graphite. Most of the high quality engineering irons, with which we are most concerned, are required to possess a fair degree of strength and hardness, and these qualities are normally required in the heaviest parts of the casting. There is usually not much difficulty in securing such qualities, provided that the properties in the thinner sections are unimportant, but, unfortunately most castings are not simple in shape, and to secure the desired qualities in the heavier sections without chilling of the thinner portions, corners and edges, is frequently a matter of much difficulty. But even a small amount of chilled structure, which is practically unmachineable, is fatal in any position of a casting that must be machined. We may say, therefore, that for practical purposes, the machining qualities of an iron are mainly determined by its liability to chill. The property of nickel, in preserving the general hardness while reducing chill is therefore of special value in improving machineability.

It is not only iron possessing a white structure that can give machining difficulty: the presence of carbide spots (pro-eutecroid cementite) in a grey iron is a common source of machining trouble, since the intensely hard constituent rapidly dulls the cutting edge of a tool and reduces its efficiency. In this connection also, the graphitising action of nickel can be utilised to break up the carbide colonies.

The characteristic action of nickel in breaking up carbide while preserving a strong matrix has therefore a special importance in connection with the production of hard and strong machineable castings and observations in the author's laboratory have repeatedly shown that commercially machineable castings can readily be made with Brinell hardness numbers exceeding 250.

There is another direction in which the equalising action of nickel may have an important bearing on machineability. We have shown that heavy sections, particularly in large castings, are liable to have a very open structure in ordinary irons, where silicon has to be maintained sufficiently high to prevent chill on the thin sections. This open grain, due to large graphite flakes, can give rise to machining troubles due to the tearing out of bits of machined surface by the tool, particularly when heavy cuts are taken; this produces a poor machined finish suggesting porosity in the metal. Here again, the proper use of alloy will close the grain of the iron and eliminate the trouble.

From the economic point of view the value of nickel in its relation to machineability is worth careful consideration, since the reduction of rejections in the machine shop alone may well justify the extra cost of the alloy addition.

Nickel and Chromium in Cast Iron.

We have examined the effect of nickel in cast iron and have pointed out its characteristic action. In the development of alloy irons, other elements will play their part, and it is necessary to examine the effect of such other additions on the action of nickel. The only other addition that has as yet received much consideration is chromium. The action of chromium differs in certain important respects from that of nickel. Nickel promotes the formation of graphite, but hardens the matrix; silicon is a graphitising agent both above and below the critical range, and softens both the carbide and the matrix of the iron. Chromium, on the other hand, is a carbide-forming agent as well as a very effective matrix-hardener. Thus, while it acts in the same sense as nickel on the matrix, it acts in the opposite sense in regard to chill, which is rapidly increased by chromium additions. The use of chromium alone is therefore likely to accentuate troubles due to chill, hard spots and difficulty in machining.

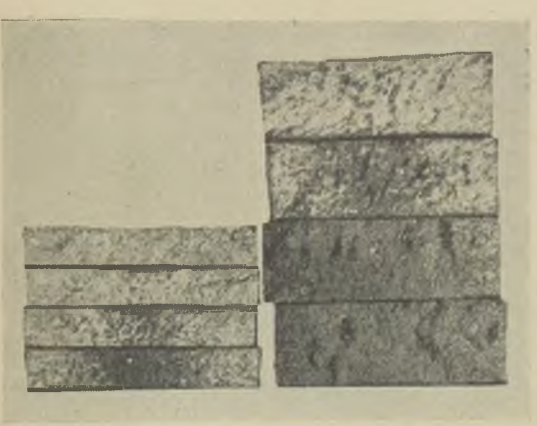

Fig. 7.—Action of Nickel on Refined Iron containing 0.5 per cent. Cr.

Experiments have shown that nickel preserves its characteristic effects in the presence of chromium. Its action on chill is no less pronounced, as is well illustrated in Fig. 7, which shows the fractures of a series of steps from castings made of a refined iron containing 2.8 per cent. carbon and 1.7 per cent. silicon; the chromium is constant throughout the series at 0.5 per cent., while the nickel is nil in the top fracture, and 1, 2 and 3 per cent. respectively in the lower fractures.

The effect of nickel in equalising the hardness of different sections is demonstrated in Figs. 8 and 9. Fig. 8 represents the hardness of the steps in castings of the refined iron containing 2.8 per cent. carbon; 1.75 per cent. silicon; 0.6 per cent. manganese; 0.05 per cent. sulphur; and 0.14 per cent. phosphorus.

The reduction in chill is also illustrated in the sections of the step-bar casting included in this diagram, the black shaded area representing the chilled iron.

The equalisation in hardness of the different sections is in part due to the reduction in chill of the thin parts, and in part to the hardening of the matrix in the thicker sections, the action of nickel being here identical with that already described of irons containing no chromium. The same equalising effect is shown in Fig. 9, which refers to an automobile cylinder iron, containing 3 per cent. carbon, 2 per cent. silicon, and low sulphur and phosphorus. The comparison here is really between the original iron containing no alloy addition and the same iron after the addition of 1 per cent. nickel plus 0.25 per cent. chromium, the silicon content being maintained constant throughout.

The equalising action of nickel and chromium is here well demonstrated in the production of widely varying sections of readily machinable iron with Brinell numbers varying only from 228 to 241.

It is clear that while the characteristic action of nickel is preserved in the presence of chromium, the introduction of another element with such a marked chilling tendency must be taken into account in deciding the amount of nickel suitable for any particular purpose.

Chromium acts in the opposite sense to silicon in its effect on chill, and the same adjustment in the silicon content is not, therefore, necessary when chromium is present. According to Houston, one point of chromium is roughly equivalent to two points of silicon in respect to chill, and since nickel acts in the same sense as silicon, then one point of chromium is roughly equivalent to two points of nickel. This equivalence doubtless varies somewhat with the grade of iron used; the author's experience suggests a figure more nearly approaching 3 : 1. These relationships can be utilised to meet important practical needs, experienced particularly by foundrymen making a large variety of castings from the same cupola, since the addition of chromium in suitable proportions can be made instead of a reduction in the amount of silicon, to compensate for the amount of nickel added. The results shown in Table III show the improvement in properties of an automobile cylinder

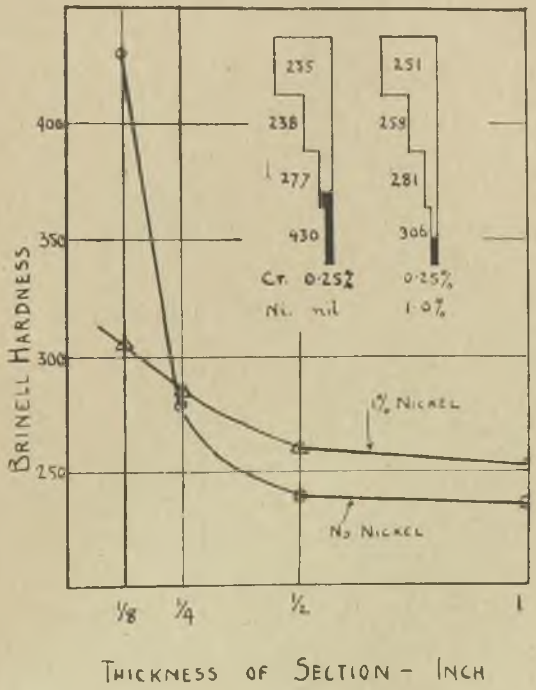

Fig. 8.

TABLE III.—*Effect of Nickel and Chromium on Cast Iron.*

Material: Automobile Cylinder Iron, T.C., 3.07 per cent.; Mn, 0.85 per cent.; S, 0.10 per cent.; P, 0.17 per cent.

Ni. Per cent.	Cr. Per cent.	Depth of chill on ⅛-in. step.	Brinell Hardness.				Transverse test on standard "M" bar.		Tensile strength. Tons per sq. in.	
			1 in.	½ in.	¼ in.	⅛ in.	Max. load, cwt.	Mod. of rup. Tons sq. in.	1.2 in. bars.	0.875 in. bars.
nil	trace	0.5 in.	199	213	228	241	28.15	37.3	15.3	19.4
1.02	trace	trace	210	217	335	241	26.93	35.7	16.8	18.8
1.10	0.27	trace	228	231	238	241	28.27	37.5	18.6	20.5
1.14	0.414	0.35 in.	230	238	258	269	28.15	37.3	18.0	22.45

iron brought about by the combined addition of nickel and chromium in this manner. The addition of nickel alone had produced a slight improvement in the hardness of the thicker sections, and a slight increase in tensile strength. The simultaneous addition of chromium has resulted in considerably greater improvement both in the hardness and tensile strength, while the chilling tendency of the iron is less than when no alloy was added. In these tests, a nickel to chromium ratio of rather less than 3 : 1 appears to have produced an iron of practically equal chilling tendency.

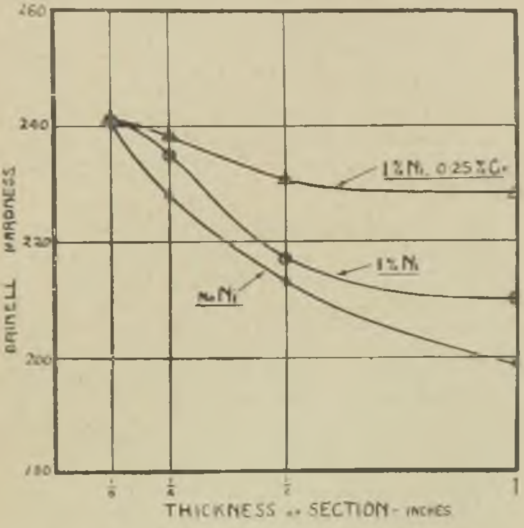

Fig. 9.

While chromium can be used as described to neutralise silicon, it is necessary to remember that this substitution can be carried too far, and that irons very high in silicon may give disappointing results on account of the open grain produced by this element. Reduction of silicon is much more effective in refining the grain than addition of chromium, and in such a case, if the best results are to be obtained from alloying, the silicon should be reduced at least to such a point as will ensure a satisfactory graphite structure in the iron.

The combined effect of nickel and chromium in suppressing the formation of pearlite is well known in connection with alloy steels, and is equally effective in producing a sorbitic structure in alloy cast irons. This can be utilised to give improved hardness and resistance to wear, and, with proper adjustment of the alloy additions, to eliminate hard carbide spots, these qualities can be obtained in an iron that is readily machinable. Such a use of alloy cast iron is already being made with success in the production of cylinders and cylinder liners, dies, grey-iron rolls, etc., where a combination of these qualities is required.

Effect of Nickel in the Presence of Phosphorus.

We have so far only considered cast irons in which the phosphorus content is quite low. Many of the irons used in this country for the production of high-grade castings contain appreciable amounts of this element, and it is, therefore, important to know how its presence affects the influence of alloy additions. Dr. Everest and the author have carried out a number of experiments on phosphoric irons which throw an important light on this question.

Opinions differ as to the influence of phosphorus itself on cast iron; on the one hand, it is held that phosphorus induces graphitisation, and, on the other hand, that it increases the amount of chill. In the author's experiments on a refined iron containing 3 per cent. carbon and 1.8 per cent. silicon, as well as from the synthetic irons produced from a washed-iron base, phosphorus had a definite action in increasing susceptibility to chill. The influence of nickel was found quite definitely to counteract this influence, as is illustrated in Fig. 10, which shows the chill on different sections of the refined iron containing different phosphorus and nickel contents. The graphitising action of phosphorus was also definitely disclosed by chemical analysis of the different alloys. Step bar castings, furthermore, disclosed that nickel has a definite regular hardening action on all sections, except where chilling had produced white iron, when nickel is effective in removing the hard structure. It is thus possible in phosphoric irons to utilise nickel additions in the manner already discussed to equalise the hardness in different sections, and Figs. 11 and 12 illustrate this action in the refined iron already referred to. Fig. 11 shows the effect of 2 per cent. nickel on an iron containing 0.5 per cent. phosphorus, and discloses a striking equalising action on the iron. Fig. 12 shows a similar effect of nickel on iron containing 1.2 per cent. phosphorus. It was also observed that the iron containing 0.5 per cent. phosphorus was readily machinable on the larger sections in spite of the high Brinell number of 260.

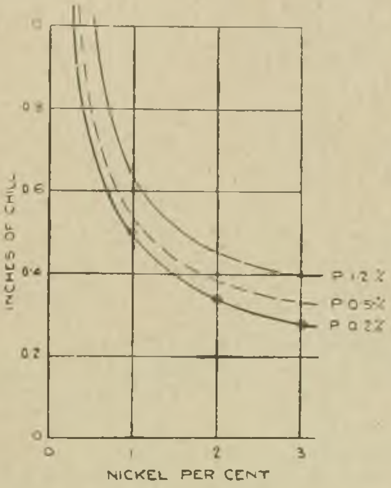

Fig. 10.—Refined Iron. Depth of Chill on $\frac{1}{8}$-in. Step.

Nickel and phosphorus both have a refining action on the graphite, and in irons containing high phosphorus (1.2 per cent.) the effect of nickel is very small. The action of nickel in producing a finer form of pearlite was confirmed, and it was also noticed that phosphorus itself has a definite action in this direction.

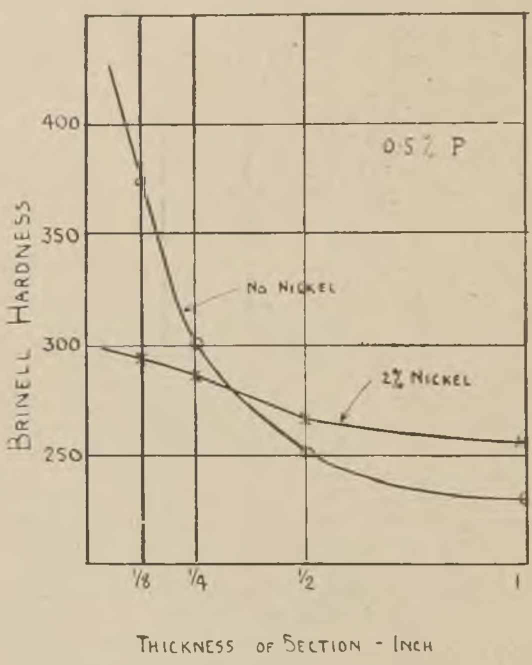

Fig. 11.

In order to confirm these observations, some experiments were carried out on foundry irons containing about 0.6 per cent. phosphorus, nickel and chromium being added to the metal in the ladle in the usual way. Table IV shows the results of some experiments on some cylinder iron containing 3.6 per cent. carbon and 1.27 per cent. silicon with 0.6 per cent. phosphorus. The addition of 0.87 per cent. nickel definitely reduces the amount of chill and produces a slight hardening effect, particularly on the thicker sections, but without appreciably improving strength; this result would be expected since the silicon was not lowered when the nickel was added. The addition of 1.18 per cent. nickel and 0.27 per cent. chromium is accompanied by a considerable general increase in hardness, and the over-all hardness is rendered more uniform, while at the same time the tensile strength is increased from 12.1 to 13.7 tons per sq. in. This improvement in properties is achieved, as shown in the table, without sensible alteration in the chilling tendency of the iron. A comparison of

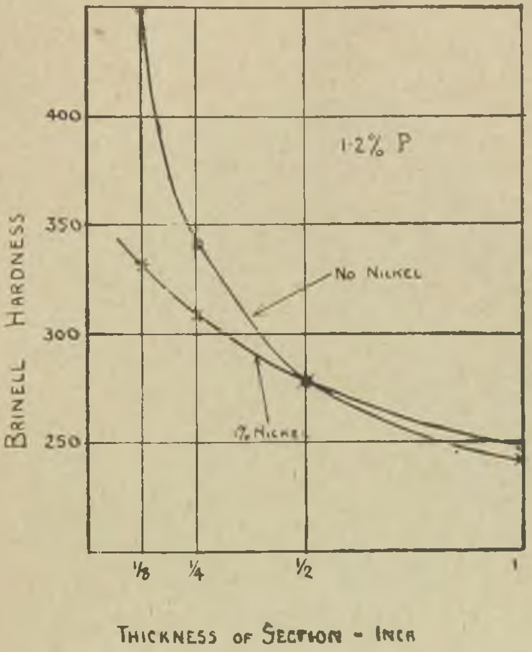

Fig. 12.

TABLE IV.—*Effect of Nickel and Chromium on Cylinder Iron.*

Material: C. 3.6 Si, 1.27 ; Mn, 0.7 ; S, 0.12 ; P, 0.6. Nickel and Chromium added to Iron in Ladle.

Ni	Cr	Chill on $\frac{1}{8}$-in. step.	Brinell hardness of steps.				Transverse on "M" bar.	Tensile Tons/sq. in.
			1 in.	$\frac{1}{2}$ in.	$\frac{1}{4}$ in.	$\frac{1}{8}$ in.		
—	—	0.18	190	205	227	240	28.9	12.14
0.87	—	trace	202	202	228	245	25.2	12.36
1.18	0.27	0.30	220	223	248	260	30.3	13.70

these results with those given in Table III for a cylinder iron containing 0.17 per cent. phosphorus shows a remarkable similarity, confirming the similarity of action of the alloy in the two cases. Figs. 13, 14 and 15 show a microstructure of the three irons tabulated in Table IV. Fig. 13 shows the structure of the original iron; Fig. 14 shows the structure with 0.87 per cent. nickel added; and Fig. 15 shows the structure with 1.18 per cent. nickel and 0.27 per cent. chromium. The refining action of the nickel alone on the pearlite is quite definite, while the nickel-chromium additions have produced a matrix of very fine sorbitic pearlite.

FIG. 13.—MOTOR CYLINDER IRON.

The beneficial effects of nickel and chromium were also confirmed in an iron containing 3.4 per cent. carbon, 1.24 per cent. silicon, and 0.54 per cent. phosphorus, used for making cast-iron dies; the addition of 1.70 per cent. nickel and 0.4 per cent. chromium to this iron produced a very considerable increase in hardness without increasing the amount of chill, and dies made from this metal were found to have a greatly increased life. The improvement in the structure of the matrix is illustrated by Figs. 16 and 17, which show respectively the original iron, showing a well-defined pearlitic structure, and the alloy iron in which the matrix is largely sorbitic.

Fig. 14.—Motor Cylinder Iron. × 1 per cent. Nickel.

The results already described show that the action of nickel is substantially the same in these phosphoric irons as in similar irons low in phosphorus. In the laboratory tests it was found that slightly more nickel is required to produce a given result in the high-phosphorus irons where there is any tendency to chill, than in the lower phosphorus irons, and this is probably to be accounted for by the definite chilling action of the phosphorus in these cases. It is possible that this would not be experienced in all varieties of iron, in some of which phosphorus appears to be without effect on chill.

FIG. 15.—MOTOR CYLINDER IRON. × 1 PER CENT. NI AND 0.25 PER CENT. CR.

The presence of phosphorus in an iron has one effect which we have not yet considered, namely, that it gives rise to the presence of phosphide eutectic. This very hard constituent has a marked effect on the properties of any iron; it increases the general hardness as measured by the Brinell test, and, if present in appreciable quantities, has a marked effect on the machinability. Nickel appears to be without appreciable effect on the phosphide eutectic, which continues to exert its own characteristic influence. Excessive hardness or difficulty in machining due to the presence of phosphide eutectic, as distinct from the general influence of phosphorus on chill, will therefore be unaffected by nickel additions, except in so far as these additions, together with modifications in silicon content, may lead to a general refining of the iron and reduction in segregation, leading to a more uniform and satisfactory distribution of the phosphide areas.

Fig. 16.—Die Iron without Ni or Cr.

Thus, though we see that nickel acts in a similar manner in phosphoric irons, as in irons low in phosphorus, in reducing chill, equalising hardness and improving strength, account must always be taken of the inherent properties due to the presence of phosphide eutectic. Further work is required on irons of this class, and experiments in this direction are proceeding in the author's laboratory.

FIG. 17.—DIE IRON. × 1.7 PER CENT. NI AND 0.4 PER CENT. CR.

General Conclusions.

It has been shown that the additions of nickel with or without chromium can be effective in cast iron in controlling chill, increasing and equalising hardness, raising the strength, and improving machinability. These effects are due to the characteristic action of nickel in decomposing eutectic and pro-eutectoid carbide, while maintaining a high combined carbon in the matrix on which its refining and sorbitising action can take effect. It is, however, necessary in making nickel additions to take into account not only the fundamental action of this element, but also the influence of the other elements that may be present in the iron.

The characteristic action of nickel is effective in the presence of both chromium and phosphorus, and can be utilised with advantage in the presence of those elements, provided that due attention is also given to the characteristic effects of those elements themselves.

The author acknowledges with much pleasure the valuable co-operation of Dr. A. B. Everest in the experimental work described in this Paper and in preparing diagrams and photographs to accompany it.

DISCUSSION.

Mr. E. R. Taylor said he was glad to hear the warning which the lecturer had issued that they could not expect the remarkable results shown unless they took into consideration the various elements of the iron under treatment. In America there had been a considerable use of nickel and chromium additions, but even so it had been suggested that the process was likely to be overdone. There was indeed a tendency towards using alloys of nickel beyond the point intended. He should like to know what were the benefits to be derived from an increment of nickel and chromium to malleable cast iron. He was interested in white heart iron, and having seen some of the results of these alloys, it seemed to him that the trouble was a liability to honeycombing and general unsoundness of the casting.

Mr. A. Harley, acknowledging the lecture as admirable for practical men, said that if the nickel corporations would reduce the price of their product a great deal more would be used. It was interesting to notice that in dealing with low-phosphoric irons the lecturer showed that their physical values, either with or without the addition of nickel and chromium, were very much higher. The best figure shown in phosphoric irons was 13 tons tensile, and in low phosphoric irons with additions the strength reached up to 22 tons. Now he preferred to do without phosphorus wherever possible, but there was one factor which they could not ignore—the question of wear. Thus, in certain automobile castings and so forth it was necessary in the majority of cases to utilise a phosphoric iron, for there was no doubt that the hard phosphide was a valuable adjunct in increasing the resistance to wear. Whether a neutralising agent could be employed, such as very low total carbon, without rendering the metal unmachinable, he did not know; but he would like to inquire whether additions of nickel and chromium would to any extent minimise the tendency of phosphoric irons to draw. Other things being equal, high phosphoric irons were without a doubt weaker than low-phosphoric irons. His experience of such irons was slightly different from that of Professor Hanson, but it was by no means definite. Now phosphoric irons, even with as low a carbon content as low-phosphoric semi-steel, had a greater tendency to chill at the corners and edges than high-phosphoric irons of otherwise similar composition. In other words, while the phosphide eutectic deposited throughout the iron increased the hardness of the iron generally, it appeared to neutralise the tendency of the iron to chill at the edges and corners. He was referring to irons containing 0.8 to 1.0 per cent. of phosphorus, as against those with up to 0.2 per cent. Concluding, Mr. Harley asked what was the best method of adding nickel and chromium to cast iron, assuming they had considered the question of balance, for obtaining uniform results.

Nickel and High-grade Phosphorus Irons.

Professor Hanson, replying to Mr. Harley, said, in regard to the tensiles being lower in phosphoric irons, that they must remember this: in their experiments the silicon content was not lowered when nickel was added. In all other cases in which a great improvement in strength was obtained the silicon was lowered when nickel was added. He had every hope that definitely better results could be secured with phosphoric irons than had been shown in the Paper. But so far they had not reached the stage of making the silicon adjustment when using those irons. On general grounds one preferred to cut phosphorus down. However, he must say there was every hope, even in irons where this was not possible, of obtaining an improvement in strength by using alloys, though perhaps not quite so high as when phosphorus was low. As to the occurrence of drawing, it had been associated with a certain amount of openness of grain, and if they could lower the silicon and close the grain, less trouble from drawing was likely. This could be done if nickel were added to replace silicon, enabling one to produce an iron of closer grain, having less tendency to drawing and to the segregation effects which occurred to a marked degree in phosphoric irons. The iron used in his experiments was refined iron, low in carbon, and phosphorus had a chilling effect. But it was by no means inconceivable that both effects should take place in irons of different types. In so far as alloying was concerned, the softening action, in regard to chill, on the part of phosphorus was probably better than the hardening action, because when the hardening action was present a little more nickel was needed to produce the desired result than when phosphorus was absent.

Additions as F Shot.

Continuing, Professor Hanson said there were several reliable methods of adding nickel and chromium. In the experiments referred to they had used principally F Shot, a variety of nickel containing about 6 per cent. silicon, 92 per cent. nickel, and small amounts of iron and other elements. It had a melting point approximating to that of cast iron, and was absorbed readily, Pure nickel shot could be added and absorbed satisfactorily if care was taken to ensure adequate heat in the molten iron. It was advisable in making alloy irons to run the cupola hot so that sufficient heat was always secured. In using the ladle it was necessary to run a little metal into the bottom of the ladle, and then sprinkle the shot into the stream, thus ensuring that the nickel shot was mixed before the ladle became full. As to chromium, that could be added either in the form of powdered ferro-chromium, or in a combined form with nickel known as Nichrome B. In the first instance the addition was powdered fairly fine, but the dust should be screened away, otherwise losses were likely to be high. The advantage of adding the alloys separately was that the user was not bound to one ratio of nickel to chromium; in their experiments they obviously preferred to make separate additions of nickel and ferro-chromium.

Mr. Harley observed that low phosphoric irons were more susceptible to chill, but undoubtedly phosphorus hardened the metal (he instanced green sand moulds as causing corners and edges to become chilled).

Mr. J. B. Murray inquired whether the lecturer had noticed if the formation of graphite, with the silicon unaltered, became coarser and flaky. If so, the hardening of the matrix would be nullified by that coarsening, and in that case, he took it, the effect of the nickel would be abortive. When ferro-chromium was put through the cupola there was a tendency to lose more chromium than nickel. If it was run through the cupola a ladle was necessary to give a proper mixing to the alloy, otherwise the only alternative was, as the Professor said, to use chromium in powdered form.

Some Practical Hints.

Dr. Everest quoted an instance of complicated motor-cylinder work in which there had been an elimination of chill without softening the casting, which was of very different thicknesses. Experiments had shown that low-silicon nickel irons could be produced which indicated a very definite advance not associated with ordinary cast iron Nickel did not appear to exercise any injurious effects, and they could assume it was perfectly safe to add nickel even if the iron was unsuitable. Dealing with the cost of nickel from the economic side, Dr. Everest said that for the extra 30s. per ton on their alloy product—nickel being reckoned at £175 per ton—they gained a greatly improved metal, and they could still obtain good quality with a cheaper base material. However, on the question of rejects alone they could effect a considerable saving in scrap which would counterbalance that additional cost, quite apart from a better quality casting. Regarding the method of adding nickel, for continuous production it should be put through the cupola, but for ordinary jobbing work added to the ladle. Ordinary nickel pellets should not be added in the ladle, being too large. It was preferable to use the special fine or alloyed form. It was also advisable to use ferro-chromium with a higher carbon content, because it was more easily crushed and the carbon gave a lower melting point. This ensured less trouble in distributing the chromium in the iron.

AUTHOR'S REPLY.

Replying to the discussion, **Professor Hanson** said he had no experience of nickel and chromium in malleable iron, but chromium did not strike him as a very suitable metal for alloying purposes with malleable, because of the stabilising effect of carbide, which was so pronounced. He was not so sure about nickel. Nickel would assist graphitisation, and to that extent would be good; and it would be retained in solution in the finished casting, and increase its strength. But there was a danger that in the presence of very low silicon it might introduce a stabilising effect on carbon below the critical range. Therefore it might not be suitable for black heart purposes, but it might possibly find application in the white heart process. Regarding unsoundness, he should not suspect nickel for any responsibility. Their experience was entirely in the opposite direction. Nickel additions to white iron which was unsound produced an improvement and removed the blowholes. As to the effect of nickel on graphite structure with the silicon unaltered, their own results had confirmed the investigations of American workers. This was that, generally speaking, nickel additions up to 2 per cent., or a little higher in some cases, showed a definite action in refining graphite; but beyond 2 per cent. these additions coarsened it. Hence, for all ordinary small additions of nickel to grey iron they could rely on nickel not to coarsen the graphite, but usually to refine it. They could not get the full value of nickel additions if the grain was open, and it was preferable to lower the silicon to secure the maximum benefit. Even if this was not done, they still gained an advantage by matrix hardening.

Continuing, Professor Hanson touched on losses, declaring that when alloys were put through the cupola there was no loss whatever of nickel, though if the cupola was run badly they might find the distribution irregular. Neither did they lose nickel when added in the ladle, nor in remelting scrap. Chromium losses were rather variable, ranging in some cases up to 30 down to 10 per cent., particularly when worked from the cupola. In the ladle they had experienced varying results, but as a rule they had noted very little loss. In the finely divided form great care must be taken to prevent the chromium dust getting into the cupola, otherwise there would be loss, and there was also danger of loss if the alloy was added in large pieces, especially when a low-carbon ferrochromium was used. It would not always dissolve, and gravitated to the bottom of the ladle. With reasonable precautions not more than a 10-per-cent. loss need be incurred in the ladle.

London Branch.

EVALUATION OF THE PROPERTIES OF CAST IRON FROM FORMULÆ.

By J. E. Hurst (Member).

Mr. Hurst said that, though the title of the lecture was a very wide one, namely, "Grey Cast Iron," it was desirable to confine attention to a particular aspect of the subject, and the particular aspect he wished to deal with was one which interested all thinking foundrymen. He proposed to deal with the attempt which had been made from time to time to devise some formulæ which would express a relation between the composition and the properties which one might expect to get from cast iron. It was a remarkable thing, very remarkable in many ways, that most of these attempts had been made by German investigators, and whilst he was afraid a good many serious-thinking English metallurgists were rather inclined to regard these formulæ with a certain amount of diffidence, the fact that the names of the German investigators associated with the formulæ were names which were highly respected in metallurgical circles made the formulæ all the more deserving of our serious attention.

Of the very concise formulæ that had been devised from time to time, probably the earliest one, and one with which metallurgists were very familiar, took the form of what might be called an equation. The formula was as follows:—

$$\mathrm{Sc} = \frac{\mathrm{C}}{4.26 - \dfrac{\mathrm{Si}}{3.6}}$$

This had received great attention in this country at the hands of that well-known investigator, Mr. Cook. In this formula the letter C represented the total carbon content, the Si represented the total silicon content, and the Sc was a "kind of co-efficient." It is difficult to trace the exact origin of this formula.

The earliest publication of it, of which he was aware, was in the first edition of that famous German handbook Hütte, and in the French edition of Hütte it was stated that C represented the percentage of total carbon, Si represented the percentage of silicon, and that the figure 4.26 corresponded to the amount of carbon in a cast iron free from silicon at the eutectic point. The figure of 3.6 in the formula was the percentage of silicon which diminished the saturation of the carbon down to 1.0 per cent. Presumably one must read into that statement that the 3.6 per cent. of silicon was the amount of silicon with which the eutectic point was moved to a point corresponding to 1 per cent. carbon. That was all the information given to us with regard to that formula, and it was very difficult to appreciate what is conveyed by the construction of the equation.

Key to Formula.

Indicating the manner in which the formula was used, Mr. Hurst said that a series of values were assigned to the co-efficient. Thus:—

For general castings, Sc = 0.9 to 1 per cent.

For loco castings, Sc = 0.8 to 0.9 per cent.

For internal-combustion cylinders, Sc = 0.76 to 0.85 per cent.

For ingot moulds, Sc = 0.9 to 1 per cent.

For rolls, Sc = 0.71 to 0.83 per cent.

For hard cast iron, Sc = 0.75 to 0.88 per cent.
He supposed that "hard cast iron" meant "chilled cast iron."

This was the complete list of these constants taken from Hütte, and he considered it advisable to give it because he believed that the list had not been commonly available up to the present. The value of the formula, or the inferential value of the formula, he indicated by applying it to the production of good satisfactory general castings, as an example. The percentage of total carbon was divided by 4.26 minus silicon content divided by 3.6, and that division gave a value of 0.9 to 1.0 per cent. The same remarks applied to locomotive castings, ingot moulds, internal-combustion engine cylinders, and to hard cast iron. He confessed his inability to explain the basis on which the formula was constructed, but the formula could be turned round into the following form:—

$$3.6\ C + (Si \times Sc) = 15.366 \times Sc,$$

When the formula was in that form one could see at once that it was equivalent to saying that the total carbon content plus the silicon content multiplied by a co-efficient was equal to a certain arbitrary co-efficient which varied according to the character of the material one was making. That was about as far as one could go. It was noticed, by turning the formula round, as he had done, that it involved the summation of the total carbon, plus silicon, which it was important to bear in mind. This formula, in common with all the rest, was open to the objection that it ignored the influence of manganese, sulphur, phosphorus, and thermal conditions (by which latter he meant the rate of cooling and the casting temperature). One might assume, however, that the range of variation in the co-efficient was sufficient to take care of any variations caused by the variation in other constituents not included in the formula, but he considered that was rather a bold assumption.

Without proceeding to consider the fallacy of the formula—and he considered that the word " fallacy " could fairly be used—it was necessary to point out that the practical value of a formula of that type was not very great. It seemed to him that it was equally as easy to remember a satisfactory composition or range of compositions for locomotive cylinders, rolls, or anything else as it was to remember the various co-efficients.

Another point with regard to this particular formula was that one could not help asking oneself the question, not knowing how the formula had been constructed, whether by any fortuitous combination of circumstances the formula was invariably correct and led invariably to satisfactory results. He believed all practical foundrymen would agree that if they used the formula they could not go far wrong. If, for example, one had a composition for general castings which, when the formula was applied, gave a co-efficient of 1.1 instead of 1—this difference was equivalent to the difference between the two limits—one would not expect to find that the general castings had very seriously deteriorated.

It appeared to be safe to say, therefore, that the results obtained by using the formula were not seriously wrong, but the point was whether the results obtained by the use of the formula were the very best that could be obtained in any particular case. Mr. Cook had given a good many examples from his extensive practical experience, and his experience had shown that this formula, so far as it had been applied, had invariably given him satisfactory results. Also he had been able to show unsatisfactory results in particular cases which did not comply with the formula.

He (Mr. Hurst) did not think there would be the slightest difficulty in showing equally as many cases of castings the composition of which did not comply with the formula, but which had still given satisfactory results in the particular type of work to which they were applied. As a matter of fact, in the case of centrifugally-cast piston rings, the actual composition which was specified did not comply with this formula, and it could not be denied that centrifugally-cast piston rings did generally give good results; indeed, it was generally admitted that they were the best. One might say that the objection was that they were cast centrifugally, but this discloses the fallacy of the formula, that it did not take into consideration the cooling conditions, and it was becoming more and more realised that the cooling conditions constituted one of the most important factors in the production of successful castings.

The Maurer Diagram.

Mr. Hurst then went on to deal with another concise expression of the relation between the composition and the character of the product, namely, the Maurer diagram, which was also of German origin. The diagram was not really new, but it was an application of an old method of representing the constitution of steels, which was dealt with ably by M. Guillet and M. Guillaume, and other investigators of about 25 years ago.

It was not very difficult, continued Mr. Hurst, to find among the mass of investigational work which had been done, numbers of cases which did not fit in with the diagrams. The diagrams did not take cognisance of manganese, sulphur and phosphorus, nor did they take into consideration the effect of differences in casting temperatures, and if one referred to some of the investigations of casting temperatures carried out by Hailstone or Hatfield one would find remarkable drops in the combined carbon content at certain casting temperature conditions without alteration in the total carbon and silicon content, and, therefore, without alteration of the position on the Maurer diagram, which latter depended on those two things. This showed that the diagram was likely to give false indications, because it left out of consideration the question of casting temperatures. It was generally realised that under perfectly stable conditions the whole of the structures of these cast irons would be the same, viz., ferrite and graphite, and it was largely due to the difference in rates of cooling that the structures which the diagrams attempted to represent existed at all.

Greiner and Klingenstein's Work.

Another diagram put forward by Greiner and Klingenstein, which was also German in origin, attempted to take the rate of cooling into consideration. The method adopted in this case bore a very close resemblance to another formula for cast iron, namely, the formula for the Perlit iron process. In the Greiner and Klingenstein diagram the thickness of the casting was indicated along the horizontal axis, and the sum of TC + Si on the vertical axis, as in the previous case.

Greiner and Klingenstein tell us that their diagram is applicable to cupola melted irons of not less than 2.8 per cent. of total carbon content (thus indicating a minimum), and operated at casting temperatures up to 1,450 deg. C. Presumably it was to be inferred from that statement that reasonable casting temperatures not exceeding 1,450 deg. C., made no really appreciable difference to the structural results obtained. The diagram was of similar type to that of the Maurer diagram, and followed upon the original method laid down by the alloy steel investigators, and it was open to the same objections.

The T.C.+Si Fallacy.

Dealing with the question of the sum of the total carbon plus silicon content, Mr. Hurst said that this was one of the points which was most open to criticism in connection with the various attempts at formulating a relation between the constitution of cast iron and its composition. We all knew that cast iron contained a large number of constituents, and any attempt to make a diagrammatic representation of the relation between the constitution and the variation of any one of that large number of constituents was a very difficult matter. In fact, it might be said that it was practically impossible to take cognisance of every constituent present in cast iron diagrammatically, and it seemed to him that the idea of adding together the total carbon plus silicon content was purely a sort of trick though probably it was justified. It was advisable to attempt to ascertain whether there was any reason why the summation of the total carbon plus silicon content should be used in the diagrams, and so far as he could see there was no reason from first principles why it should give satisfactory results. The practice of adding the total carbon to the silicon content embodied the assumption that within the limits over which the total operated, a reduction in one of the constituents, coupled with a corresponding increase in the other, should be accompanied by identical results. If we considered the Greiner and Klingenstein diagram and applied to it a silicon plus total carbon content of 5 per cent., that total could be made up in a variety of ways, always bearing in mind the minimum of 2.8 per cent. total carbon specified by the authors. The sum of the total carbon plus silicon might be made up of total carbon 3 per cent., and silicon 2 per cent.; total carbon 3.25 and silicon 1.75; total carbon 3.5 and silicon 1.5; total carbon 4 and silicon 1; or it might be made up in any other way. All these compositions were presumed to give exactly identical structural results, all other things being equal. Was it reasonable to assume that all those different ways of making up the total would give the same results, and was it in accordance with practical experience? We should be inclined to say that it was not.

T.C. and Si not Reciprocal.

This defect might also be regarded in another way, that the summation of the total carbon plus silicon content involved the assumption that the influence of silicon and total carbon on the structural constitution of cast iron were reciprocal, *i.e.*, that a reduction in the percentage of total carbon would have the same effect as would a similar reduction in silicon in changing the structure from grey to white, and, what was very important, that it did it in the same numerical value. Again, he did not think practical experience was in agreement with that. To put it in still another way, the variation in the amount of silicon produced an effect which could be balanced by the variation in the amount of total carbon quantitatively. There was no experimental evidence to support this; indeed, all the experimental evidence was to the contrary.

If the methods he had so far referred to of giving a concise interpretation of the relation between the structure and the chemical composition were examined along the lines he had indicated it would be appreciated that they did not take into consideration all the factors which we knew had an influence on the structure of the iron.

Thrasher's Diagram.

Another diagram, which from many points of view is the most satisfactory of the simple diagrams published, is that known as Thrasher's diagram. It was described originally in the American "Foundry" of December, 1915, and in view of its merit and its rationality it was worthy of more extended reference.

In this diagram (Fig. 1) the vertical axis indicated the silicon, and the horizontal axis indicated the total carbon.

The limit of total carbon content to which Thrasher's diagram applied was 2.4 per cent., and the limit of silicon was 1.2 per cent. Thrasher had, with remarkable intuition, indicated a line of further investigation by showing that with a $1\frac{1}{2}$-in. diameter test-bar this line became the mottled line. That was equivalent to saying that with a reduction in the section of the bar this average line was moved up into the position shown, so that it was safe to assume that as the bar was decreased in size from $1\frac{1}{2}$ to 1 in., one could draw a series of curved lines along the diagram and each line represented the average mottled condition with each par-

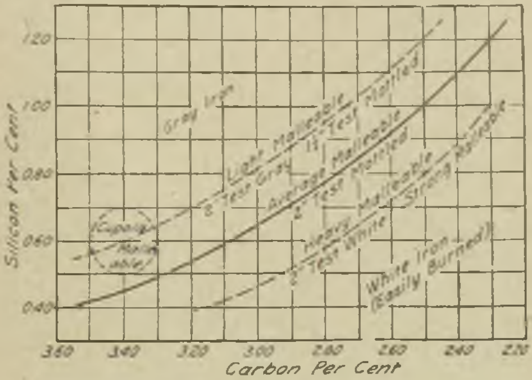

Fig. 1.—Diagram showing Lines of Equal Natural Chill (Thrasher's Diagram).

ticular thickness of bar. In other words, Thrasher had disclosed the method of relating the total carbon content, the silicon content and the thickness of the bar in a perfectly scientific fashion.

A complete survey of the rate of cooling necessitated a series of these curves for each set of conditions, and the curves were to be transposed in the upward direction for quicker rates of cooling, and in the downward direction for slower rates. The extent of the transposition was not necessarily in strict linear relationship; *i.e.*, the extent of the transposition from a 2-in. to a 1½-in. bar curve was not necessarily the same as that from a 1½-in. to a 1-in. bar curve. As a matter of fact it could be confidently expected that the curves would gradually come closer together. Within a very narrow range the effect of any variation and size could be detected by simple interpolation. He had constructed a diagram covering other sizes of bar from ½ in. to 3 in. in diameter, and he believed it would be of some value in determining the limits of total carbon and silicon content which would give the border line structures, which it would be agreed were those accompanied by the best results. As in all other diagrams, the influence of manganese, sulphur, phosphorus and casting temperature was neglected, and a multitude of similar diagrams would be needed to cover every possible condition.

He believed it would be found, if one examined diagrams drawn correctly to scale, that they gave results which were not very far from those obtained by practical observations. The diagram presented the relations in a more rational manner, and avoided the irrational summation of the total carbon and silicon contents. The personal experience of Mr. John Shaw, extending over many years, supported the statement that the figures given by the diagram are correct. For this and other reasons he considered that the diagram deserved extended examination.

Summarising the position, Mr. Hurst said it could safely be stated that whilst the German diagrams which had been put forward during the last few years might be expected to give truthful indications so far as they could be applied, *i.e.*, so far as we might assume the influence of casting temperature and the rest of the composition could be neglected, we in this country, and particularly iron-foundry metallurgists, should take a very strong line against this attempt to build up concise formulæ based on the summation of total carbon and silicon contents. All the evidence seemed to point to the fact that it was nothing more or less than a trick to enable a diagram to be constructed, and the trick had absolutely no justification in practice. He felt that British cast-iron metallurgists were very likely to be misled by the extent of the German support which had been given to the diagrams he had referred to.

DISCUSSION.

Mr. Wesley Lambert (President-Elect of the Institute), after expressing indebtedness to Mr. Hurst for presenting so comprehensive a review of the various formulæ and diagrams, said that in earlier days, when he was more directly interested in cast iron than he is to-day, he had made use of a formula, not referred to by Mr. Hurst, which took into account the effect of manganese, and he believed phosphorus also. Unfortunately, at that time the microstructure of cast iron was not examined so critically under the microscope as it is to-day, but, so far as one was able to judge, this early formula was fairly reliable. We are certainly indebted to those pioneers who attempted to put forward something in the way of either formulæ or diagrams.

The examination of a large group of analyses of cast iron was rendered difficult by the multiplicity of figures, whereas by the use of a diagram the constituents of an iron of a particular composition can more readily be determined. He quite agreed with Mr. Hurst that anything based merely on the summation of the total carbon and the silicon content was very weak, and for that reason a diagram such as the

Thrasher diagram represented a great advance on the earlier efforts. It had occurred to him that it would be possible to construct a diagram with a sliding panel to correct for thickness of section. He asked if this had been done.

Mr. Hurst said it had not, but it might be done with advantage.

Mr. Lambert added that with such a sliding panel one could readily correct for differences in thickness of the iron, and it seemed to him that with the addition of a sliding panel the diagram would serve a very good purpose. To-day he was more particularly interested in manganese bronze, and that, like cast iron, was a very complex material, and anything in the way of determining the microstructure solely by means of diagrams or a simple formula was out of the question. Thanks, however, to the researches of Guillet, one was able, by means of a series of simple calculations, to determine fairly accurately the microstructure of these complex brasses, but, unfortunately, the same method of calculation is not readily applicable to cast iron.

Mr. H. C. Dews, in a tribute to Mr. Hurst for his interesting and instructive review, said that it must lead metallurgists to think a great deal about these diagrams and formulæ, and to crystallise many ideas which might have been more or less nebulous in their minds. He agreed with Mr. Lambert that we were in debt to the early pioneers who had the courage to attempt these diagrams, even though subsequent research had shown how fallacious were most of their conclusions. It was, perhaps, gratifying to know that the formulæ and the diagrams which were of German origin were the ones which Mr. Hurst had most severely condemned. Lately they had had before them a repletion of German work, and there had been a tendency in the British technical Press to laud rather too highly a good deal of that work. They all appreciated much brilliant work that had been done by German investigators, but at the same time some very specious work had been published in Germany, not only lately but for a good many years. They should not get into the habit of overlooking the work of British metallurgists in favour of foreign work. Mr. Hurst's reference to the straight-line law was worthy of the very deepest consideration by metallurgists, foundrymen, and all who studied technical questions. There was too great a tendency to try to conform results to a straight-line law. Scientists knew full well that practically no natural phenomena obeyed a straight-line law. In considering specific heat, thermal conductivity or almost any other property of materials they found the variation with temperature, etc., to be not linear but parabolical, and they should try to remember that when considering diagrams with straight lines. Mr. Hurst had warned British metallurgists to be wary of relationships based on the summation of total carbon and silicon contents. It was a coincidence that in a Paper presented to the Iron and Steel Institute this autumn by a British metallurgist—and he believed the Paper had the backing of a group of British cast-iron metallurgists—there were a number of diagrams which were based entirely on total carbon and silicon contents. In view of what Mr. Hurst had said, it would be interesting to hear the view of those associated with this Paper.

Mr. A. Gibbs, having spent a good deal of time that afternoon trying to understand a diagram in a Paper in which the total carbons and silicons were grouped together, and having failed to appreciate its import, agreed heartily with the remarks of Mr. Hurst, Mr. Lambert, and Mr. Dews in regard to this matter. In the Paper by M. Louis Piedbœuf,* which was the Belgian exchange Paper of 1926, the Maurer diagram was included. On the horizontal axis was given the thickness of the casting and on the vertical axis the silicon, and there were not the discrepancies which Mr. Hurst had referred to. The diagram in Mr. Piedbœuf's Paper was easy to understand, and therefore we ought not to agree to the adding together of the total carbon and silicon. With regard to the formula from

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* Proceedings, I.B.F., Vol. XIX., p.92.

Hutte, to which Mr. Hurst had referred, he suggested that it was used a little more than Mr. Hurst had seemed to imply. The figure of 4.3 was given, and there were figures to prove that something was going to occur above 4.3 which would not occur below or at 4.3. Above 4.3 apparently there existed a different state of affairs altogether, and it would have been rather enlightening if Mr. Hurst had worked out some further figures; he had given the maximum and the minimum silicon in one case, and it would have been interesting if he had reversed it and had given the maximum silicon and the minimum of carbon. If that had been done he felt sure there would have been some variations in the results. Certainly we should not condemn Maurer for his attempts to produce a useful formula, for there was no doubt that he had done some very fine spade work.

Dr. M. L. Becker, referring to Maurer's diagram—which he believed was brought out considerably later than Thrasher's diagram, the date of the latter being about 1915—said he did not think it mattered very much, from the point of view of the use of the diagram, if one did add the total carbon to the silicon. If, for instance, instead of plotting the sum of the two, we plotted the product, we should then get a diagram consisting of a series of curves instead of straight lines. He believed it would be found that if these two diagrams were plotted from the same data (the one diagram showing the sum and the other the product of the total carbon and silicon plotted against thickness of section), the type of fracture determined from either would be practically the same. To carry the matter a little farther, if one plotted $\sqrt{\text{total carbon} \times \text{silicon}}$, one would obtain a further diagram consisting of curves.

There again one would obtain similar results. When working within a limited range of composition, as specified, no matter whether one took the sum, product or square root of the product of the total carbon and silicon contents, one would not be very far wrong provided one used the appropriate form of diagram. He quite agreed, however, that there was no real reason why we should say that irons having the same sum total carbon and silicon should necessarily graphitise at the same rate.

Vote of thanks.

The Branch-President, proposing a vote of thanks to Mr. Hurst, expressed indebtedness to him for having so kindly consented to lecture to the Branch, though at great inconvenience to himself. Further, his Lecture gave to the members a great deal of food for thought, and they were all very grateful to him for all he had done for them.

Mr. V. C. Faulkner (Past-President of the Institute), seconding the vote of thanks, said that the Institute as a whole was deeply indebted to the lecturer for his ready willingness always to place at their disposal his great metallurgical and practical experience. He wondered whether it would not be better for the practical foundrymen to utilise the list of compositions as given by Mr. Field for the various applications of cast iron, or an earlier one published in The Foundry Trade Journal, as these were based on wide practical experience, instead of memorising a factor which had later to be translated into percentages, but still leaving the choice of at least three elements to the discretion of the foundrymen.

The vote of thanks to Mr. Hurst was carried with acclamation.

AUTHOR'S REPLY.

Mr. Hurst, after expressing his appreciation of the vote of thanks, and his pleasure in having another opportunity to lecture to the Branch, said that apparently most of those present had given a good deal of thought to the diagrams he had referred to, and appeared to concur generally in the conclusions he had expressed. He believed that what was giving the metallurgists considerable concern in connection with cast iron to-day was the fact that whilst the old method of working strictly and rigidly to fracture had disappeared, and he believed had been definitely displaced by working to composition, there was difficulty in reconciling the fact that the same composition does not always give the same results. Mr. Hurst disclosed an example of two piston-ring drums identical in shape, thickness and chemical analyses, differing only in diameter. These two castings showed very great differences in mechanical properties.

The vital point, however, upon which metallurgists must concentrate for the benefit of foundrymen was that of explaining why a casting made in an Italian foundry did not give the same results as one made of the same composition in a French foundry, or why a casting made in Peterborough did not give the same results as a similar casting of the same composition made in Sheffield.

Mr. W. Lambert said in the case of piston rings one had to consider the shaped article rather than the metal *per se*, and he asked Mr. Hurst if he was satisfied that the state of internal stress in each casting was the same. All the figures which had been given were, of course, influenced somewhat by the initial state of stress in which the metal of the casting happened to be as a result of the rate and method of solidification of the metal. Nothing had been said with regard to the microstructure, nor had anything been said as to whether when rings taken from each of the two piston pots were machined and split each and every ring sprang open or closed in to a like degree.

Mr. Hurst replied that there was nothing abnormal whatsoever. It was part of the procedure in all the piston-ring tests to note any opening or closing or any movement of the gap formed immediately on cutting. In the case of the rings he had exhibited there was no sign of internal stress whatever. The difference in test results was such as would not generally be detected in ordinary foundry testing, because ordinary foundry testing, in his view, was not sufficiently delicate. If one found half a cwt.

difference on a transverse bar in the foundry, one did not worry much about it. It was considered as an " as-cast " bar, and the dimensions were not strictly accurate as in the case of piston-ring testing. .

He mentioned all this to show that the diagrams did not take into consideration many of the vital factors which went to make up the properties of cast iron, and to draw attention to the fact that in spite of our notions on control by composition there is yet some other factor we have not traced, and which composition does not thoroughly explain.

Scottish Branch—Paisley Section.

THE POUMAY CUPOLA.

By J. Cameron (Past President).

The CHAIRMAN (Mr. George Mackay), in introducing the lecturer, said that they were pleased to welcome Mr. Cameron to the Paisley Section, he was a Past-President of the Institute of British Foundrymen, had travelled extensively in America, India and the Continent, and he would be able to tell them how Scottish foundries compared with foundries in other countries. They were to listen to a Paper having special reference to the Poumay cupola.

MR. CAMERON said that it was a pleasure to make his first appearance at a meeting of the Paisley section, and to have a little talk on cupolas. He said that more ingenuity had been displayed in attempting to improve the cupola than in any other department of foundry work. He had recently been reading Kirk's book on the cupola, and found it most interesting, he strongly recommended them to obtain that book as it gave an excellent idea of the development of the cupola as a melting apparatus. Mr. Cameron then showed a large number of slides to illustrate the development of the furnace. He showed the large variety of tuyeres and blast arrangements which had been tried at various times, and also the different types of construction of the cupola. He pointed out that two main ideas were evident in all these early attempts, viz., more perfect combustion of the coke and a better utilisation of the heat within the cupola, and that many of the tuyeres were designed with the idea of obtaining a gyratory motion of the air as it entered the cupola, and also to admit supplementary air supply above the main inlets. All these attempts led up to the Greiner cupola in America, which was really the same as the Poumay (Fig. 1). Mr. Cameron said that there was really no patent in the auxiliary tubes or the use of tuyeres to give the air a gyratory motion, anyone was free to adopt them, but Poumay had combined both these very old ideas, and his patent was for the combination. Figs. 2, 3 and 4 show views of the Poumay cupola.

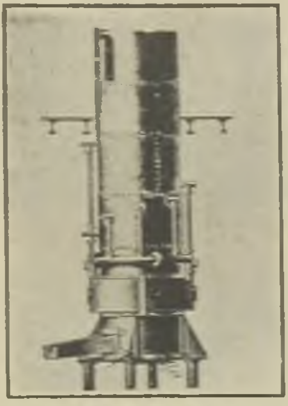

Fig. 1.

His experience of this cupola was that it was at the moment the most economical to be had; it melted quickly and cheaply, dropped clean and required very much less repairs and saved hundreds of pounds a year in the coke bill.

Tables I and II show the coke consumption in an ordinary cupola and a Poumay, each doing

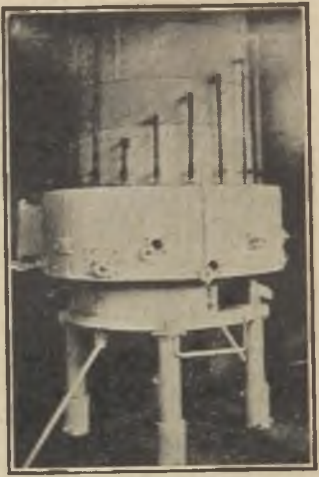

FIG. 2.

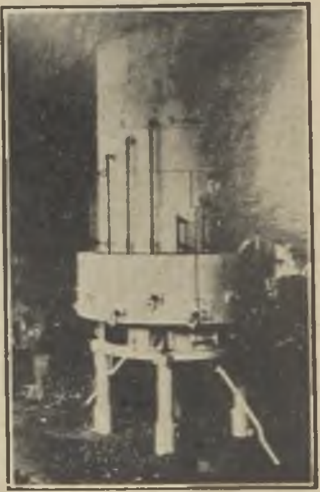

FIG. 3.

exactly the same work on alternate days, and each of 54 in. dia. at the melting zone.

Table III showed the analyses of the gases from the same two cupolas. Tables IV and V showed the tapping temperatures and the metal analyses respectively. He found that the Poumay metal was hotter and freer from sulphur than in the case of the ordinary cupola.

He found that the 54-in. dia. Poumay furnace melted too quickly to deal with, as his work was entirely light castings, so he reduced the diameter to 51 in. at the melting zone. The coke consumption and tapping rate of the reduced Poumay compared with the full-sized ordinary cupola is shown in Tables VI and VII.

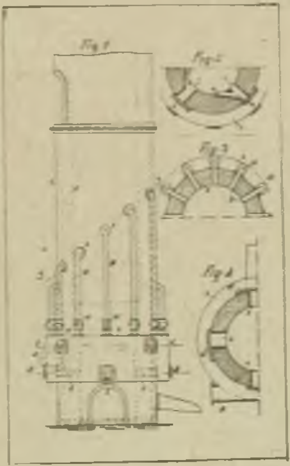

Fig. 4.

Mr. Cameron emphasised the fact that the Poumay cupola required very careful adjustment if success is to be attained. He stated that it was essential that the blast be properly adjusted as regards volume and pressure, and that a volumeter was a necessity. The Poumay was extremely sensitive to changes in conditions, and everything must be correct if good results were to be obtained. He had, as the chairman mentioned, travelled a good deal and seen many varieties of cupolas. He said that it was amazing how some of the furnaces worked at all, let alone gave satisfactory metal. It was

Table I.—*Comparative Coke Consumption per cent. of Coke used to Metal Melted, excluding Bed Charge in each case.*

Before alteration.	After alteration. per cent.
Approximately 10 per cent.	7.3
	7.0
	7.5
	6.8
	7.2
	7.0
	7.4
	6.7
	7.3
	7.5
	Average 7.17

Table II.—*Comparative Tapping Rates. Diameter of Cupola 54 ins. at Melting Zone, not altered when Cupola was converted.*

Rate per hour.	
Before alteration.	After alteration.
Tons per hour.	Tons per hour.
10.7	13.9
10.75	13.2
10.0	13.7
10.9	12.9
10.2	13.1
10.3	13.0
10.8	12.5
10.5	12.7
10.3	13.5
10.7	13.1
Average 10.52	Average 13.16

impossible to play tricks with the Poumay cupola, if it was to work well everything must be just right. The bed had to be exactly the right height, and everything weighed or measured, and especially the air. The Poumay really required humouring until in the best condition. He found

TABLE III.—*Analyses of Cupola Gas Sample taken at Charging Door.*

Carbon dioxide.		Oxygen.		Carbon monoxide.	
Before alteration.	After alteration.	Before alteration.	After alteration.	Before alteration.	After alteration.
per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
12.3	18.0	0.4	0.2	10.5	0.15
13.0	17.6	0.2	0.4	10.1	0.10
12.7	18.4	0.4	0.7	10.9	0.10

TABLE IV.—*Comparative Metal Temperatures. Average Readings taken every ½ hour of run in each case.*

Ordinary cupola temperature deg. C.	Poumay cupola temperature deg. C.
1,291	1,339
1,333	1,340
1,320	1,352

TABLE V.—*Analyses of Metal Tapped on Consecutive Days from No. 1 Cupola and Poumay Cupola.*

Per cent. sulphur.	
No. 1 cupola.	Poumay cupola.
0.069	0.041
0.073	0.059
0.064	0.055
Average 0.068	Average 0.052

Difference, 0.016.

once or twice that it worked well and then fell off a good deal, and it was necessary to readjust things. Mr. Cameron concluded with a statement and explanation of the claims of the Poumay Patents.

TABLE VI.—*Comparative Coke Consumption per cent. of Coke used to Metal Melted, excluding Bed Charge in each case.*

Before conversion to Poumay type (54 in. diameter).	After conversion to Poumay type (51 in. diameter).
	per cent.
Approximately 10 per cent.	6.74
	6.67
	6.57
	6.34
	6.46
	6.73
	6.66
	6.76
	6.61
	6.74
	Average 6.63

TABLE VII.—*Comparative Tapping Rates. Diameter of Cupola at Melting Zone,* 54 *inches before conversion,* 51 *inches after conversion.*

Rate per hour.	
Before conversion.	After conversion.
Tons per hour.	Tons per hour.
10.7	12.8
10.75	12.85
10.0	13.45
10.9	12.9
10.2	12.95
10.3	13.05
10.8	13.2
10.5	13.1
10.3	12.95
10.7	13.0
Average 10.52	Average 13.03

DISCUSSION.

The Chairman said that he thought that all present would agree that they had heard a most interesting and instructive lecture from Mr. Cameron. He had shown a large selection of cupolas and tuyeres from which they could choose what they thought best for their own work. He thought that the most interesting point was the quick melt and low coke consumption which all foundrymen desired. Mr. Cameron had spoken from knowledge and experience and they were very much indebted to him for his lecture. He hoped that during the discussion full advantage would be taken of the opportunity to obtain first-hand information on any points they wished to mention.

Mr. Hurst said he had heard a great deal about the Poumay cupola, and had heard opinions favourable and unfavourable about it. Personally, he was not quite convinced, and would not care to say that it was so much better than any other cupola without studying it at work. He quite agreed that the cupola was the heart of the foundry, and it was for that reason that he thought very careful study and consideration was necessary before accepting all that was claimed for the Poumay. He would like to know the nature of the charge of 30 cwts. which Mr. Cameron stated he used. Was the scrap light, heavy or medium? What proportion of the charge was scrap, and what kind of pig-iron was used?

He had a small furnace 30 in. dia., and he could run a six-ton melt at 3.1 tons per hour with a coke consumption of 8 per cent. This came very near to the Poumay result. The Poumay would, as Mr. Cameron had said, require a greater amount of care and supervision, and he would like to ask Mr. Cameron if he though it would pay him to instal the Poumay. He was, at present, not convinced that it would.

He was interested to see the Stewart rapid cupola shown on the screen, as at one time he was with the firm who made it. They cut the pipe out of their own cupola, yet they sold them with the pipe. They also tried the sheet tuyere, which gave a complete circle of blast, but they had great trouble with bridging. Splayed tuyeres, they found, were of no advantage, and they tried to solve the difficulty by splitting the wind-belt in two.

He had tried many experiments with the Stewart cupola; the sheet casing was reduced at the melting-zone and later altered so that the whole stack tapered from the top to the bottom which gave rather better results. At that time the cupolas were made with three rows of tuyeres, but in their own foundry the top row were stopped up with ganister.

In the Whiting cupola they had a wide space between the tuyeres, which he disliked if they were splayed very much on the side. He altered them so that they were splayed both ways and also upwards and downwards; this gave a much increased speed of melting, and it was also unnecessary to use the very best coke.

He had been interested in seeing the tuyere in the furnace which was used for semi-steel as recommended by McLain. He would like to ask Mr. Cameron if he thought that the successful working of that cupola was due to the downward direction of the pipe, which allowed the blast to take more head, like a tuyere, to deflect the blast downward a little. The flame at the top of the furnace would depend upon the pressure of blast and the height of the door from the tuyeres. It was necessary to regulate the blast in order to get the full benefit of all the oxygen going into the cupola.

Mr. Cameron, in reply, said that he appreciated such criticism. He liked to meet a man who was not afraid to experiment with his cupola, and he recommended every member to do the same if the cupola was not exactly as they would like it to be. By experimenting and taking expert advice and guidance in the matter he could assure them that they would be well repaid.

He agreed with Mr. Hurst as to the downward deflection of the blast—undoubtedly the success of the cupola he had mentioned was largely due to the downward inclination of the tuyeres. He admitted that a cupola having a single row of tuyeres with the blast properly controlled and measured and other factors carefully adjusted was very hard to beat. He also agreed that in a cupola of 36 in. dia. it was easy to get the air to the centre and that the tuyeres should be splayed more in order to ensure a soft and non-oxidising blast. He thought that if Mr. Hurst was working with a coke consumption in the neighbourhood of 8 per cent. and in a 30-in. dia. cupola it would not pay him to instal the Poumay system.

Poumay Cupola and Semi-Steel.

A Member: Is the Poumay cupola suitable for melting semi-steel?

Mr. Cameron said he had never used the Poumay when he melted semi-steel, but that was not on account of any fault in the cupola. He always melted 10-cwt. charges for semi-steel so that the whole charge could be tapped separately, and in the Poumay, 30-cwt. charges were necessary. He had made inquiries from certain people who had told him semi-steel could be successfully melted in the Poumay.

Mr. Davis said that as a moulder interested in the cupola end of the foundry he had listened with much pleasure to the paper. He was impressed by the strong claims made for the Poumay cupola with regard to fuller use of the calorific value of the coke: hotter metal, less fuel for melting, and the quicker rate of melting. He asked Mr. Cameron if the Poumay was suitable for all classes of work, and whether it would be equally successful if employed on a smaller scale than that used by Mr. Cameron. He would like to know if the Poumay system could be universally applied to all cupolas.

Mr. Cameron said that in his foundry there was no heavy work done; it was entirely devoted to light castings. He thought that for heavy work it would be necessary to have a receiver on the cupola in order to collect the large quantity of metal. As to whether it was suitable for small cupolas, he believed that his own was the largest that had been tackled at the time he adopted the Poumay system. He thought that if less tuyeres were put in, the system was quite suitable for small cupolas, say 3 ft. dia.

Mr. T. Bell said he was inclined to think that the Poumay cupola would not be profitable in a shop smaller than that of Mr. Cameron's, owing to the small quantity of metal to be melted. The economy of coke affected by Mr. Cameron was not to be doubted, but if instead of a melt of 50 tons daily they had, say, only 7 tons daily, would the same percentage of coke hold good and would the benefits be proportional? He had had the privilege of seeing Mr. Cameron's cupola at work and had stood by throughout the melt, and was much impressed with what he then saw. He noticed, however, that the pig-iron was larger than he would like to put in the cupola and the scrap was of a fair size. Everything seemed to him to be economically carried out. He could not agree with Mr. Cameron that a receiver would be necessary for heavy work if, as stated, the cupola melted 13 tons per hour, it would be quite an easy matter to gather the metal in the ladle in a couple of hours or so for most of jobbing shop requirements. It was no unusual thing to have to hold the metal in the ladle for a couple of hours even when the metal was not nearly as hot as that obtained at Mr. Cameron's foundry. He would hesitate to advise the raising of the blast belt so as to hold metal in the well; this might involve raising the charging door and would also increase the bed coke. He would like to refer to Mr. Cameron's statement that he preferred one row of tuyeres and ask why he did not use one row in his own cupola. The Poumay which Mr. Cameron said was the best and last word in cupolas had two rows of main tuyeres.

Mr. Cameron, in reply to Mr. Bell, said that perhaps he had not been very clear in his statement about the receiver. He had no experience of very heavy castings, as his work was mainly light, such as pipes, where the metal was required to run a long distance and only about $\frac{1}{8}$ in. thick. He also meant to say that the ordinary cupola with straight lining and one row of tuyeres was excellent and hard to beat. He extended a cordial invitation to any member of the Paisley section to visit his foundry and see the Poumay cupola at work; he or his foreman would be only too glad to show them everything.

Scottish Branch.

MONEL METAL.*

By W. McCulloch (Associate Member).

The President of the Scottish Branch of British Foundrymen, Mr. Longden, made mention in his Presidential Address that there was no difficulty in securing the services of highly competent men to lecture to the Institute on the theoretical or academic side, but it was very difficult to induce men who were actually engaged in practical moulding operations to state their views and experiences in the form of a paper. Speaking for the average moulder, it is not with the object of trying to hide or keep everything to oneself, but rather a feeling of one's inability to put one's views on paper.

For many purposes castings are required having higher physical properties and greater resistance to corrosion than the usual brass-foundry alloys. For such applications, the best all-round commercial alloy to-day is probably Monel metal. This is a nickel-copper alloy, containing approximately 68 per cent. nickel; 29 per cent. copper, together with iron 2 per cent. and manganese 1 per cent.

Particularly for castings which have to withstand the high temperature and severe conditions of superheated steam, Monel metal has become the standard metal. Valves, seats, pump-impellers, turbine parts, etc., in Monel metal can be handled satisfactorily in the ordinary brass foundry, with only such special equipment and special care and precautions required by its high melting-point and considerable shrinkage.

Melting Monel Metal.

For making sound castings, special attention must be given to the melting. The melting point is 1,360 deg. C., and the pouring temperature about 1,500 deg. C. The molten metal

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* Slightly abridged.

readily absorbs carbon and sulphur, the latter from the furnace atmosphere, which is injurious to the metal; therefore careful attention must be given to the handling of the metal in the furnace or crucible, as well as in the mould.

The quality of the casting depends greatly upon the quality of the metal put into the furnace, and difficulty may arise in the re-melting of headers, risers, etc., if these have absorbed carbon or sulphur in the previous melt. Monel metal can be melted successfully in graphite crucibles and in brick-lined electric-arc furnaces.

Melting time in the pit fire furnaces, with a 250 lb. charge, is two hours. It is necessary to have a good draught in the furnace to obtain the high temperature. The empty crucible is inserted into the pit fire and brought to a bright red heat. It is then lifted out and a new bottom of coke inserted into the fire; then the crucible is replaced in the fire and coke charged round the sides.

First 1½ lbs. of manganese ore is charged in the bottom of the crucible. This is put into the crucible to keep out carbon and form a good slag. This is followed by the small scrap, which is placed immediately on the top of the manganese ore; finally the ingots are placed crosswise on the top of the crucible. The whole charge of metal is inserted into the crucible at one time, and is placed in such a position that no coke, or practically none, gets into the crucible. The furnace is now filled to the throat and the fuel allowed to burn down. The crucible is then eased up and a new bottom put into the fire. This is essential, otherwise the crucible will be cold at the bottom and the desired temperature will never be attained. The fire is charged once more to the throat and allowed to burn down. The last charge should bring down the metal ready for pouring. It is important that all the operations be carried out rapidly and no time lost. The time taken for melting never exceeds two hours. The weight of coke nuts used averages about 1 cwt. 1 qr. 18 lbs. per charge.

When the metal is melted and raised to the required temperature for casting, 2 lbs. of silicon are added. This acts as a deoxidiser, and is charged about five minutes before withdrawing the crucible from the furnace. Immediately after adding the silicon the metal should be stirred quickly with a rod or skimmer, to make sure that the silicon is thoroughly melted. Before pouring, further deoxidation is necessary, and this is carried out by the use of metallic magnesium.

Magnesium Deoxidation.

Generally 5 ozs. of magnesium is added to every 250 lbs. of metal. It is desirable to make part of this addition, say about 2 ozs., immediately before withdrawing from the furnace. The best method of applying the magnesium is on the end of an ordinary $\frac{3}{8}$-in. malleable iron rod. The magnesium is supplied in 1-in. round bars, which are cut into lengths weighing one or two ozs. each; a hole is bored in the magnesium, and the point of the iron rod is inserted into it. This bar is then plunged to the bottom of the crucible. It is important to do this, otherwise it will burn on the top of the metal. When the metal has been withdrawn from the furnace, which should be done quickly, add the remainder of magnesium, an amount varying from 2 or 3 ozs. The crucible should then be skimmed clean of any slag, which, being of a sticky nature, adheres to the side of the crucible and the skimmer. After a little experience, one can easily tell by visually examining the metal, through blue glasses, when it is properly deoxidised. It can be seen to change colour, gradually assuming a greenish tint.

A suitable test of the success of deoxidation is to pour a small test-bar, say $\frac{3}{8}$ in. by $\frac{1}{2}$ in. by 6 in. If the metal has been completely deoxidised, this bar, when cold, will bend through 180 deg. on a radius of about $1\frac{1}{4}$ in. without cracking. The deoxidation causes the metal apparently to lose its fluidity; therefore it must be poured quickly. All ladles or crucibles used for transferring metal should be pre-heated to conserve heat in the metal.

Melting should not be prolonged beyond the time required to reach the necessary temperature, but it is essential to have in the metal sufficient heat to cover transference losses associated with transporting the metal from furnace to moulds. Unless this is controlled the metal is liable to show cold sets or misruns.

When increased fluidity is necessary for making thin sections, a higher silicon-content is desirable. Silicon also adds strength and increases the hardness of the metal. The tendency to hot shortness, however, increases with high silicon, and is decreased by high manganese. Practice must be so controlled as to avoid formation of graphitic carbon in the metal, which makes it brittle.

Measurement of High Temperatures.

It would be very helpful if one could measure the temperature of Monel metal quickly and accurately. Unfortunately there is no apparatus which can do this economically. Optical and radiation pyrometers are available for high temperatures, but they only measure the heat or light radiated from the surface. The accuracy of the reading is very much affected by the presence of slag and also by the conditions of the test. Metal inside a furnace shows quite a different reading from metal in the open air; even though the temperature is the same in both cases.

Accuracy demands an immersion pyrometer for molten metal, and for ordinary foundry work speed is a necessity. This in turn necessitates the use of a bare wire couple. Such couples are available up to about 1,250 deg. C., but for temperatures in excess of 1,300 deg. C., no couples are yet commercially available.

Oil Furnace Melting.

The average time for melting 250 lbs. of Monel metal in the oil furnace is from 1 hr. 45 min. to 2 hrs., 2 hrs. never being exceeded. The oil consumed for the average heat is 15 gallons, whilst the air pressure at 60 lbs. is used. A test piece was cast from every heat, and so far the author has found only a trace of graphite present in the metal in about two or three heats out of 60 casts. It is also noteworthy that the number of heats from the crucible used in the oil furnace is exactly the same as those used in the pit fires—namely, 14.

Moulding.

The practice followed in making sand castings of Monel metal is similar in some respects to steel foundry practice, and in others to iron or brass foundry technique. The methods of moulding, gates and risers necessary for feeding, very strongly resemble those of steel. The extreme care in moulding and ramming is similar to that used for the non-ferrous metals, the shrinkage being $\frac{1}{4}$ in. to the foot. Cores must be collapsible, to allow free shrinkage of the metal.

In moulding, no general rule can be given, as every pattern is a law unto itself. Headers and risers must be placed so as to feed the casting well and suppress shrinkage cavities. Sometimes it is best to feed the casting directly from the top; in other cases to feed it from the side, but no definite rule can be enunciated. The one characteristic to be kept in mind when moulding especially large and complicated castings is the shrinkage of the metal, and every precaution and care must be taken to allow the metal to shrink without being held in any way by the sand, such as avoiding freezing through a narrow neck in the riser. To fill the mould with metal, or to get a solid casting, this shrinkage must be taken care of by ample feeding through large sink heads and risers. Special care must be given also in moulding patterns which have abrupt changes in cross section. Ample fillets should always be used, and as far as possible sharp corners should be avoided.

Take an ordinary flange or cover with a boss on it, say 8 in. at the bottom, 4 in. at the top, 1 in. thick at the bottom flange and 4 in. deep at the top, cast with the boss uppermost with a fillet at its base. After the casting is stripped, one invariably finds practically no fillet at all; in fact, if it is cast with the first of the metal, when the temperature is high, or if the metal is not properly deoxidised, or again if the riser is rather small, one finds the casting drawn right under the angle at the base. Thin sections should be avoided on account of liability to misruns. Monel metal is sensitive to gas from core-binders, therefore this material should be kept to a minimum. An open sand should be used.

Dry-Sand Monel Metal Castings.

Castings weighing over 1 cwt. are generally made in dry sand—that is, whenever they have to be proof under pressure. If they have not to withstand any pressure, then latitude is given. Small castings are made in green sand, principally Belfast sand. In making green-sand castings, the moulder has his own rough and ready method of testing the sand. He rubs it between his finger and thumb in order to ascertain its texture or grain-size; then he squeezes a handful in order to test the bond or strength—not a very scientific way perhaps, but still very useful when associated with experience. Care must be taken not to work the sand too wet, and if the sand is of a close nature it is desirable to make it vent freely.

The author once made two castings in green-sand, each weighing about 50 lbs. One was made in Belfast sand; the other in rock sand. This was done to determine the difference between Belfast and rock sand when used as a mixture for facing. Both were cast green without any skin drying, just a little plumbago being brushed on the face of the mould. The casting produced in the mould made from the Belfast sand had a very good skin, but the one made in the rock sand was very rough.

The moulds are finished in the usual way, dressed with a little plumbago, but very little, and cast green, except when there is quite a large body of metal in the casting; then the mould should first be sprinkled with molasses water, plumbago brushed on the face of the mould, dusted with resin, and skin dried with a blow or gas lamp. All ornamental work is cast green without any skin drying.

When ramming the sand around risers, care should be taken to have it as soft as possible. When it is too hard the metal will not lie quietly, with the result, if there are two or more gates in the one box (which is very common if the best results are sought), the metal bubbling or blowing off the hard sand will roll into the next gate. Although it is only ⅛ in. in diameter, and it is followed up quickly by pouring metal into the same gate, the little ball, or pile of metal, will not melt and become part of the casting, but remains on the bottom of the mould, to fall out of the casting while dressing, or it may make a cold shut.

The casting temperature of Monel metal being high, the layer of sand forming the face of the mould is generally burned; therefore, the addition of new sand to the facing mixture balancing the discarded burnt sand is necessary. The object of the new sand which is added to old sand in order to form a mixture for facing consists in supplying to it whole grains which induce aeration and fresh bonding material, which, after being suitably prepared, restores cohesion.

Gates and Risers.

The feeding riser is a moulding tribute to shrinkage or contraction, and, from a moulder's standpoint, is necessary for the production of good, solid castings in Monel metal. From the engineer's view, it is a necessary evil. Time and again founders have been told that the casting has neither shape nor form. According to the nature or shape of the castings when moulding, it is often necessary to cut off parts or pare the mould to suit to overcome the shrinkage, resulting in the condemnation that it is the worst-looking casting that one could make. According to a contributor to the recent discussion on steel castings,* all holes are blow holes,

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* Page 651.

or non-metallic inclusions, when in reality they are neither, but just " drawn " holes. Contraction is a decrease in the volume of a metal body, and is common to all metals and alloys, though not necessarily to the same degree. Between a light and a heavy section adjoining each other a severe rupture or cleavage may take place by the setting strain, the thin section cooling or freezing first; the heavy section, if it is not provided with a riser or feeder, when solidification takes place, will tear or crack away. Cases exist where, because of conflicting conditions, the metal has to be poured above or below the temperature at which its shrinkage is least expressive.

Castings, as, for instance, a disc 24 in. dia. by 2 in. thick, to be solid throughout, require a feeding riser. The distance from any one circumference pouring gate to the centre of the disc, and on to the extreme opposite point from this pouring gate, is too great to be completely dominated by the gate feed. This casting would need more feeding if cast horizontally. It would require three or four feeding risers, and if one is placed in the centre, it would require to be higher and heavier. The better method, then, would be to be cast vertically.

For a disc 12 in. dia. and 1 in. thick, with a solid hub 3 in. high in the centre, the casting could be run either from the circumference or from the hub, but in neither case could it be depended upon to control shrinkage in the hub; a feeding riser on the hub would be necessary.

The best pouring point is not always the best feeding point. It is sometimes necessary to put the riser on the side of the casting, which is used as a gate. Always have the basin or header about 1 in. from the casting, and on no occasion have it any farther away.

In side gates or risers a gate pin-hole often develops. A heavy riser or upright stack set over the gate, close to the casting, will supply and deliver a feeding quota of metal and obviate the pin-holes. It is bad practice in Monel metal to have too many castings connected with the one gate, for two reasons:—(1) It will be impossible to feed all the castings alike, the one nearest the pouring basin standing the best chance of being solid; the farthest away develops a pinhole on the gate; and (2) in gate-cutting it is very awkward to get the saw blade in position, or the casting in position to suit the saw or gate-cutting knife.

Risers should be high, heavy and hot, and in direct and unbroken communication with the shrinkage loss. They should be placed as close as conditions will permit to the freezing zone, which is usually the centre of mass in the casting. Metal flowing from a mould into a riser is obviously colder in the riser than in the casting, and will naturally freeze quicker, which is the improper order for feeding, the correct condition being achieved by pouring hot metal back in through the riser into the casting whenever possible.

A riser (exhibited) illustrated the shrinkage of Monel metal. It was cut from an ordinary suction-valve seat, 14 in. dia., solid in the centre, having nine or ten 1½-in. dia. holes. In this head was seen the little beads which form when the metal passes from the liquid state into the solid, and which past experience has shown to be desirable, as it is usually associated with good metal beneath.

Fig. 1 shows a casting 2½ in. dia., 12 in. long, cast vertically with no feeding head. This was cut right through to reveal the draw, which is fully 70 per cent. of the full length; the same casting, when surmounted by a tapered head, was solid throughout, except for about 3 or 4 in. at the top. The third is a different kind of casting, with the same tapered head, and is also solid throughout, yet the draw on the head is about 25 per cent. of its full length.

Fig. 2 shows the same casting as Fig. 1 (left), but cast horizontally with a cut gate. The upper sample was cast with the first of the metal out of the crucible, and resulted in the top being irregular and the presence of a draw-hole. The other half had the draw-hole right up through the top. The lower specimen was cast with the last of the metal, and is sound throughout, except for some irregularity at the top. Monel metal is similar to aluminium inasmuch as that the higher the casting temperature, the greater the draw. This has been proved many times by casting two or more castings from the first and then the last of the metal in the crucible, the last generally proving the soundest casting. This is the reverse from gunmetal, wherein the lower the temperature, the greater the draw.

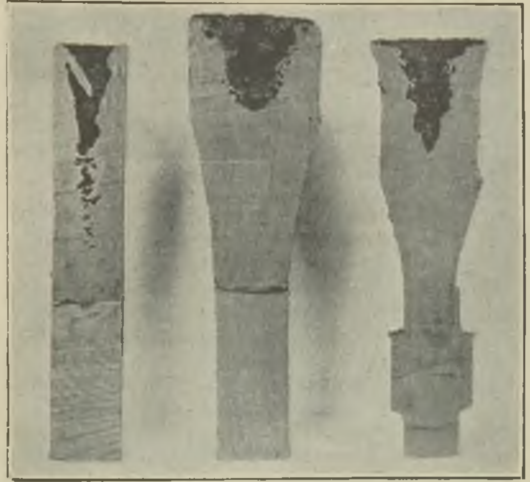

Fig. 1.—Showing the Necessity for Feeding Heads.

Nozzle Segments.

Fig. 3 shows a nozzle segment, which is a very important part of the turbine arrangement. It provides the means by which the steam passes from the steam-chest or valve-chamber to the blading. The blades or veins in the nozzle are set at a suitable angle, so that the most effective use may be made of the steam pressure. Initially this casting gave a great amount of trouble, owing to the light character of the blades associated with the heavy rim. If it was cast at a high temperature to ensure that the blades would run, then there was trouble from drawing on the flange. If, on the other hand, the temperature was kept low, then there were

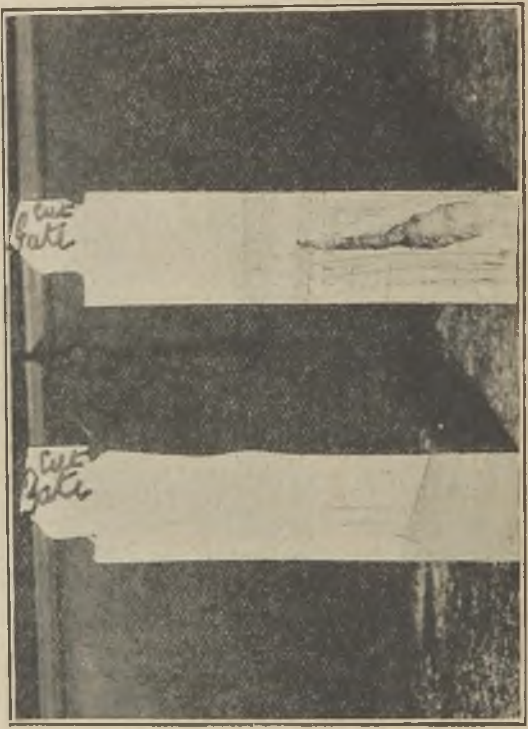

FIG. 2.—AS FIG. 1 (LEFT), BUT CAST HORIZONTALLY.

cold-shuts and misruns in the blades. All these segments were cast in green-sand, with the gate at the end. A core is made with a gate cut in it; this is first dried and then placed on the pattern near the bottom and rammed up in the box. This gives a good, clean gate with the metal running into the blades near the bottom of the mould. This method ensures against misruns or cold-shuts in the blade owing to having a supply of metal flowing up the blades until the mould is filled.*

Impellers.

The author's firm manufactures a wide range of impellers. These are generally run from the bottom, although at times it was found necessary to run them from the rim. These castings are usually made in a three-part box, the metal being poured at the side. The gate is 1 in. dia., which leads into the channel at the bottom. There are either one, two or three inlets at the bottom of the casting, according to the size and shape. The centre riser is generally about 6 to 9 in. deep; the diameter varies according to the size of the impeller, with three or four feeding-risers, about 3 in. by 1 in., on the

FIG. 3.—NOZZLE SEGMENT IN MONEL METAL.

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* The riser is in this case on the side of the casting with a heavy feed from the top. This casting is always cast on the "bank." When the mould is filled pouring is stopped; the gate is then covered with sand, and a weight put on the top; then hot metal is poured into the riser, which should be from 6 to 9 in. high, according to the size and weight of the casting. Since adopting this method the author rarely has a bad nozzle segment cast in Monel metal.

outer rim. This forms one main riser, which feeds the centre and the rims at the same time. The making of the moulds is comparatively easy compared with the confection of the cores.

The core (Fig. 4) is made up in sections of eight or ten, according to the number of blades in the impeller. These are then assembled together, care being taken that each blade is of the correct size and thickness. They are bound together with a piece of wire on the outside diameter and at the bottom print. The blades are required to be as thin as it is possible to cast them.

Fig. 4.—Core for Impeller Castings.

After they are assembled, each core is inspected before being placed in the mould. One way of doing so is by using a ball—an ordinary $\frac{1}{16}$-in. ball, such as is used for bicycle ball bearings. This is then passed through the spaces

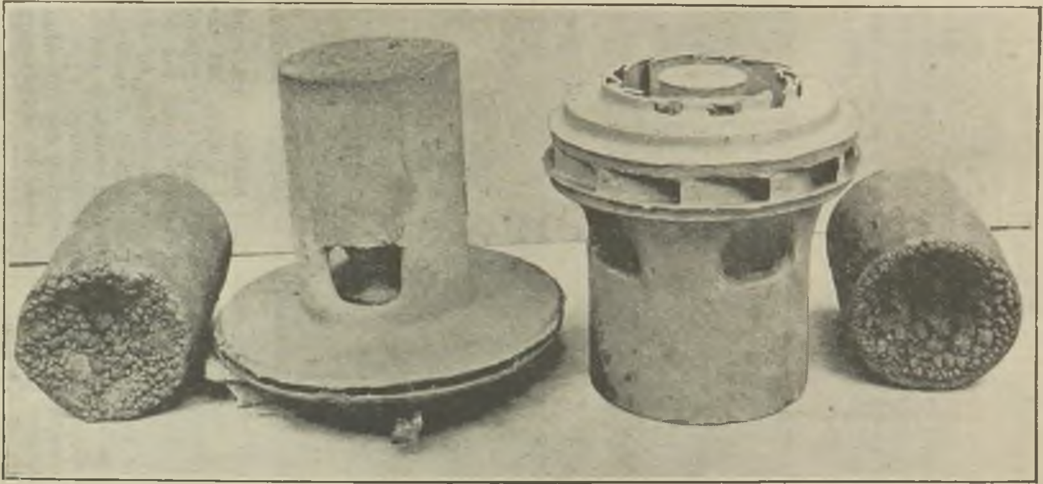

Fig. 5.—Two Types of Impeller Castings with Risers.

provided for the blades. Some of these blade cores are about 12 in. long, 2 to 3 in. broad, $\frac{1}{8}$ in. thick or deep. At first there was great difficulty in providing a sand against which the Monel metal would lie. On no account must the metal "simmer" against the core, but, on the contrary, must lie absolutely quiet; so a core has to be made so free and permeable to gases that the only path the gases could take was back in and through the core.

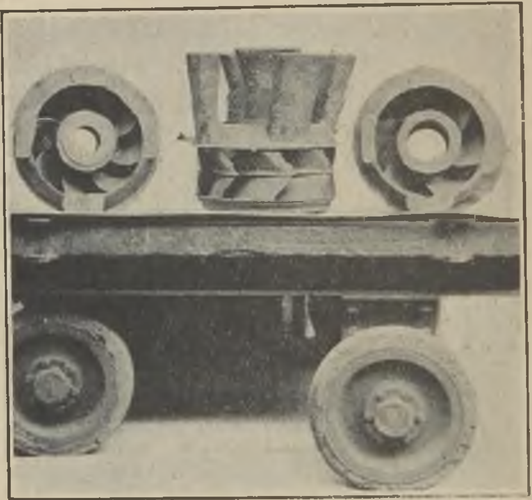

FIG. 6.—A HEAVIER TYPE OF IMPELLER CASTING.

Small cores are made from Scotch silica sand bonded with a proprietary oil binder, but the majority of impeller cores are made from ground ashes, Belfast sand, with glutrine or the oil binder. Some of these cores, according to the size of the impeller and the method of casting, have to be tied down; therefore provision has to be made in the core before assembling.

The ordinary loam, as used every day for other non-ferrous castings, will never be satisfactory for Monel castings. It will not lie against it, as the surface is too hard.

Closing and Casting Impellers.

In closing the impellers great care has to be taken that the core is resting on the print all the way round. Should it encroach $\frac{1}{16}$ in. at any one blade, then the blade, being just that $\frac{1}{16}$ in. thick, when the top part is placed on the core, would twist—only that $\frac{1}{16}$ in., but sufficient to make it a bad casting. Care must be taken to have all the vents free, and provision made either through the joint of the box or up through the top. Since adopting Monel metal for impellers the author has cast over three thousand. There is a record kept of every impeller, date cast, and a serial number on each.

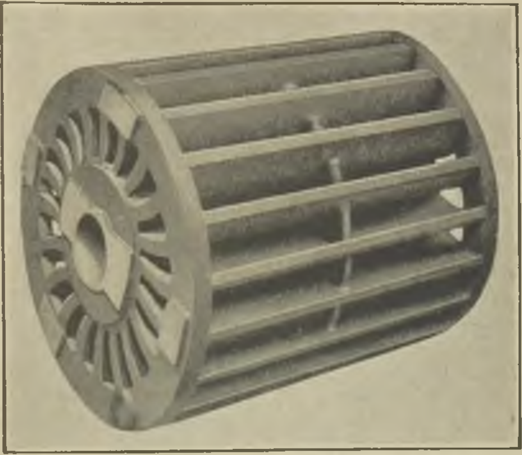

FIG. 7.—CAST MONEL-METAL PADDLE WHEEL, MADE FOR A CONTINENTAL SUGAR REFINERY.

Fig. 5 shows two impellers, with a riser on either side; the impeller on the right is comparatively easy to make as compared with the other casting, as the latter has a thin core. The two heads are shown to illustrate the draw, but, unfortunately, their depth is hardly shown.

Fig. 6 is a different type of impeller, larger and heavier. The blades are $\frac{1}{8}$ in. thick, the core space between each blade being greater. They are easier to make, being run from the bottom with three inlet gates—one on either side of the rim and one at the centre boss. Provision is made for tying the centre core down through the drag. The riser being the full size on the centre boss, the core is cut away at the top; the core-box is made to suit. Each casting requires 4 cwts. to cast, including risers.

Paddle Wheel for a Sugar Refinery.

This casting (Fig. 7) was run from the bottom. The blades, 20 in number, were all made from one core-box supplied by the customer, which, whilst closing, were all placed hard up to one another. Nineteen cores filled the mould, and there was still another to be inserted. The blades being all the same thickness, it was necessary to take them all out and file or card fully $\frac{3}{16}$ in. off each core. This is just one of the many things that foundrymen have to do about which the customer knows nothing. The thickness of the metal on the hub was about 2 in. The casting turned out extremely well, in spite of all the trouble expended in preparing the mould. The weight of the dressed casting was 6 cwts. 1 qr. 21 lbs., but the metal melted, including gates, runners and feeding risers, was $7\frac{1}{2}$ cwts.

Propeller for Steam Yacht.

The propeller shown in Fig. 8 was made for a luxurious yacht. It was made and cast similar to those cast in bronze—swept up from spindle and strickle, only it was run from the top of the boss. The owner, who was refitting his yacht and desiring something bright and enduring, stipulated Monel metal. The four bollards, when being cast, each took about 7 cwts. All the deck fittings were made of this metal, even the ship's bell, which had a beautiful tone.

Fig. 9 illustrates a pickling raft, cast in high-silicon Monel metal. This high silicon increases the fluidity and the hardness of the metal. The casting was 8 ft. long and 3 ft. broad. It was cast with the plain side down. The drag was made in dry-sand. The casting was in the top part, and was made in green-sand for two reasons:--(1) The drag, being in dry-sand, eliminated all possible chance of scabbing or sand being washed in at the gate; and (2) taking into consideration the length of the casting (8 ft.) and the contraction ($\frac{1}{4}$ in. to the foot), provision had to be made to let the casting creep in 2 in., a factor too important to allow of any

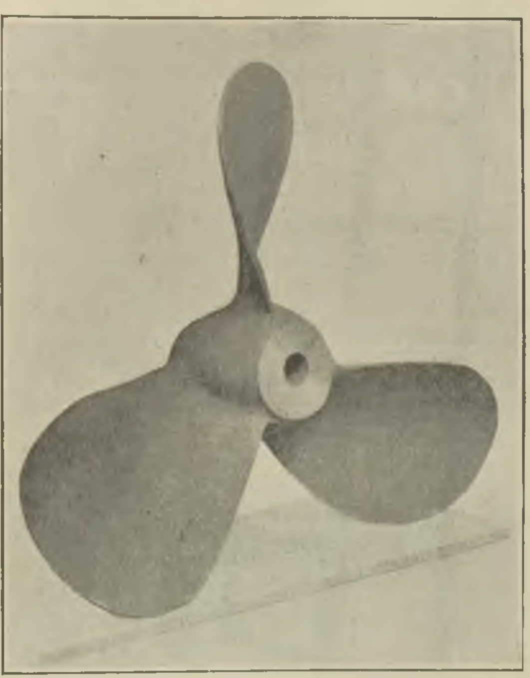

FIG. 8.—PROPELLER FOR PRIVATE YACHT.

risk of the casting being held in a dry-sand mould.

The casting was run from the side and at both ends, a gate being placed on every arm. Immediately after the casting was set, the operatives slackened around the risers and the gates, lifted

Fig. 9.—A Pickling Raft, cast in Monel Metal.

off the top part, and loosened all the sand between the arms. The weight of the dressed casting was 7 cwts. 12 lbs., whilst the metal melted, including gates and risers, totalled 10 cwts. Six crucibles were used for this cast, and one test bar was taken out of each, with the results shown in Table I.

High-Tensile Bronze.

One outstanding fact of brass founding as compared with iron founding is the great difference in the cost of the metal going into the moulds. A pound of good-quality cast iron costs ½d. per lb. in the ladle, as against non-ferrous alloys which may range from 4d. to 1s. 6d. per lb. A foundry waster in cast iron may not amount to much, whereas a similar waster in some of the non-ferrous metals involves a greater loss of profit.

TABLE I.—*Variation in Tensile Properties of High Silicon Monel Metal.*

	Yield stress.	Maximum stress.	Elongation.
	Tons/sq. in.	Tons/sq. in.	% on 2 in.
No. 1 ..	24.24	38.04	18
,, 2 ..	26.80	37.92	15
,, 3 ..	25.20	37.52	16
,, 4 ..	27.40	36.00	11
,, 5 ..	25.50	38.48	20
,, 6 ..	27.00	39.00	17

Generally speaking, non-ferrous alloys call for greater care and accuracy at every stage. In a foundry, melting materials ranging from aluminium to Monel and pure nickel, constant care and supervision are required during moulding, melting and pouring, whereas with cast iron, once the cupola conditions have been established, charging and tapping proceed almost automatically, yet every crucible of non-ferrous alloy requires individual attention, especially with regard to the correct temperature for casting.

In ordinary Admiralty gunmetal, liner-metal, mercantile gunmetal, brazen metal, the author seldom, if ever, takes the temperature before casting. It is surprising how near one can approach to a defined temperature when doing it day after day, yet for special bronzes, aluminium alloys, it is the author's practice never to cast without first taking the temperature with the pyrometer. Neglecting the correct casting temperature is quite sufficient in itself to bring about a waster casting.

Different grades of manganese brass can be made, depending on the purposes for which they are required. Owing to their peculiarities, these alloys are rather difficult to handle in the foundry. The high liquid-contraction and shrinkage must be allowed for by means of risers and large feeding heads. This is one of the many alloys used for pumps and propellers, and in places where strength and resistance to corrosion are of paramount importance. An alloy similar to this has been specified and used successfully for locomotive axle-boxes.

The method adopted for manufacturing this high-tensile bronze is to melt it in crucibles and cast into ingots, re-melting these again for pouring into the moulds. The usual procedure is to place the iron at the bottom of the crucible, which is generally supplied in pieces from ½ lb. to 1 lb. weight; ferro-manganese and copper next, adding the aluminium and zinc after the crucible has been taken out of the furnace.

A mixture of copper, special spelter, ferro-manganese, aluminium and iron, if properly manufactured, should give a test bar of the following mechanical properties:—Yield point, 24.80 tons per sq. in.; tensile strength, 40.64 ton per sq. in., and elongation, 21 per cent. on 2 in.

Pump Casings Cast in High-Tensile Bronze.

If only one or two of these castings, weighing from 5 to 6 cwts. each, are urgently required, they are generally cast either from the tilting furnaces or pit fires; but the normal method is to utilise the air furnace, which is put into commission as soon as there are 3 to 7 tons of pump castings on order. Gates, heads, runners, etc., when being remelted, are always mixed with about one-third of new metal, as experience has shown that it ensures consistent results.

High-tensile bronze has a high surface-tension, due to the formation of an oxide film on the surface. Attention must therefore be paid to gating and running, otherwise laps may be formed, due to the two streams when meeting may not unite perfectly. The casting temperature employed is 1,000 deg. C.; below 960 deg. or above 1,020 deg. C. is undesirable.

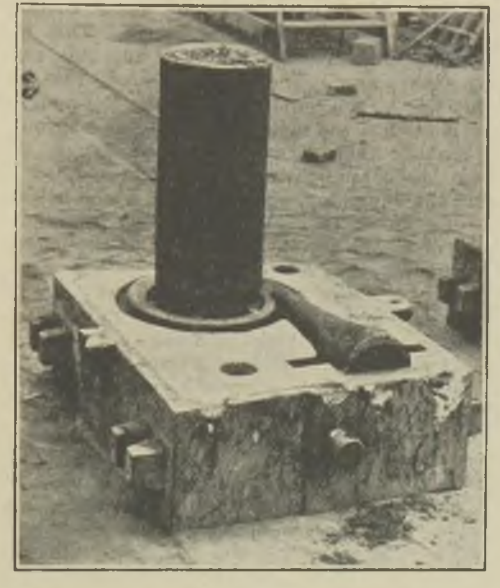

Fig. 10.—Mould for Pump Casing.

Fig. 10 shows a mould for a pump casing, with the core placed in position ready for the top part to be placed on. These are always made in dry sand, and run from the bottom flange, the gate being placed in such a position that the metal is flowing into the flange, the inlet being about 1 in. deep, 2 in. broad; and for a heavy casting, where the metal has further to run, the gate is made proportionally deeper. A heavy riser is put on the flange, and the main or centre part of the casting is "riser all around." Difficulty was experienced with some of these castings through leakage at the side flange. This was invariably in the bottom side or the side cast-down, the cause being, as was found, that the flange was at the opposite end from the pouring gate, and that the metal flowing in and through the mould, when it came into the flange, was at too low a temperature. Chills were tried all round the flange and on both sides, which helped, but did not cure. What was needed was a means of escape for the dull metal at the bottom of the flange and its replacement by hot metal, therefore a false "flower" was cut at the bottom of the flange (see Fig. 15), which cured it completely. In making fresh patterns for these castings, the pattern-maker provides the necessary risers from instructions received from the foundry.

Before closing on the top, the head box is placed in position, and all heads and risers are then made up. A strainer-gate tin is used for the gate, which keeps the mould clean and provides a means for filling up the head. In moulding these pumps, the practice is to ram them up on a board, making a parting at the top of the flange. The drag is then placed on and rammed up. When parted off the gate is cut, the pattern drawn and the flange finished. The drag is then replaced, and the whole turned over. It is made in the same way as one would make a pulley-wheel in a two-part box, which eliminates the use of a middle part. Of course, the size of the casting is the determining factor.

Fig. 11 shows the core, which is made from as poor a sand as it is possible to use, so that when solidification takes place it will collapse. The sand as used for the cores is as follows:—Ordinary core sand (generally made from ground ashes and rock sand), 60 per cent.; ordinary floor sand, 30 per cent., and sharp sand, 10 per cent. This sand is so poor that if any of the cores become damaged, it is almost impossible to repair them.

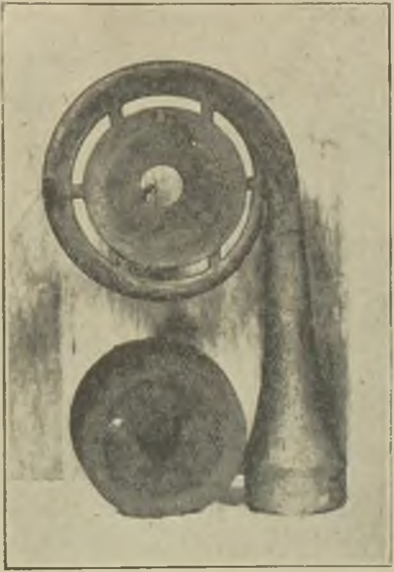

Fig. 11.—Core for Pump Casing.

The core-box is made in halves, but to facilitate closing a parting is made underneath the volute; so to be correct, the core is made in three parts, with a loam-core placed on the top to go through the riser. In Fig. 11 can be seen the spaces that are provided, through which the metal has free access to feed down to the bottom of the casting. This is done purposely—provision being made for it in the core-box. These are machined out into the volute in the engineering department. The space is never any more than from ¼ in. to ½ in. in depth. The core iron is made from ⅛ in. round iron.

Closing.

In closing the boxes, the bottom or drag core goes in first, then the volute is placed in position, care being taken that it is in its proper place, lying exactly level according to the shape of the mould; then the loam core is placed in position. After the top-part is finished, a 56 lb. weight (or more if necessary) is placed on top of the core to keep it in its proper place whilst pouring.

Fig. 12.—Pump Casing showing Method of Running.

When casting, as the ladle proceeds from box to box, an operator takes the temperature of every casting separately, and a record is kept of every casting made. When the boxes are emptied, but before the castings are removed to the dressing shop, they are typed with a serial number, so that if any casting is returned five or ten years hence, it is possible to ascertain date cast; mixture of metals used; temperature; job number; pattern number, and also the identity of the man who closed the mould.

Fig. 12 shows one of the castings, weighing 10 cwts. 2 qrs. 1 lb., including head. Note the false or French " flower."

In Fig. 13 is shown a large pump casing of a different style. Two castings were made off this pattern. They were made in practically the same manner as has been described. The heavy strengthening ribs around the volute, from the designer's point of view, were essential, but for the foundryman were a source of trouble and anxiety. However, all the difficulties were overcome with chills at the fillets and feeding risers on every rib.

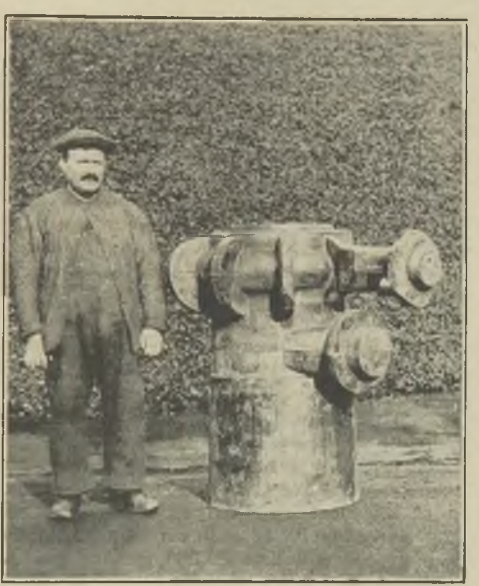

FIG. 13.—PATTERN FOR PUMP CASING.

The core also gave some difficulty owing to the design, but after consulting with the manager of the machine shop, a part of the core was cut off, this being later machined out in the engineering department.

During closing much care had to be exercised; the cores being made of the "poor" sand made it difficult during bolting down. Whilst making the cores, provision was allowed for this by leaving a 3-in. hole right through all the cores and the drag. A 1 in. bolt was passed through the whole; the complete box was lifted up by the crane, the bolt then placed in position, screwed down from the bottom, and placed on a bed and cast. Each casting weighed over two tons, including risers, but after the gate and runners were removed; the pouring temperatures of the two castings were 1,000 and 990 deg. C. They were tested to 2,250 lbs. per sq. in., the usual test such castings are subjected to, ranging from 700 lbs. to 2,250 lbs. for special castings.

These large pump casings were made to the order of the Commonwealth Edison Company, for the Crawford Avenue Power Station, Chicago, one of the biggest power stations in America. The largest one extant is in New York, and is called Hell's Gate.

Each pumping set consists of a steam-turbine-driven rotary-pump, delivering to the suction end of an electrically-driven multistage rotary pump, the capacity of each set being 500,000 lbs. per hour, or equal to 50,000 gallons per hour, against a discharge pressure of 540 lbs. per square inch. The horse power is 525, and the number of stages in the electrically-driven pump is 3. The shaft runs at 3,600 r.p.m., whilst the steam-driven pump is a single-stage type, and runs at 5,000 r.p.m.

It is something that British foundrymen should be proud of, that after many refusals in America they came to Britain to have these special castings made.

It is six years since the author started the system of keeping a record for this particular metal, and during those years he has cast 1,141 pumps in high-tensile bronze. During the last two years, from December, 1926, to December, 1928, 284 were cast. There have been ten bad castings and one spoilt in the machine shop.

In presenting this paper and the accompanying figures, it is not suggested that the methods used at Cathcart are the only ones, or even the best. However, an endeavour has been made to outline some of the methods and the results obtained there. In conclusion, the author would like to express his sincere thanks to the directors of Messrs. G. & J. Weir, Limited, and Monel-Weir, Limited, for their kind permission to publish this paper; to the management; and to Messrs. Arnott, Johnston & Bannister for their valuable assistance.

Newcastle and Scottish Branches and Lancashire Branch (Junior Section).

SOME INTERESTING MOULDING JOBS.

By E. Longden (Member).

If it were possible for the high-class jobbing moulder to translate his knowledge and experience into either written or spoken words, there would be rendered available an endless and a most interesting fund of material for the proceedings of the Institute and the industry which it serves. Due to the reticence and inability of most moulders to record their experience in any way and the great difficulty of adequately describing moulding operations, the Institute meetings suffer from a preponderance of technical, scientific and theoretical work. Much of this work is of the highest value, and the Institute is indebted to the authors, but it really lacks work of a practical nature which can be placed before the members.

Those who have close contact with the foundry must realise the extraordinary amount of mental and physical energy required of the competent moulder when making large and intricate castings. It is to his great credit that failures in heavy work are on the average below 2 per cent. A more frequent exposition of the art of moulding would also aid the technical and scientific foundry worker to a better understanding of the value of the practical moulder's work, as perhaps the relative importance of the moulder and coremaker has sometimes been lost sight of. Ninety per cent. of the efficiency of any foundry is dependent upon the trained moulder and the machinery and tools placed at his disposal. Let this type of labour fail, and there is an end to one's competency as a founder, whether it be in ferrous or non-ferrous castings.

The Papers and lectures delivered to branch, and particularly annual, meetings of the Institute are 80 per cent. scientific and theoretical and 20 per cent. practical foundry work. This percentage should be reversed. But, unfortunately, the training of the moulder and foreman will only occasionally allow us to learn of the moulding of castings. This state is not the fault of the scientific and technical lecturers, but the unfortunate effect of the call of the trade upon the mental and physical energy of the moulder. There can be no more exacting form of mental strain in any calling than that existing in the minds of the moulder, foundry foreman or manager when a large mould is being filled with metal.

A Large Centrifugal Pump Body.

Unfortunately, the author has been unable to secure a photograph of the finished casting, or of any stage in its manufacture, and in describing moulding operations one is immediately in difficulties. Photographs of moulding operations can never convey to the reader sufficient detail of construction, but by a series of sketches one is able to lend, as it were, an X-ray eye to the person in search of the real details of a mould construction. The following description should present as much information to the non-practical man, who may be more versed in the study of drawings and details as to the practical man who cannot always follow out his work when placed before him through the medium of a drawing. Fig. 1 shows sufficient drawing details to allow a reasoned statement of the requirements for pattern-making and moulding. A pump of the size outlined will deliver 400 tons of water per min. expelled through the 60-in. outlet from which the size of the pump is taken. The casting weighs a little under 7 tons. The general drawing dimensions determined by the pump engineer and draughtsman are, for obvious reasons, omitted. The bearings N in Fig. 1 and the dotted circle indicate the relative size of the impeller, which is about 78 in. dia.

Since the usual order is for one-off only, it is prohibitive expense to construct a full pattern

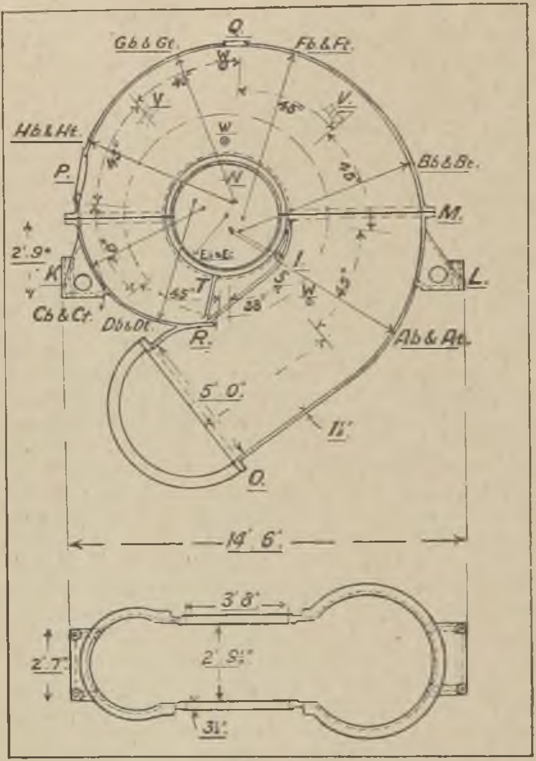

FIG. 1.

and core-boxes. The pattern-maker must, therefore, resort to the provision of sweep or strickle boards and those portions of pattern to shape sections of the casting which cannot be produced by strickles. The drawing shows that the pump body is made in two pieces, a top and a bottom, whilst the pattern work is described for both halves the practice for loam moulding, the bottom part only will be outlined. The top is produced in a similar manner, much of the tackle made for the bottom half being later used for the top half.

The series of strickle boards, sketched in Figs. 2 and 3, depict by Ab and At and Hb and Ht the various sizes of strickles required. If the drawing is studied the code letters will show from which point each strickle board is used. For instance, Ab and At are used to describe an arc of 45 deg. when working from the centre shown. With the exception of the strickles to form the bearing N and marked Eb and Et, and the straight section from Ab, At to the 60-in. outlet flange, the strickles are used to describe an arc of 45 deg. It is possible to economise in

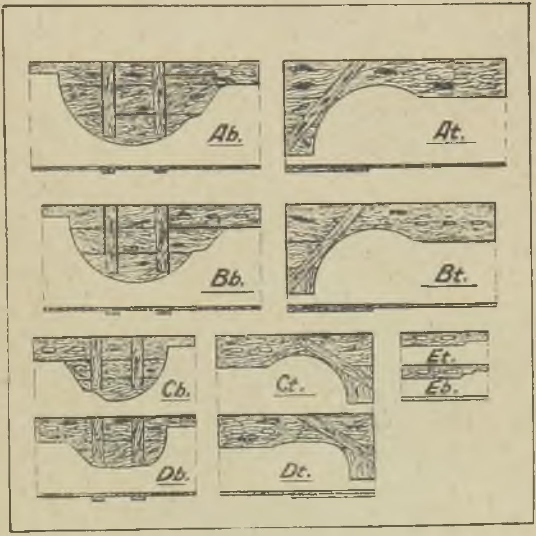

Fig. 2.

timber by cutting down the large strickle boards to serve for the smaller sizes to the extent of perhaps 25 per cent. It is obvious that Ab, At, Cb and Ct, used for striking up the bottom casting, must be retained to strike up a portion of the mould for the top casting.

Fig. 4 describes the necessary loose pieces of pattern and core-boxes used in conjunction with the strickles. The code letters again indicate for which purpose or portion of the casting they are made. K and L form the feet of the casting, and are constructed so as to allow the core to be made from inside the pattern work. The small core-boxes X, Y and Z are additional core-boxes required to complete the coring of the feet; M is the large flange, which is used to attach the two halves of the casting together; N forms the heavy bearing; O the 60-in. flange; P and Q, handholes; R the plough-like section which, along with sections S and T, form deflectors or baffles

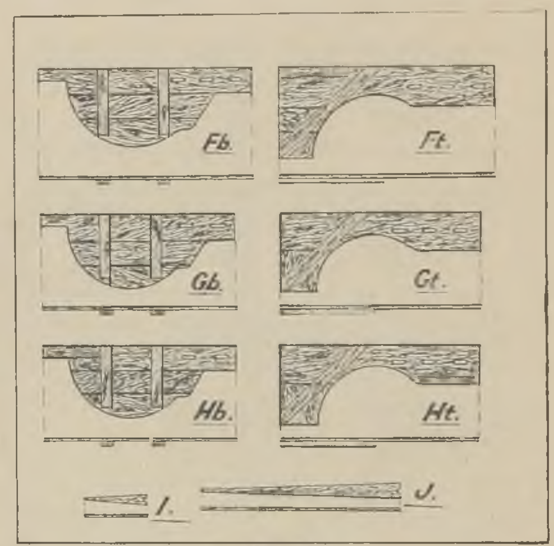

Fig. 3.

for the water being expelled; U is a small core-box, out of which $1\frac{1}{8}$-in. by 3-in. thicknessing cores are made; V, lifting lugs; and W, bosses. Having traced out the pattern requirements, one can now describe the work of moulding the casting.

Moulding the Bottom Part.

Before commencing to mould the job, much thought must be given to the requirements to produce the casting. The wise moulder endeavours to visualise his work from beginning to end. With such a casting it pays for the moulder in charge of the job and the pattern-maker to consult for quite a day before actually beginning to lay out the tackle for moulding. Since the designer has decreed that the pump body must be made in two pieces, instead of, as one might hope, in four pieces, the moulder must proceed to produce his casting. The principal

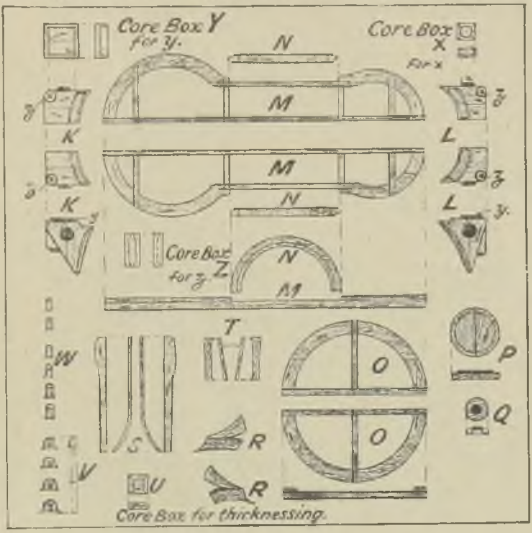

FIG. 4.

risks and difficulties lie in the thickness of $1\frac{1}{8}$ in. in relationship to the shape.

Obviously, the casting is comparatively thin for the great area, and it would be impossible to construct a core which would collapse sufficiently to allow a shrinkage of nearly 2 in. on the casting without special preparation and precaution. The core must necessarily be strong to allow of handling, and so constructed to enable a quick freeing of the casting after pouring.

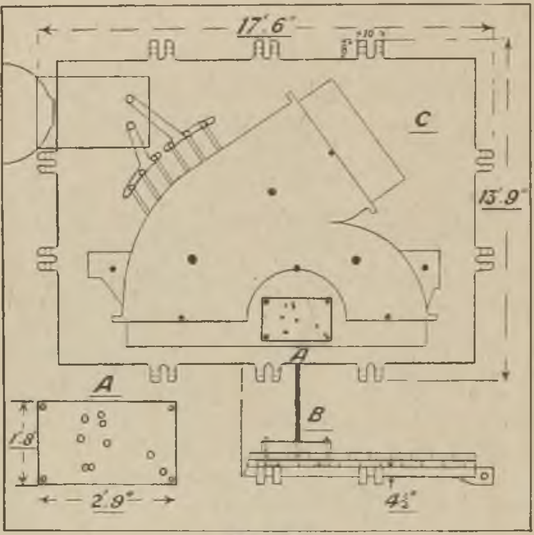

FIG. 5.

A strong bottom-plate, as outlined in Fig. 5, is made. A layer of bricks is set in black loam over the whole face of the bottom plate. Then the jig plate, A, containing nine centres, as described on the drawing, Fig. 1, is firmly located into the position shown. It is then good practice to chalk out on this first layer of bricks the outline of the casting and core prints, position of bearers leading up from the bottom plate and used for supporting the heavy core, runner and riser positions, and even the position the metal ladle will occupy during pouring, should be described in the outline. It is within the author's knowledge, and no doubt others have experienced the same trouble, that there has been on occasion great difficulty in emptying the contents of the ladle during the pouring of the casting. So much depends on the gating and pouring of castings that one is sometimes amazed at the scant attention paid to the pouring basin through which the whole of the metal must pass. Ninety-nine per cent. of otherwise competent moulders will often fail in this last important touch to the assembled mould.

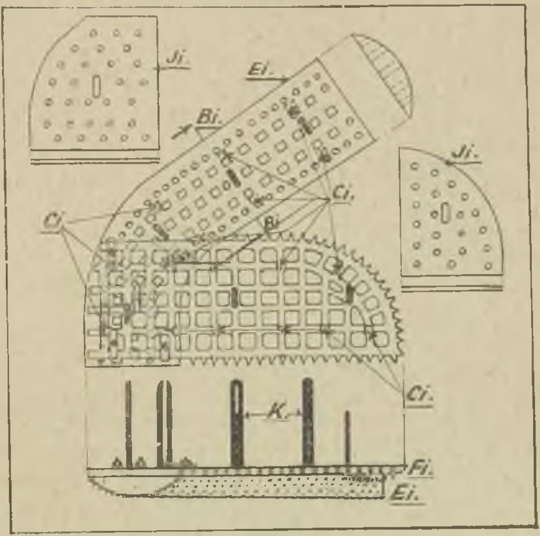

Fig. 6.

The proper planning out of steps ahead enables the moulder to proceed with a greater assurance that none of those costly hitches, so easily created, will occur. The strickles Ab and Hb are now used to strike up the contour of the bottom face of the mould up to the joint, and which forms a centre line at right-angles to the large flanges. Little information of the bricking need be mentioned, which is quite ordinary except that six horizontal in-gates are arranged to flow into the mould at the lower face-level, as shown in outline in Fig. 5 and in the sectional elevation at G2, Fig. 10. The in-gates are better formed in cores. The in-gates are fed by six vertical down-gates leading up to the joint face and which are in turn fed by the two main down-gates from the pouring basin. Loose pieces of pattern for forming the feet, flanges, bosses, etc., are located by using various gauge sticks similar to I and J, Fig. 3, and straight-edges and set-squares.

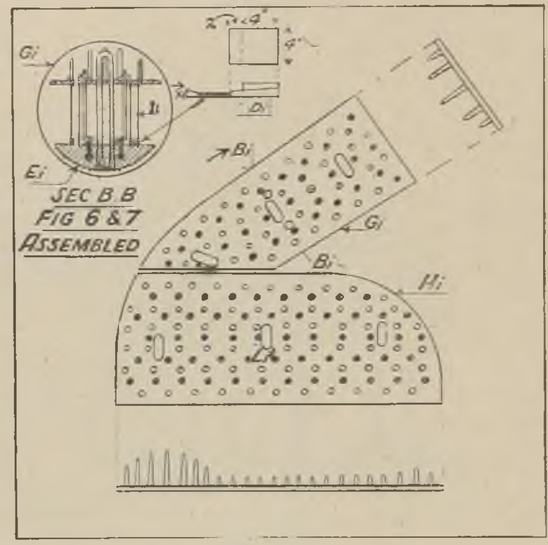

Fig. 7.

It is necessary to mention that, in spite of the large number and shapes of the strickle boards, the moulder must be provided with a number of small loose strickles to blend one section of struck-up mould with another, because, if the casting is studied, it will be noted that, whilst a perfect sweep can be arranged on the centre corresponding with the joint line, the contour of the casting calls for an increase in depth as well as width. At the point where one strickle finishes and the next commences there is an average difference of something like $\frac{3}{8}$ in. in depth. That is to say, a step is formed on the bottom face of the mould and which disappears as it rises to the joint-line, where the correct shape formed by the sweeps is encountered. It is across these areas that the moulder is called upon to use loose wooden strickles and tools to blend or graduate the mould according to design.

Having struck up the mould to the joint-face, the mould is well-finished and blackened, the loose pieces not being removed at this juncture. At this stage the mould is lifted on the stove carriage and given about 12 hours' drying, taking care not to produce too high a temperature and that all loose-pattern wooden work is well covered with wet loam to prevent too much shrinkage and perhaps burning of the material.

From this stage until completely built up the mould is not removed from the stove carriage, on which all further work of building is carried out, the reason for this being to take advantage of each night to carry on the drying of the mould as it grows, because the weight of the building will soon be beyond the lifting capacity of the cranes. The completed mould will exceed 100 tons.

Core-Making Details.

The construction of the core is the next step. The mould is withdrawn from the stove and the whole of the surface covered with a $1\frac{1}{8}$-in. layer of hard-rammed loam sand. This is done by making a large number of 3-in. by $1\frac{1}{8}$-in. square slabs of core from the core-box U, shown in Fig. 4. The surface of the applied thickness is well-finished and blackened, and again stoved for a few hours. As previously mentioned, the core is specially constructed to allow the casting freely to contract on cooling.

Figs. 6 and 7 show the necessary cast-iron grids or lifters. E1, Fig. 6, is shaped to conform to the contour of the bottom face of the core. This iron is lightened a little by coring out with loam bricks and cores, and the underside, which must come in contact with the loam, is jagged and serrated so that the material will adhere. The accompanying main core grid, F1, is soundly bolted to the main grid, E1. Grid F1, it will be noted, is made to carry the flatter surface of the bottom face of the mould. The lifting staples, K, must be made of sound material and well sunk in the cast metal.

Plates J1 are made to cover the area of the grid F1 beyond that of the main under-grid. On looking later at Fig. 10, the reason for this will be apparent. The plates, J1, are bedded on loam, spread over the surface of F1 to prevent the pressure of metal bursting through the underside into the interior of the core.

The building of the core is proceeded with by carefully laying over the thickened mould good loam to a depth of about 1¼ in. The two main core-grids are washed with thick clay-water, and are then bedded down in the loam. The surface under the grid F1 needs additional support, which is obtained by the use of a few short gaggers. After bedding the plates J1 in loam above the grid F1, to which they are bolted, a 9-in. brick wall with a loam face to the casting is built sufficiently high to allow the strengthening plates G1 and H1, Fig. 7, to be placed into position. But before placing these top plates into position cast-iron columns, marked I1, shown in Fig. 6, are located resting squarely on iron wedges, D1, arranged at intervals, as indicated by the points C1, Fig. 6. Pieces of cast-iron plate are shown at D1, placed in front of the wedges so that when the time arrives to free the core, wedges can be quickly knocked forward without mishap and loss of precious time, when it is necessary to relieve the casting for contraction.

The inside of the core is loosely filled with broken brick and cinders to reduce the air. This is done to prevent the danger of an explosion, which might occur if a drop of metal finds its way through the brickwork at the moment when an explosive mixture of gas is present. The plates H1 and G1, containing prodders uppermost, are seated down on the 9-in. brick wall and the cast-iron supporting columns. The space between the prodders is next built in with brick work and loam, and the strickles At to Ht brought finally into action to form the top surface of the core. Here again the moulder uses additional short strickles and tools to blend the points of contact of one strickle with another. After finishing and blackening the top half of the core the whole of the mould is again dried. Thicknessing cores are next laid over the surface of the core to form the $1\frac{1}{8}$-in. metal thickness and the upper and outer face of the mould.

Moulding the Top Portion.

The cope, or top side, of the mould from the joint is next proceeded with. The lifting plate A2, Fig. 8, is then located, being bedded down in loam placed on the joint. The lifting plate, A2, is made so that the casting will not close on any section whilst contracting. A minimum of 2 in. of loam is allowed between the lifting plate and the face of the mould. The various loose pieces of pattern are built in the mould during bricking, as with the bottom. Grids, B2, carry the flat surface above the feet, and C2 the "flatish" area over the body and around the bearing N and also a portion of the core-print. Grids, D2, are built in just above the top surface of the mould to help to sustain the weight of the brick work over the body and core prints. All grids, with the exception of those above the feet, contain staples to allow of bolting to the top plate, Fig. 9.

The plate, Fig. 9, is cast with a large number of holes to allow bolting up of the joint plate and the grids and riser and runner-gate openings. The openings for the runner and riser gates are elongated sufficiently to allow the use of the same tackle for more than one size of centrifugal pump body. It will also be noted that a large opening is formed in the centre of the plate and shown covered by a smaller plate. This hole is arranged to avoid the danger of a fractured plate, which is not uncommon with a solid plate. The author recalls the breaking of a 40-ton bottom plate, which, on being made a second time with a large hole in the centre, came out quite sound. A plate so made is certainly stronger than one without a hole. Quite a long story could be given as to why such plates, when cast solid, often break. One can now jump to the point where the mould has been built up, joint plate and lifting grids bolted to the top plates, runner- and riser-gates withdrawn, and locating marks for reassembly of the mould struck vertically across the joints on a prepared and smoothed loam surface.

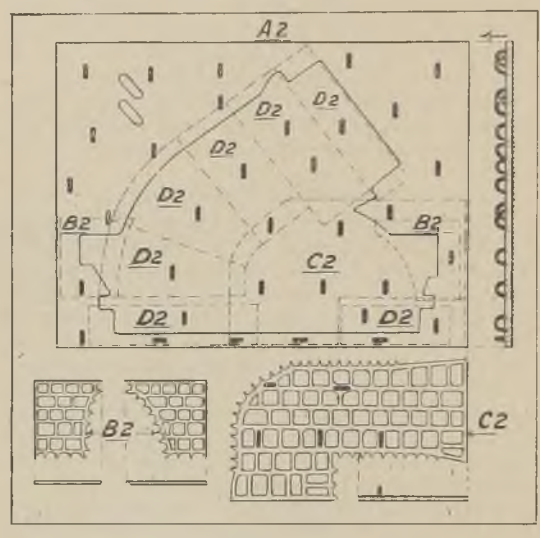

Fig. 8.

Before breaking up the mould, the whole of the construction is given 30 to 32 hours' drying; then it is broken down to allow the finishing of the mould and core. This is done by first lifting off the top part or coping, then the core extracted, finished, and placed in the stove for drying, and the top part placed again on the bottom part to allow a moulder to trim the joints from the inside of the mould. All further finishing, blackening and locating of small cores is accomplished when the top and bottom parts have again been parted.

When the mould and core are considered to be thoroughly dry, the mould is assembled in a pit sunk in the foundry floor. A cross-sectional view of the assembled mould is shown in Fig. 10, which is to a large extent self-explanatory. H2, in Fig. 10, describes the method of supporting and holding down the heavy main core. It is essential that the cast-iron stud be supported by an iron pillar built up from the bottom plate at the point of contact. The core should also have a corresponding continuity of metal support passing through the loam of the core to the metal of the grid.

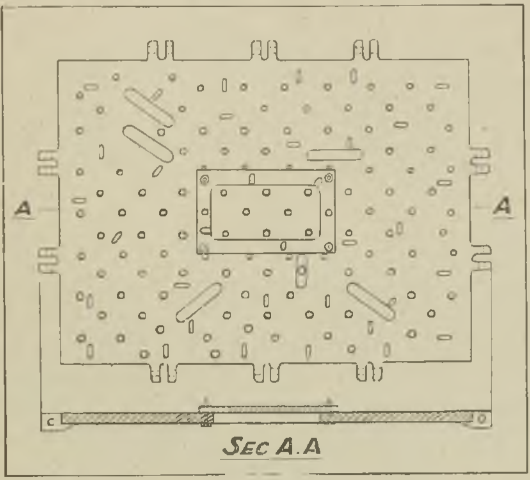

Fig. 9.

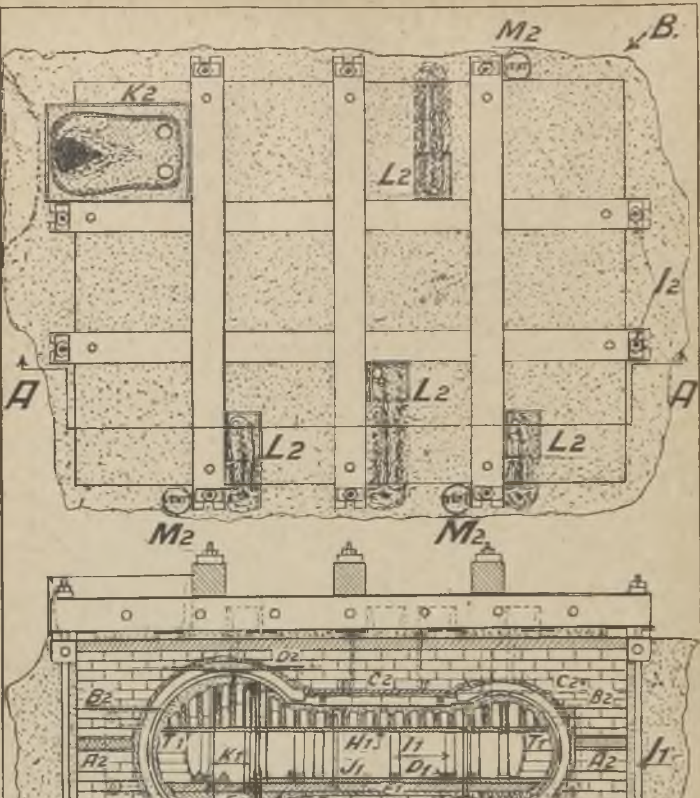
M2
B.
K2
L2
I2
A
A
L2
L2
L2
M2
M2
D2
C2
C2
B2
B2
T1
T1
H1
I1
K1
J1
D1
A2
A2
J1
E1
H
H2. CAST IRON CORE SUPPORTS.
Sec. A. A.
G2
Sec. through Runner Gates.
T1
T1
E1
Sec. through 60" Outlet End. B.

FIG. 10.

After placing in the pit and firmly securing the mould with the binders, J2, and hook-bolts, I2, and locating the vent pipes, M2, around which plates are fixed to block off the open ends, the mould is rammed round with sand to the joint face and pouring bush, K2, and riser-gates, L2, are formed. The pouring basin, K2, is made with a strong dry-sand facing material, which is blackened and dried by an open fire. The mould is then poured with an iron of moderate strength and of approximately the following analysis:—Total carbon, 3.2; silicon, 2.0; manganese, 0.65; sulphur, 0.12; and phosphorus, 0.7 per cent.

Almost immediately after pouring labourers are posted to dig around the mould to allow of freeing the casting. In the meantime a foreman moulder, the two loam moulders, the foreman dresser and several dressers retire for tea. On their return they are able to commence the freeing of the core. Section AA and B, Fig. 10, will indicate how the core is released. One gang, working from the direction of the outlet end, B, and another from the larger open end, section AA, proceed to knock out the bricks marked T1. When the bricks have been cleared right through from one side to the other, the cast-iron props, I1, are knocked over, after first driving out the cast-iron wedges, D1. There is thus full freedom for the casting to contract. The casting, when dressed, weighs only 7 tons, although having taken from six to seven weeks to make by two moulders and two labourers.

Pulping-Machine Jacketed-Cylinder.

Fig. 11 shows the type of casting to be described—a pulping-machine jacketed-cylinder, which is required to be in a very sound condition. The machine, of which this casting forms the most important part, is employed to mix and break up wood pulp for various purposes. So far as the machines the author has already made are concerned, they have been used in connection with the machinery plant producing artificial silk. The material, after pulping, is passed from the machine to the adjacent and complementary hydraulic-press machinery and formed into cakes, which are subsequently passed through a chemical process by which the material is dissolved and forms what is known in the trade as the viscose solution used for the spinning of artificial silk. The capacity of the machine is 29 cub. ft., and is subjected to water pressure. As with any casting, there is more than one way to make the cylinder, but the method to be described resulted in an entirely satisfactory casting. The casting weighed close upon 2 tons, and the thinnest metal section was $\frac{3}{4}$ in.

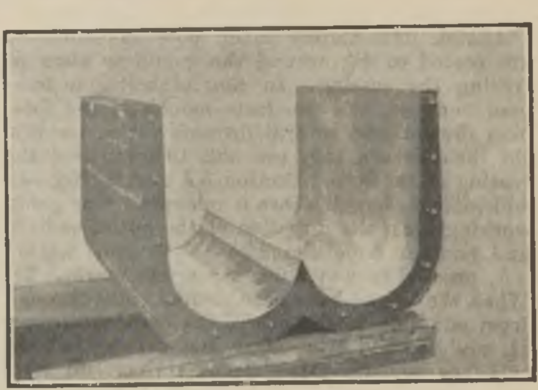

Fig. 11.

Making the Pattern.

Before commencing to make the pattern, the moulding practice to be followed was carefully considered and the pattern made in three pieces—a top and two sides, assembled on a ramming block as shown in Fig. 12. The ramming block is shown pushed well back on the under side of the pattern sections to enable the operative to get a clear view of the outline of the pattern. Plates holding tapped holes to allow of bolting the sections of pattern to the moulding boxes were located, two of which can be seen in Fig. 12. Below these plates can be seen markings. These marks were used as guides to locate bearers to support the metal studs when coring. The core boxes were also made in three pieces and corresponded with the three sections of the pattern. The design of the core boxes is shown on the far side and behind the pattern. The print for the cores is seen in the front of the pattern. A core made out of the core box on the right of the pattern would fit into the bottom half of the core print on the side turned towards us according to the photograph.

Core-Making.

The making of the cores is made more difficult by the introduction of the strengthening ribs, which pass through from one wall of metal to the other, thereby breaking up the continuity of the core. The side cores were consequently made in two pieces, divided vertically along the centre rib. Pieces were cut out of the core-box ribs to allow the core irons to pass through from one panel to the other for the purpose of strengthening the core. The core iron was, of course, of a composite nature, cast-iron bars holding a number of wrought-iron bars bent to conform to the shape of the box. Cast-iron bars were also passed through the section of metal framing the ribs and were wired to the wrought irons and were easily broken when extracting the core. The large number of bosses were chilled from the cores. These chills or denseners were wired to the core irons.

The cores were rammed up in oil sand made of large-grained washed silica sand in the proportion of one of oil to 25 of sand. Several strings of cinders were led up to the print of the core from about 2 ft. from the bottom side. These strings of fine cinder were gathered together and were met by small tubes set in the print of the core. It may be asked why were cinders introduced into an oil-sand core? It is surprising how much gas is given off from an oil sand core, and in such cases as the casting described there would be no hesitation in aiding the exit of the huge volumes of gases formed when the metal is poured. The flames from the vent tubes were a yard long for quite five minutes after pouring.

Moulding Details.

Fig. 13 shows at AA a sectional elevation of the assembled mould ready for pouring crown upwards. To commence moulding, the bottom box, B, is rammed up to form a flat oddside to receive the assembled pattern which sits on the ramming block as outlined when describing the pattern. The middle box parts, C, on the undersides of which is bolted the lifting plate, F, are placed into position and the mould rammed up until the top joint, O, can be formed. During the ramming of the mid-parts, bearer studs, G, are soundly located (guided by the marks of the pattern). Hook bolts pass through from the outside of the box and into the holes in the plates attached to the side of the pattern, and iron bearers, M, placed under the core prints, N. The top joint, O, does not coincide with the joint of the pattern, but with the top of the print of the core. Before taking out the two side sections of the patterns, the sand above the joint-line is cut away and subsequently made up after coring.

Fig. 12.

In ramming the top part, D, riser-gates are located on the majority of lugs and bosses, several of which are indicated by dotted lines. During the ramming of the top, bearers are inserted to receive the studs, K. After bolting

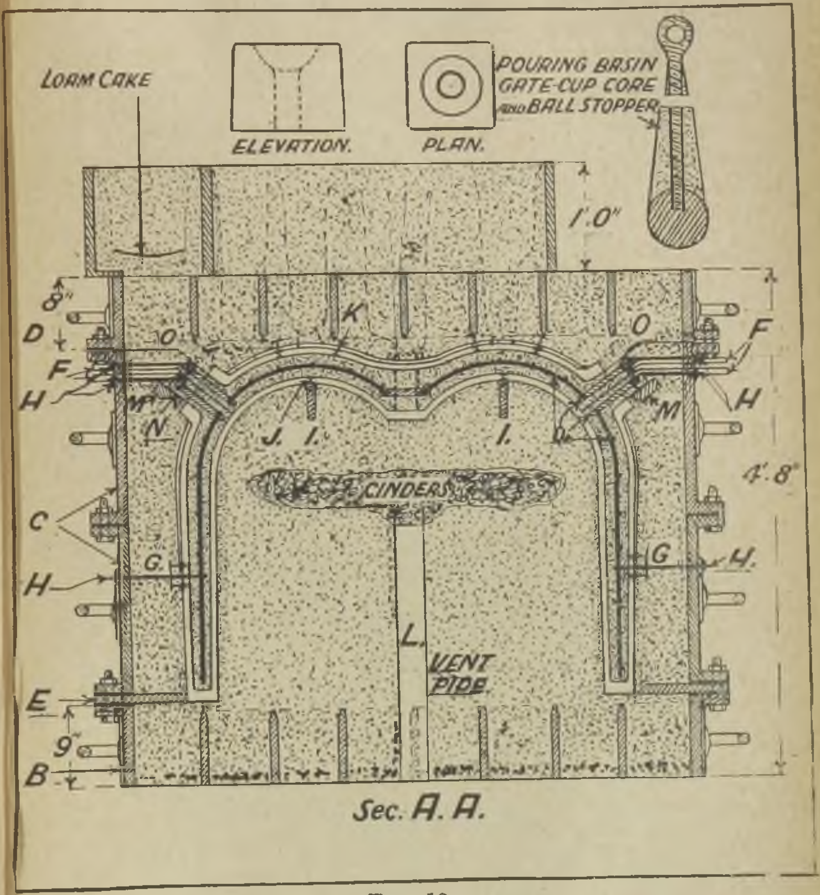

Fig. 13.

the sections of pattern to the top and mid-parts, the mould is turned over and the mould-core and bottom part rammed up, during which operation bearer supports, I, are located to support the studs, J, and cinders, and the vent pipe, L, inserted to carry away the gases passing down from the vent holes made by the vent wire. The joint of the mould-core, or cod, conforms to the shape of the inside of the casting and is carried forward about 12 in. from the face of the casting to allow of making a well-tapered and safe joint and also to allow the arrangement of the sixteen 2-in. by ¼-in. in-gates, as shown in Fig. 14.

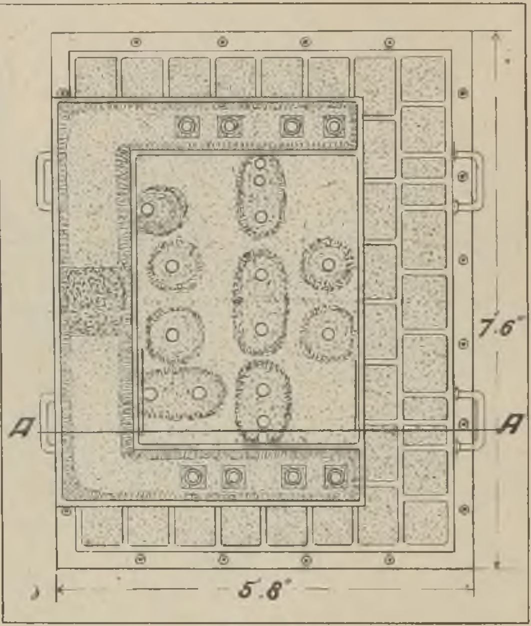

Fig. 14.

The rammed-up mould is turned back to the position required for casting. The top part, D, is first lifted off, carrying with it the top section of the pattern, and then the middle parts, H, carrying the two remaining sections of the pattern, are lifted, leaving the mould-core standing on the bottom parts. The work of finishing the mould is thus greatly facilitated. The mould is well dried, especially the bottom part holding the cod.

After drying, the middle parts are placed to enable the side cores to be fastened to the mould, as shown in section AA, before lowering the middle parts over the bottom part. The letters H indicate hook-bolts passing from the core through the mould to the outside of the box. The bolts in the bottom part of the mould pass through the section of metal forming the outer wall, pulling against thickness studs which rest against the metal bearer studs, G. After making good the joints of the core so that the continuity of the core section is not divided by a flash of metal the middle parts are then located on the bottom box. The top core is next placed in position, resting on the prints of the two side cores and bolted back to the sides. Vent pipes, F, are located and the core prints sealed and formed to correspond with the top joint, O, again.

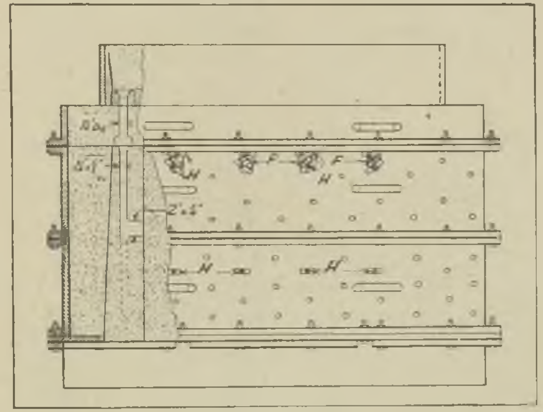

FIG. 15.

The top core was too weak to avoid the use of studs under and above, but the minimum number were used by the arrangements outlined. The studs were carefully selected, samples of which were tested before using, and the hook-bolts, H, were thoroughly ground and cleaned on that part which passes through the metal section. Wherever possible it is the best practice to use clean machined or ground metal studs or chaplet stems. It is only necessary to smear the material with oil to prevent oxidation whilst waiting for the metal to be poured.

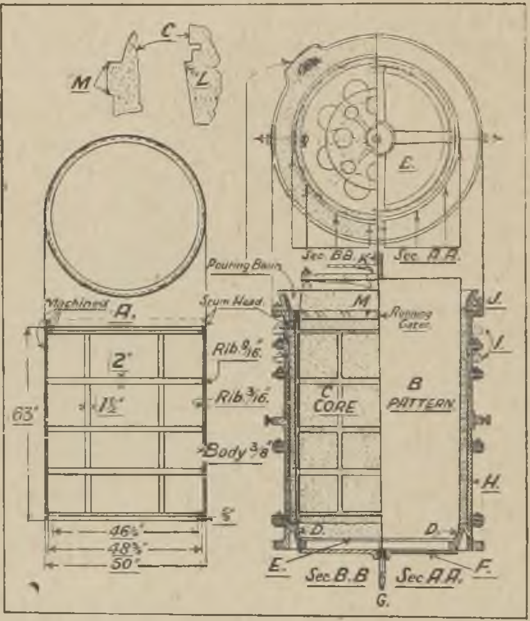

Fig. 16.

The top part, D, was not placed in position until the runner basin and riser gates had been made. The entrance to the eight down-gates were formed with dry-sand ball-cup cores, as shown in the upper part of the drawing in Fig. 13. Fig. 14 gives a plan view of the runner and riser-gate box, which is made in one piece. All risers were left open during casting.

The metal is first admitted through eight ingates situated 6 in. from the bottom of the mould and pouring in on either side of the core by lifting first the four ball-stoppers controlling the four outside main down-gates. When about one-third of the metal has been poured, the remaining four ball-stoppers are lifted, allowing a quick and uniform filling of the mould. This scheme of gating was arranged to secure freedom from unsoundness, as would be most probable if gated from one or two points only, and also to prevent erosion of the oil-sand core.

Fig. 15 shows a part-sectional elevation of the gating and a view of the outside of the box, showing the vent pipes, F, and the hook bolts, H. The analysis of the metal poured was as follows:—Total carbon, 3.2; silicon, 1.75; manganese, 0.8; sulphur, 0.13; and phosphorus, 0.65 per cent.

Carding-Engine Cylinder.

The cylinders are the most important castings used in the construction of carding engines, which are employed for carding and cleaning cotton, wool, worsted, or waste in the textile trade. The drawing A, Fig. 16, shows the section and plan of a carding-engine cylinder weighing approximately 18 cwts. This casting is chosen to illustrate principally the design of a collapsible core-barrel, although there are other interesting features connected with the casting. The method described is the practice followed in the several textile engineering foundries for making cylinders varying from 24 in. dia. to 60 in. dia., and in lengths or widths, as described in the trade, from 40 in. to 72 in., and in weight from a little under 4 cwts. to 28 cwts. Castings 54 in. dia. and up to 108 in. in length are made by the ordinary loam-moulding practice, and weigh up to 2 tons.

The physical requirements, so far as strength is concerned, are only moderate, as the cylinders do not revolve at more than 500 revolutions per minute, but the quality of finish must be of a high order. To secure such castings without blemish requires a carefully-studied and standard practice. On looking at the sketch in Fig. 15, it will be noted that the casting is 64 in. long and 50 in. dia., yet the metal section is only $\frac{5}{8}$ in. for a $\frac{3}{8}$-in. finished casting section. In smaller sizes, from 50 in. by 40 in. downwards, the section is under $\frac{7}{16}$-in. finish.

It is much simpler to produce a cylindrical casting such as obtains in, say, gas, oil and steam engine liners in which the section is much thicker compared with the size of the casting. There is, therefore, with carding-engine cylinders a thin section of comparatively large area, and it will be evident that any scum or dirt left in the mould or created by scabbing and erosion, or entering with the metal, will have little chance of floating into the 2-in. scum-head provided. Dirt formed by scabbing is almost invariably found adjacent to the area where it originated, or, if it enters with the metal, it will be found in the zone corresponding to the amount of metal which has been poured at the time of the entry of the scum. The head metal serves a more useful purpose in clearing the top side of gas holes, and, of course, a certain amount of dirt.

Pattern-Making Details.

B, in the half-section AA, is a sketch of the pattern, which is made either of rolled steel or cast iron, machined to allow a draft or taper of $\frac{1}{16}$ in. on the length of 72 in., and also contraction and $\frac{1}{8}$-in. machining allowance. The pattern is supported on the inside, top and bottom. by end-plates through which runs a 3-in. spindle with a hole for a shackle, as shown at K in the sketch. Great care is taken to balance the pattern so as to allow as perfect withdrawal from the sand as possible. The pattern holds a tapered print which, when located in the moulding box, sits in a machined metal print, D.

Moulding-Box Construction.

Both sections AA and BB show the design of moulding box used, and which is moulded in sections and bolted together. The moulding boxes, H, are cylindrical and perforated for venting and drying purposes, and allow 2 in. of rammed sand around the pattern. The bottom box is machined on the inside to form a metal print, as shown at D. F indicates a bar bolted to the bottom box, through which is bored a hole $\frac{1}{8}$ in. larger than the spindle, G, in the core bar, and is used as a guide to centre the core prior to it entering the tapered print, D. J is a circular runner-bush bolted to the box. I shows by dotted lines the varying depths of moulding boxes to take the varying depths of castings. E indicates the clearance allowance between the core bar and the bottom section of the moulding box.

Moulding.

The 2 in. of space is rammed with a mixture of equal parts of red and black sand and 5 per cent. of manure. The ramming is straightforward, although care must be exercised, otherwise swelling or scabbing will take place where the sand is loosely rammed. The mould is wet-blacked with a plumbago mixture and then thoroughly dried.

Core-Making.

Section BB shows the core, C, placed in the mould and sitting in the metal print, D. The horizontal ribs are formed when strickling the core, but the vertical ribs are rubbed with a special gauge, the position of which is determined by rotating the core until one of the holes in the top plate of the spider can be engaged by a pin. M shows the top print, which is the same diameter as the outer mould and, when lowered into position, blocks out and forms the top face of the rim of the casting. A number of spray-top drop-gates, $\frac{1}{4}$ in. by $\frac{1}{2}$ in., and 16 in number, are equally spaced and arranged round the periphery of the casting. These spray-gates are formed by rubbing with a file across the print, giving them, whilst doing so, a slight tangential entry into the mould, as shown in the sketch.

The sketches M and L show the chamfering of the sharp edges of the core print, both top and bottom. This is done to prevent crushing of the keen edges, as will be expected when it is stated that the total weight, with core barrel, is nearly 5 tons.

Construction of Core Barrel.

Fig. 16 illustrates the drawing details for the collapsible core barrel, whilst Fig. 17 shows the constructed core barrel resting on trestles, with one of the four loose segments slung in the crane ready to lower into position and complete the barrel. The barrel is composed of a 3-in. spindle, long enough to allow one end, slightly tapered, to protrude 18 in. and to act as a guide when coring the mould and the top end, with a hole through it to take a shackle when lowering into position in the mould. The cast-iron flanges are fixed firmly to the spindle and well braced with steel rods, the whole forming a spider to hold four segments, which form a complete circle

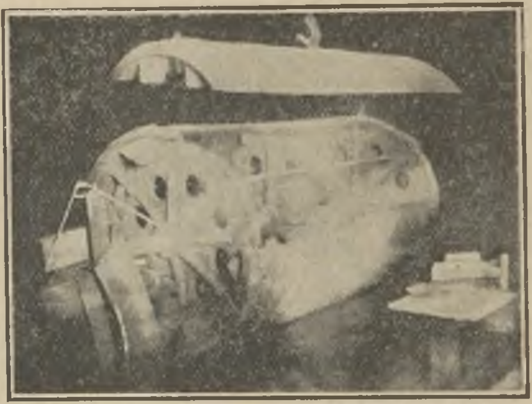

Fig. 17.

when in position. The segments are easily placed into position, being located by a long pin at what will be the top end, when in position in the mould, and is secured by a cotter. The bottom end of the segment is located by a short pin, the nose of which enters a countersunk hole in the bottom flange of the spider. The segments are perforated and serrated to hold the loam, the allowance on the barrel being 1 in.,

Fig. 18.

excepting the tapered print, on which a minimum of loam is required.

Obviously great accuracy is required in such a core. The tapered print must also close exactly into the metal print, otherwise leakage of metal will occur. The core is swept up on permanent iron trestles, the spindle revolving on rollers. The position of the metal strickle is also permanent, and is held into its correct place by locating pins.

Fig. 18 shows the mould ready for casting, with the core lowered into its place. This photograph will also serve to illustrate the act of withdrawing the spider after casting. The casting is relieved about five minutes after pouring by knocking out the cotters securing the segments to the spider and withdrawing the latter with the crane in the manner shown in the photograph. After withdrawing the spider the two small segments are knocked forward by a bar, they being held in the crane slings whilst doing so. Thus, all four segments are withdrawn from the inside of the casting.

Very often the spider is placed on the trestles, the segments assembled thereon, and the loam swept on the barrel while still warm. If this is done, the core can be slipped up twenty minutes after the roughing coat. The metal poured into such castings is of a medium quality, and of the following composition:—Total carbon, 3.5; silicon, 2.0; manganese, 0.5; sulphur, 0.15; and phosphorus, 0.8 per cent.

Birmingham Branch.

HISTORY OF IRONFOUNDING IN THE MIDLANDS.

By D. H. Wood (Member).

The history of the Midlands, presenting many features of unique interest, with an intimate bearing upon national economics and industrial development, has been written in terms of coal and iron. It was not here, however, that the earliest coal hewers and ironworkers in Britain were to be seen.

When the Romans, profound believers in the law that might is right, wrested the country from its native races, they found the metal already known to the primitive islanders whom they encountered on the coasts. Probably the knowledge was first introduced by nomadic wanderers from Europe, who had themselves acquired it from the east where iron had been used, mainly for the purposes of war, since the earliest Biblical times.

But the Roman colonists were the first to undertake iron production in England on a scale worthy of serious notice. Wherever they settled they lost no time in utilising the natural riches which they found readily available. Their enterprise was as remarkable as their industry was prodigious. They left striking proofs of their activity in enormous heaps of cinders and offal, and as late as 1677 that extraordinary Worcestershire genius—Andrew Yarranton—estimated that the Roman cinder mounds in the Forest of Dean and at Worcester alone were sufficient to "*supply the iron works some hundreds of years,*" and he added that "*these cinders are they which make the prime and best iron, and with much less charcoal than doth the ironstone.*"

Trade followed the flag of the Romans along the great highways into the Midlands, and the iron forgers who set up smelting fires at the crossings of valleys, or on the tops of hills, on or near Icknield Street and Watling Street, where they penetrated deepest into the Staffordshire, Warwickshire, Worcestershire and Shropshire forests, unconsciously provided pointers for the ultimate destiny of the area whose industrial expansion, attested by a chain of great and prosperous towns, has had few parallels.

A Lost Opportunity.

The transition which produced the "Black Country," challenging the supremacy of the Northumberland mining area, which, previous to the eighteenth century, was known as "The Black Indies," was slow in developing. One of the facts which most strongly impresses itself upon the student of iron-trade history is the utter failure of the people in the fourteenth and fifteenth centuries to grasp the potentialities at their command. The lessons of the Romans seem to have been entirely lost upon them, and, although iron was so scarce that Parliament prohibited its exportation under heavy penalties, they made no effort to turn the existing wealth of English iron-ore deposits to account, but obtained their supplies of iron and steel principally from Spain and Germany.

The Sussex Iron Industry.

For nearly two centuries the manufacture of iron in this country was at a standstill. It was actually in Sussex that the first symptoms of revival appeared. Camden, writing in 1607, quaintly tells us that Sussex is "*full of mines everywhere for the casting of which there are furnaces up and down the country and abundance of wood is yearly spent. Many streams of water are drawn into one channel and a great deal of meadow ground is turned into pools for the driving of mills which, beating with hammers upon the iron, fill the neighbourhood day and night with their noise.*"

Many of the noble families, such as the Nevilles, the Percys, the Howards, and the Ashburnhams owned ironworks in Sussex. The Fullers won their fortune from, and owed their social rise to, the same source, and recognition of their indebtedness is implied in their family coat of arms, which fittingly shows a pair of tongs with the motto "*Carbonê et Forcipibus.*"

According to one well-known authority, the total number of blast furnaces in England about 1720 was sixty, which produced an annual output of some 17,000 tons of pig-iron between them, or a total considerably below the capacity of a single big modern blast furnace. As an example, the output of a modern furnace, such as the Dowlais plant, produces approximately 3,300 tons weekly.

It may be worth chronicling as a point of historic interest that one of the last extensive contracts executed in Sussex was the casting of the iron railings for St. Paul's Cathedral. The contract was considered too large for one ironmaster to undertake, and it was consequently divided amongst several contractors. The knell of the iron trade in Sussex was rung with the destruction of the adjacent forests, the consumption of wood being tremendous. It required four loads of timber converted into charcoal fuel to make a ton of pig-iron, while for every ton of bar iron three additional loads were needed. Wood was the only fuel used either for manufacturing or domestic purposes. Coal had been more or less known in England from at least as early as 832. It was first brought from deposits on or near the coast, and so became known as "sea coal." But it had not at this time entered into serious competition with wood as a fuel, and the disappearance of the forest growths through the insatiable demands of the "*voracious iron mills*" excited the gravest apprehensions lest there should not only be insufficient timber left for naval construction, but that, as a result of the absence of fuel, "*the fishermen would not be able to dry their clothes or warm their bodies when they came in from* *the sea.*" Acts of Parliament were accordingly passed for the protection of the forests. The establishment of ironworks within a radius of twenty-two miles of London was prohibited, and iron manufacture was distributed over other parts of the country, including South Wales and the Midlands. The tightening of the restrictions against wood consumption plunged the industry once more into depression, which was accentuated by the destruction during the Civil Wars of all the works belonging to Royalists, but out of chaos came the industrial revolution, one of the distinguishing features of which was the triumph of the Midland iron-foundry trades.

Birmingham's Original Industries.

Birmingham cutlers, we are told, supplied Cromwell's armies with pikes and swords, but the speciality of the town even at this early period was ironmongery, including every kind of article, some of daily use, and others which varied with the fashion. They ranged from nails and locksmiths' necessities to metal buttons and shoe-buckles, and included the whole of the Birmingham toy industry. The inhabitants of the town were said to be as industrious as they were skilful, and " the sound of hammering was to be heard at three o'clock in the morning." The demolition of the Welsh ironworks, followed later by those in the Forest of Dean, and the ultimate blowing out of the last of the Sussex iron furnaces, left the field clear for Midlands enterprise, and very soon the "*villages*" of Wolverhampton, Dudley, Wednesbury, etc., expanded into busy and thriving towns. As a rule, mine and blast furnace at first constituted parts of one undertaking. The ore was smelted on the spot and the amount extracted was originally limited by the demands of the ironworks in the immediate neighbourhood.

There was amongst the early ironfounders, as amongst householders, a strange unreasoning prejudice against the use of coal. The old manufacturers, indeed, held it to be impossible to reduce the ore by any other means than charcoal of wood, and their resistance to the innovations and improvements in methods of iron production which so speedily raised England to the status of the chief metal-working country in the world and, incidentally, established the reputation of the Midland ironfounders on a basis which has never since been seriously shaken, stands as one of the most amazing historic examples of short-sighted ignorance on record.

Then, as now, the very foundations of society, "*the tools and implements of peace*," as Smiles expresses it, "*as well as the weapons of war*," depended upon an abundant supply of iron, and the policy which contributed to its curtailment was, in effect, a dangerous public menace.

How foolish it had really been was emphasised by nothing so much as the gigantic leap forward which was taken when the industry was liberated from the shackles of narrowness, and welcomed the inventor as an auxiliary instead of fearing him as an enemy.

A miracle of transformation was effected, and all classes shared in an unprecedented spell of prosperity. Vivid pictures have been presented by Dickens, Disraeli, and other eminent writers of the extraordinary spectacle of feverish industrial activity which the Midlands presented in their response to inventive genius. From thousands of chimney stacks dense clouds of black smoke poured unceasingly, to hang over the whole district like a pall. From mines, mills and forges came a no less insistent volume of sound, while at night the glare of blast furnaces lit up the whole countryside, producing effects which left an ineradicable effect upon the minds of strangers.

The Development of Smelting.

Necessity compelled the ironmasters to turn to substitutes for wood-ash or charcoal in the smelting of iron, and at the outset they groped very hesitatingly with the problem in those trying and difficult times. The most perplexing trouble presenting itself in their tentative experiments with coal as a fuel arose out of the action of iron ore in contact with the sulphurous compounds liberated from coal by the process of combustion. It was found that the iron first yielded was impure and brittle, and it was quite impossible to hammer it.

Progress was really held up until 1612, when a certain Simon Sturtevant, who, if not a German, was certainly of German origin, secured letters patent conferring upon him the exclusive right to "*neale, melt and worke all kinds of metal oares, irons and steeles with sea-coale, pit-coale, earth coale and brush fewell.*"

Sturtevant, whose idea seems to have been to reduce the coal by an imperfect combustion to the condition of coke, and so rid it of "*those malignant proprieties* (sic) *which are averse to the nature of metallique substances,*" set up extravagant claims for his discovery, contending that it "*will prove to be the best and most profitable business and invention that ever was known or invented in England these many years.*" But nothing came of it. Before the year was out, his patent was declared to have lapsed on the ground that he had failed to use it. His rights were transferred to John Rovenzon, a *protégé* of the then Prince of Wales. Like Sturtevant, he, too, promised a good deal more than he found it possible to perform, and it was left to Dud Dudley, the natural son of Edward, Lord Dudley, of Dudley Castle, to prepare the way for the palmy days of the iron trade with his discovery of the process of "melting iron ore, making bar-iron, etc., with coal in furnaces with bellows." His patent was taken out by his father—Lord Dudley—in 1620. Dud Dudley, a student at Baliol College, Oxford, was gifted beyond the ordinary with capacity for scientific investigation, and practical experience, gained at an iron furnace and two forges belonging to his father in the chase of Pensnet, Worcestershire, set his mind working along new lines, presenting a wide field for exploration.

Dudley's Experiments.

As the result of his experiments, Dudley evolved a method of adapting coal as a fuel by subjecting it to a process similar to that of charcoal burning, and, by way of complement to a discovery which more than fulfilled expectations, he devised an improvement of the blast which enabled him to maintain the active combustion of the fuel and so increase its effectiveness. He was particularly fortunate in tapping a splendid seam of coal running from ten to sixteen yards thick, and he produced a "good merchantable iron," both at Pensnet and also at Cradley where he erected a new furnace. But both the ironsmelters and ironmasters of the district, embittered by the fact that he was able to make good iron and sell it more cheaply than they could, regarded this new process as "a dangerous invention," and appeals were actually made to King James to stop him from working. These efforts were unsuccessful, so law suits were fastened upon him, He was ousted from his works at Cradley, but set up furnaces at Himley and Hasco Bridge, near Sedgeley, which latter were wrecked by rioters at the instigation of the charcoal ironmasters. He himself was attacked by mobs, and, finally, after a career full of vicissitudes, during which he served in the Royal Armies, he settled for a time at Green's Lodge in Staffordshire, and finally retired to St. Helen's, Worcestershire, where he died in 1684 at the age of 85.

Yarrington, Blewstone and Darby.

Other great figures crowd upon the vision in that expansive period; men who contributed in no small degree to the improvement of the processes of production and to the general advancement in material prosperity of the iron-foundry and kindred trades in the Midlands.

While Dud Dudley was busy soldiering, Andrew Yarranton, the Worcestershire farmer's son from Larford in the parish of Astley, entered upon the manufacture of iron at Ashley, near Bewdley. He it was who wrested from Saxony, as the result of a personal visit and observations, the secret of tin-plate manufacture, and introduced the trade to this country. He was also responsible for setting on foot various schemes of public utility, and he gave the first impetus to plans of inland navigation, which found their fulfilment in the construction of the network of canals ultimately established to serve the needs of Midland industries. Yarranton profited by the Roman cinders left near the walls of Worcester and transported thousands of tons, it is said, along the Severn to his iron furnaces to be melted down into iron with a mixture of the Forest of Dean ironstone.

There are records of experiments between 1677 and 1686 by a German named Dr. Blewstone, who built his furnace at Wednesbury, with "*a new and effectual way of melting down, forging, and extracting and reducing of iron and all metals and minerals with pit coal and sea coal, as well and effectually as ever hath yet been done by charcoal and with much less charge.*" The inventor's idea was to permit only the flame of the coal to reach the ore, but the notion was more novel than practical, and he only succeeded in turning out iron inferior to that made with charcoal.

It is to Abraham Darby, the first of a succession of ironmasters bearing the same name, that the credit of first adopting the smelting of iron by means of coke and coal on a large scale as the regular method of manufacture belongs. Darby, the son of a farmer at Wren's Nest, near Dudley, had served an apprenticeship with a Birmingham maker of malt kilns. But the iron trade claimed him and early in his career, emulating Yarranton's example, he visited Holland to learn the secret of making cast-iron pots. His adventure was crowned with success, and on his return to England, he adopted the most rigorous precautions to prevent the piracy of his methods by other makers. He even went to the length of stopping the keyhole of his workshop door while the casting was in progress. He had made arrangements for manufacture on a large scale at Bristol, but a disagreement with his partners compelled a change of his plans, and in 1709 he settled at Coalbrookdale, where he won world-wide fame for his castings not only of pots, kettles and other "hollow-ware," direct from the smelting furnace, but for grates, smoothing irons, door frames, baking plates, cart brushes, iron pestles and mortars and other products. In 1764 another works was erected at Horshay, a few miles away.

The Coalbrookdale Works.

It was at the Coalbrookdale works that the famous Cranege process of iron manufacture, introducing the reverberatory furnace, was patented, and the first cast-iron bridge ever erected was cast at the same foundry in 1777-8. This bridge is well known to most founders as Iron-bridge, near Coalbrookdale works and, of course, is still in existence. It is interesting to note that quite recently attention has been drawn to the fact that there are *steel* and *wrought-iron* bridges which have been in existence for 50 or 60 years and are still in good condition, whereas this cast-iron bridge has been in use for over 150 years. The extension of the Coalbrookdale works and the developments which took place there were largely due to Richard Reynolds, who took charge of the works on the death of Darby—his father-in-law.

> "That the wood of old England would fail did appear,
> And tough iron was scarce, because charcoal was dear,
> By puddling and stamping he prevented that evil,
> So the Swedes and the Russians may go to the devil."
>
> *Song of John Wilkinson's workmen.*

Puddling and the Cupola.

The ancient ironmasters obtained iron and steel by the crudest and simplest possible methods. The iron ores were reduced in conical furnaces called air-bloomeries erected in exposed places, in order to obtain the greatest blast of wind. Ore and charcoal were mixed together and the blast applied to obtain the necessary temperature.

John Wilkinson, generally known as "the father of iron trade," came to the Midlands in 1748. At Bilston he built the first blast furnace. Wilkinson experimented with this furnace until he succeeded in substituting mineral coal for wood charcoal. Since he was also undoubtedly the inventor of the cupola as it is known to-day, a reference in some detail to him will be of interest. Born in 1728, near Ulverston, he was the son of the patentee of the "laundress's box iron." During the fifty odd years he lived in the Midlands his activities were extended over a wide field. He held a partnership with his brother in a foundry at Bersham, near Wrexham, where he constructed an improved plant for boring cylinders, an invention which proved of the greatest possible value to James Watt in the building of his Soho engines; he set up a forge on a large scale at Brosley, near Bridgnorth, for the manufacture of wrought iron, and here built the first iron barges ("*which swims remarkably light*"); he cast the first large working steam engines in France for the Paris waterworks, took out a patent in 1790 for making lead pipes, manufactured ordnance extensively, and came within an ace of anticipating James Neilson in the invention of the famous "hot blast."

Wilkinson's Enterprise.

As a matter of fact, it is claimed that Wilkinson conducted experiments on similar lines to those of Neilson, at Bradley, between 1795 and 1799, and only failed through lack of an iron instead of a leather joint. Wilkinson was of hot and violent temper; he was ceaselessly at loggerheads with his brother, actually started a project in opposition to the Bersham Works, and in the end dragged Boulton and Watt into the dispute, compelling them to withdraw from him the right they had conceded for the manufacture of the all-important nozzles for their engines, and to build a foundry of their own on the banks of the canal at Smethwick. Wilkinson never forgot and never forgave. "*Peace*," he once wrote, "*is a most desirable thing, and the more so to one of my constitution, which cannot be angry by halves. Resentment with me becomes a matter of business and stimulated action beyond any profit.*" One of his ideas was the construction of a cast-iron chapel with a cast-iron pulpit at Bilston. He actually designed and cast his own coffin, and when he died in 1808 a massive cast-iron tombstone, which he also designed, was erected over his grave. He was three times buried, twice being disinterred, and he found a final resting-place at Lindale, on the slopes of a hillside, amidst scenes of his boyhood days.

In his youth friends had prophesied that "*John sum tyme wod bee a gurt man.*" A great man he truly was, in spite of his elemental passions. He left an indelible impression upon the Midland iron-foundry trades, and enriched them by a great legacy of improvements, and Midlanders at least cannot forget that he was indirectly responsible for the establishment in Boulton & Watts' Smethwick foundry of a prolific nursery of men of invention and industry. Incidentally, it may be observed in passing that his sister married Dr. Priestley, the discoverer of oxygen, and the victim of the notorious Priestley riots in Birmingham.

It was from John Wilkinson that the manufacture of wrought iron derived its greatest stimulus, and as the iron trade gathered vigour improvements in manufacturing methods followed in rapid succession. In 1762 a patent was taken out by Dr. Roebuck for melting the cast, or pig-iron, in a hearth heated with pit coal by the blast of bellows. The iron was then worked until it was reduced to nature or metallised, after which it was exposed to the action of a hollow pit-coal fire urged by a blast until it was reduced to a loop drawn out into bar-iron under a common forge hammer.

Cranege, Onions and Cort's Inventions.

In 1766, four years before the introduction of Watt's steam engine, the brothers Cranege, one of whom was associated with the Bridgnorth Forge and the other with Coalbrookdale, invented the reverberatory or air furnace, so called because the flame or current of heated gases from the fuel was caused to be reverberated or reflected down upon the substance under operation before passing into the chimney.

Then Peter Onions produced his puddling furnace, the fire of which was urged by blast. He propounded new ideas. Having charged his furnace, bound with ironwork and well annealed, with pig- or cast-iron from the smelting furnace, it was closed up and the doors were luted with sand. The fire, which was urged by a blast admitted underneath, was to be kept until the metal became less fluid and "*thickened into a kind of froth which the workman, by opening the door, must turn and stir with a bar or other instrument, and then close the aperture again, applying the blast and fire until there was a ferment in the metal.*" The inventor declared that "*as the workman stirs the metal the Scoriæ will separate, and the particles of iron will adhere, which particles the workman must collect or gather into a mass or lump.*" This mass or lump was then to be raised to a white heat and forged into malleable iron at the forge hammer. The next stage of iron development was reached with the discoveries of Henry Cort, who, like the Craneges, employed the reverberatory or air furnace without blast, and, like Onions, worked the fused metal with iron bars until it was brought into "balls," when it was removed and forged into malleable iron, but he carried the processes farther and increased their efficiency. The changes he introduced in puddling and rolling were as important as they were far reaching in their results. His first efforts were directed towards the perfection of methods of "*preparing, welding, and working various sorts of iron, and of reducing the same into use by machinery, a furnace, and other apparatus* *adapted and applied to the said process.*" He made iron for "large uses," such as shanks, arms, rings, and palms of anchors, by piling and faggotting, bars of iron of suitable lengths being laid over one another in the same way as bricks in a building. The faggots were then placed in a common air or balling furnace and brought to a welding heat, and when the correct pitch of heat was reached they were brought under a forge hammer and welded into a solid mass.

Cort cleansed the iron and produced a metal of purer grain by passing the faggots through rollers. His method of manufacturing bar-iron from the ore, or from cast iron, presented a skilful combination of the various practices in general use before his day. Smiles succinctly describes his procedure:—"*The bottom of the reverbatory furnace,*" he says, "*was hollow, so as to contain the fluid metal introduced into it by ladles, the heat being kept up by pit coal or other fuel. When the furnace was charged, the doors were closed until the metal was sufficiently fused, when the workman opened an aperture and worked or stirred about the metal with iron bars, when an ebullition took place, during the continuance of which a bluish flame was emitted, the carbon of the cast iron was burned off, the metal separated from slag, and the iron, becoming reduced to nature, was then collected into lumps or loops of sizes suited to their intended uses when they were drawn out of the doors of the furnace. They were then cut into plates, and piled or worked in an air furnace, heated to a white or welding heat, shingled under a forge hammer, and passed through grooved rollers.*"

Cort, a native of Lancaster, benefited little by the results of his inventive genius. His partner proved untrustworthy, manufacturers unscrupulously availed themselves of his misfortunes to infringe his patents. He himself was reduced to penury, but during the last years of his life his circumstances were mitigated by a pension £200 per annum from the Lords of the Treasury.

It is a tribute to Cort's prescience that, though somewhat modified here and there, his processes have in the main successfully withstood the most searching tests of time. James Watt seems to have had doubts as to the exact quality of the iron produced by Cort's process, but he had no doubts with regard to the ingenuity of the inventor. Writing in 1784 to Dr. Black he said: "*Though I cannot perfectly agree with you as to its goodness, yet there is much ingenuity in the idea of forming the bars in that manner, which is the only part of his (Cort's) process which has any pretensions to novelty.*"

Midland ironfounders benefited in common with others from James Beaumont Neilson's discovery of the hot blast which Fairburn declared "*effected an entire revolution in the iron industry of Great Britain and forms the last era in the history of this material.*"

The essential principle of the invention was the passing of air through the tubes or passages of iron or fire clay heated by a flame or hot air surrounding them. The heat was obtained by utilising the profuse inflammable gases that formerly blazed to waste from the top of the blast furnace. The economy of fuel achieved by this means was tremendous. It rendered possible the use of coals of inferior quality for the purposes of iron manufacture. Not only so, but by lowering the cost of production, it infused new life into the industry, lessened unemployment, and increased the wealth and resources of the iron districts to an extraordinary extent.

A Mould-Making Discovery.

Delving among the records of the past one comes across many evidences of the shrewdness and inventive genius of the men who laid the foundation of the foundry trades, in directions other than those upon which their fame is generally considered to rest. Abraham Darby, for instance, laid the foundry trades under tribute of gratitude by solving the secret of mould making. The first moulds for his iron pots were made of clay, and they cracked and burst. After diligent inquiry he substituted moulds of fine dry sand for clay, and achieved success.

Early Discoveries in Steel.

David Mushet, while engaged in experiments for quite different purposes, discovered the certain fusibility of malleable iron at a suitable temperature, and other examples in which inventors were helped by what may be described as "accidents of chance" will no doubt be readily recalled. David Mushet was responsible for the preparation of steel from bar iron by a direct process combining the iron with carbon, and also, among other things, for the discovery of the beneficial effects of carbide of manganese on iron and steel, the use of carbides of iron in the puddling furnace in various modes of appliance, and the production of pig-iron from the blast furnace suitable for puddling without the intervention of the refinery.

Out of the wealth of discovery and invention, coupled with the incidental growth of machine making, necessitating a higher quality of work than had hitherto been attained, grew the idea of the cupola, which owed its invention to John Wilkinson. By means of the cupola, the principle of the blast furnace is adapted to the remelting of pig-iron. The reverberatory or air furnaces of those early days produced a hard but somewhat brittle casting, but there was a demand for a metal which was less liable to break, and this the cupola, provided with engine blast, proved capable of supplying to perfection. The solution of this problem solved also the difficulty of the makers of machine parts, and, to a large extent, that of makers of hollow ware, for whose purposes hard brittle material obviously is valueless. The mention of hollow ware serves as a reminder of the fact that this important industry was wrested by the Midlands from Wandsworth, in Surrey, although one local firm—Messrs. Izons & Company—now in West Bromwich, claims to be the oldest makers of cast hollow ware in the world, their works having originally been established in Birmingham in 1763. It was probably this factory which contributed most of all to the consolidation of trade in the Midlands.

There is no need to dwell upon the effects upon the iron industry of the introduction of Watts' steam engines, much less upon the more modern changes introduced into the foundry, forge, and engineering shops through the improvements effected in manufacture by Sir Henry Bessemer's process for the production of mild steel, which was patented in 1856. This process has a rival in the "Siemens-Martin" method of steelmaking, which is even more extensively used.

What stands out most clearly in all these things is the continuity of invention through the centuries since the epoch-making discoveries, and heart-breaking struggles, of the great pioneer of the Midland iron foundry trades—Dud Dudley. In the history of the iron trade the hour always seems to have produced the man, and the latest discoveries and improvements in processes of production, embodying the triumph of the puddler, backed by advanced scientific knowledge, impart a very satisfactory sense of completeness to what is in the fullest sense of the term a great industrial romance, the evolution of the iron trade.

Midland Firms.

In the heyday of iron-trade prosperity there were 171 blast furnaces in South Staffordshire and East Worcestershire. Of these, 24 were situated at Wolverhampton, 3 at Willenhall, 25 at Bilston, 14 at Wednesbury, 26 at Tipton, 13 at West Bromwich and Oldbury, 19 at Walsall, and 47 west of Dudley. In addition there were at Wolverhampton 260 puddling furnaces, with 39 mills and forges; Bilston, 238 puddling furnaces, with 47 mills and forges; Willenhall, 15 puddling furnaces, with 3 mills and forges; Wednesbury, 210 furnaces, with 28 mills and forges; Walsall, 136 furnaces, with 68 mills and forges; Tipton, 172 furnaces, with 47 mills and forges; and Dudley, 131 furnaces, with 13 mills and forges. These figures will afford a good idea of the tremendous industrial activity that prevailed, and it requires little exercise of the imagination to conjure up visions of the combination of smoke and flaming furnace which greeted and, in many cases, startled the stranger.

Bradley and Foster.

While he lived, John Wilkinson was the uncrowned kind of this iron kingdom, but no record of the coal and iron trades of the Midlands would be complete without reference to Reid, Parker, the Addenbrookes, Samuel and John Fereday, Firmestone, and Foley, amongst others, who played a by no means insignificant part in the early iron-making developments. Many memories, too, cluster round the name of James Foster, who became associated with the works of John Bradley & Company, of Stourbridge, established by his uncle John Bradley. Bradley's supplied nail rods to the nailers of Stourbridge, Wordsley, Brierley Hill, Dudley, Sedgeley, and Wolverhampton. At first, the nail makers were accustomed to send their carts to the works for the iron, but Mr. Foster altered this arrangement, delivering the iron in horse wagons, and settling the accounts quarterly. It was through this innovation on the part of Foster that the Ironmaster's Quarter Day originated, and it led eventually to the establishment of the Iron Exchange.

Under the able supervision of Foster, Bradley's developed rapidly. A man of great acumen and enterprise, it is said of him that he never hesitated to put his hand to a bar of iron in case of need. One of his most successful ventures was the purchase of the Madeley Court Estate, Shropshire, overlying seams of the best coal and ironstone in Salop. Here he smelted the ore into pig-iron for use at the Stourbridge works. Foster joined John Baker and George Jones in establishing the great Chillington works. He remained a partner in the concern till his death, when his interests were inherited by his nephew,

W. O. Foster, a member of Parliament, who thoroughly maintained the family reputation for the production of first-class iron. In addition to the parent establishment at Stourbridge, W. O. Foster carried on mills, forges and blast furnaces at Shutt End and Madeley Court, and malleable ironworks at Brockmoor and Brierley Hill.

Another name well known in the industry in those great days was that of Philip Williams, who erected the Wednesbury Oak Works, comprising three furnaces, with extensive mills and forges, which, when in full working order, were regarded as the most complete of their type in South Staffordshire.

A Fortune for Puddled Iron.

At the close of the eighteenth century John and Edward Bagnall, natives of Broseley, and primarily mine owners, launched into iron-making at the Golds Hill Iron Works. On the death of Edward Bagnall, John took his brother's son into partnership, and, under the title of John Bagnall & Sons, the firm gave its name to a brand of iron which was justly famed wherever iron was known throughout the entire world.

The Addenbrookes turned out many excellent iron-makers, but none better than George and Edward Thorneycroft, who established the Shrubbery Works at Wolverhampton, where they made their famous bullet iron, which was in great request among the Lancashire cotton-machine makers. For some time the Thorneycrofts also carried on the old Bradley Works originally belonging to John Wilkinson, and later on they acquired and greatly enlarged Swan Garden Works.

The Sparrow family brought fame to the Stow Heath Furnaces and Bilston Mill. At the former Wm. Hanbury Sparrow made a huge fortune, amounting to between £1,300,000 and £1,500,000. The specialities of the Bilston Mill were rods, bars and hoops. The works were carried on for many years under the name of W. & J. S. Sparrow.

Another leading house, well known throughout the trade, was the New British Iron Company, which ran the Corngreaves works and works at Brierley Hill, comprising no less than 64 puddling and six blast furnaces. The iron manufactured by this firm is said to have been known at all the smithies and engine shops in Europe.

The Addenbrookes worked the Moorcroft concern in John Wilkinson's time, and they also ran three blast furnaces at Rough Hay. They patented a process of drawing off the gas which is said to have eclipsed all other methods. William Ward & Sons and New Priestfields turned out a first-class forge iron, but no works in their day were better equipped than the Earl of Dudley's celebrated malleable ironworks, situated at Round Oak, Brierley Hill, with 54 puddling furnaces. These forges were regarded as the model works of the Black Country, and, indeed, no effort was spared to render their technical efficiency complete.

A Record Puddling Plant.

The record for the largest number of puddling furnaces at one establishment in Staffordshire—one hundred—was held by W. Barrows & Sons, proprietors of the Bloomfield Factory and Tipton Ironworks. The capacity of the concern totalled 1,000 tons of finished iron per week.

Just about a century ago the firm of Bradley, Barrows & Hall enjoyed considerable repute in the iron trade, and the same thing may be said of Earl Granville's forge at Lilleshall. Many of the old ironmasters and founders were rough, hard and uncultured men, but notable exceptions were provided in the case of William Dawes & Sons the proprietors of the Bromford Ironworks, situated near the Oldbury Station. The Dawes family were gentlemen, born and educated. They exported nail rods in large quantities to China. Besides their Oldbury Works, the firm had two blast furnaces at Withymoor, near Dudley.

Roundabout 1853, a method of puddling iron with steel of a kind particularly well suited for the needs of the Sheffield cutlers was discovered in Staffordshire, and amongst the first makers were Messrs. Solley and Leabrook. The Chillington Company, by the way, were also quick to grasp the possibilities of this trade and developed it with marked success. At the same time Isaac Jenks commenced production at the Minerva and Beaver Works at Wolverhampton. Jenks was a man of unusual gifts, who commenced business with the slenderest means and eventually established himself as one of the wealthiest ironmasters in Wolverhampton. He carried his " Minerva " brand of steel into all markets.

Oldest Steelmakers.

The reputation of being the oldest steelmakers in Staffordshire is claimed by Messrs. William Hunt & Sons, of the Brades, Oldbury. Their plant comprised seven puddling furnaces with three mills, with extensive converting ovens on the old Sheffield plan.

The Darlaston Steel and Iron Company took to the old establishment of Bills and Mills, and built up a considerable connection for iron and steel. The Lloyds of Wednesbury, whose association with the staple industries of the community was as long as it was honourable, held a large interest in these works, which were situated at Darlaston Green.

An Ancient Welfare Effort.

It was Samuel Lloyd, perhaps the most famous member of the family, who built the old Park Works at Wednesbury, being joined by Foster. The firm, which was known as Lloyds, Foster & Company, possessed foundries with machine equipment which challenged comparison with anything to be found either at Manchester or on the Tyne. Lloyds, Foster & Company built the beautiful Blackfriars Bridge. Their works were colloquially known as " Quaker " Lloyds,. and jobs there were greatly sought after by local workmen. Samuel Lloyd was the embodiment of beneficence. A " truck " shop (still existing) was connected with the works, and it was known near and far for the superior quality of the goods stocked. The best butcher's meat in Wednesbury, it used to be said, was sold there. Old Samuel Lloyd took a special pride in buying the tea, the bullocks and the sheep himself, and it is related that he often walked up to the shop and looked over it.

Influence of Large Units.

About 1866 Old Park Works were emerged into a limited company called the Patent Shaft and Axletree Company, one of the largest concerns in, Staffordshire, which is still flourishing. Wednesbury is also known, by the way, as the centre of the gas-tube trade. James Russell & Sons were the original patentees. In 1824 Messrs. T. & J. Roberts established the Great Swan Foundry at West Bromwich, which speedily won celebrity both for pipes and machinery.

Thomas Wells set up 22 puddling furnaces and three bar and plate mills at the Moxley Iron Works, and another eminent firm, Marshall & Mills, of the Monway Works, Wednesbury, were reputed to be the makers of the best gun-barrel iron in the world. For years they supplied the iron to the Birmingham gun makers and to the British and American Governments. Henry Mills erected a modern concern, unique of its kind, in the Victoria Works, at Walsall, and the record of the old ironworks and workers may fittingly be completed by mention of the names of the Mars Ironworks, Priestfields, Wolverhampton; the Horsley Company, at West Bromwich, and Wright & North's Monmoor Works.

In recent years the conditions of industry in the Midlands have been transformed. The glare of the hundreds of blast furnaces has to a large extent disappeared, but it does not necessarily follow that the output has been reduced. It has been earlier mentioned that the output, for instance, from a single modern blast furnace in one month is almost equivalent to the total output from all the blast furnaces of the country 200 years ago. The invention of the cupola by John Wilkinson was apparently quickly followed by the erection of new foundries and commencement of new businesses in the Black Country and surrounding districts. It is extremely difficult to obtain reliable information as to the establishment of many of the works, and particularly their subsequent history.

Foundry Establishments.

The foundry of Izons & Company was established in 1763 as "Izon, Whitehurst & Izon" at Duke Street, Birmingham. They were brass and general ironfounders, and the goods manufactured at that time—according to an old catalogue—consisted chiefly of humane man-traps, rat-traps, door-knockers, kitchen-stoves and other household utensils. This business continues to flourish, and it is interesting to note that the present chairman of the company is the great-great-grandson of the founder of the business.

Some 30 years later, in 1791, Archibald Kenrick commenced business as an ironfounder in West Bromwich. The purpose of the foundry was to make articles which were in daily use and constant demand, his principal manufactures being hand-mills for grinding coffee, and cast-iron saucepans. These are still being made in the factory, although many hundred additional articles of manufacture have been introduced. A few years later, about 1794, there was established a foundry at Stourport; the manufactures were somewhat similar to those of Archibald Kenrick. This business is still carried on under the name of Baldwin, Son & Company, being a subsidiary of Messrs. Archibald Kenrick & Sons. In the year 1795 a foundry was established in Wolverhampton by Wm. Clark, and this business is still in existence under the style of T. & C. Clark & Company.

Swan Garden Ironworks.

It has not been possible to obtain definite information, but it is believed that the Swan Garden Ironworks, which for the last 50 years have been carried on by Messrs. John Lysaght, Limited, were one of the original foundries belonging to John Wilkinson. Between the time of Wilkinson and Lysaght the works were carried on by G. & B. Thornycroft, as has already been mentioned. Early in the last century a works was established in Deepfields by Edward Sheldon & Company, also for making cast-iron hollow-ware. These works are still in the hands of the descendants of the Sheldon family, and are now known as the Cannon Ironfoundries, Limited. Mention has already been made of the Coalbrookdale works, which, of course, is still in existence, and also of Boulton & Watts' Soho Foundry, which, as generally known, is now incorporated in the works of Messrs. W. & T. Avery, Limited.

Sufficient has been stated already for it to be gathered that the iron trade in the Midlands has passed through many vicissitudes, with their records of sweeping industrial changes and upheavals. It is therefore an extremely gratifying reflection that many of the old works have stoutly and successfully maintained their positions in the van of progress. The foundries referred to are still conspicuous in the foundry world, and the works are as famous as ever for the quality and variety of their productions. The iron and steel trade and ironfounding in the Midlands has had a wonderful history, the last chapter of which has by no means yet been written.

If this attempt at a brief *résumé* of the iron and steel trades in the Midlands, disjointed though it is, serves no other purpose than to bring to mind some of the almost insuperable difficulties with which our forebears had to contend, it may have served a useful purpose.

THE INSTITUTE OF BRITISH FOUNDRYMEN.

LIST OF MEMBERS.

February 1st, 1930.

B.—Birmingham and West Midlands Branch.
E.M.—East Midlands Branch.
Lncs.—Lancashire Branch.
L.—London Branch.
M.—Middlesbrough Branch.
N.—Newcastle-upon-Tyne Branch.
S.—Sheffield Branch.
Sc.—Scottish Branch.
W. & M.—Wales and Monmouth Branch.
W.R. of Y.—West Riding of Yorkshire Branch.

Gen.—General or unattached to a Branch.

B'nch.	Year of Election.	MEMBERS.
E.M.	1908.	Aiton. J. A. (Aiton & Company), Derby.
S.	1924.	Alder, A. J., Glenora, Langdales Road, Lincoln.
N.	1924.	Allan, F., 7, Dene Street, Sunderland.
S.	1928.	Allan, J. B., 10, Whiteley Wood Road, Sheffield.
S.	1918.	Allan, J. M., "Broomcroft," Parkhead, Sheffield.
B.	1906.	Allbut, J. E. H., Woodcote, Bourne Street, Dudley, Staffs.
W. & M.	1928.	Allday, G. W., Llanerst, Somerton Road, Newport.
S.	1906.	Allen & Company, Edgar (Subscribing Firm), Imperial Steel Works, Sheffield.
B.	1928.	Allen, T. F., The Drive, Gravelly Hill, Birmingham.
E.M.	1924.	Allin, G. E., Ashleigh Grove, Etwall, near Derby.
Sc.	1927.	Anderson, G. L., 25, Cluny Drive, Edinburgh.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1907.	Andrew, F., 643, Oldham Road, Failsworth, Manchester.
Sc.	1920.	Andrew, J. H., D.Sc., Royal Technical College, Glasgow.
Lncs.	1919.	Andrew, J. W., 964, Oldham Road, Thornham, Royton, Oldham.
N.	1925.	Appleyard, K. C., Birtley Springs House, Birtley, Co. Durham.
N.	1921.	Armstrong Whitworth & Co. (Engineers), Ltd., Sir W. G. (Subscribing Firm), Close Works, Gateshead-on-Tyne.
L.	1929.	Arnold, J., Sandy Mount, Leighton Buzzard, Beds.
Sc.	1920.	Arnott, J., 114, Broomhill Road, Newlands, Glasgow.
Lncs.	1924.	Arstall, J., "Kenmarlean," Back, Bowe, Hyde, Cheshire.
M.	1927.	Ashmore, Benson Pease & Co., Ltd. (Subscribing Firm), Parkfield Works, Stockton-on-Tees.
W.R. of Y.	1929.	Aske, Wm., 4, Savile Row. Halifax.
B.	1924.	Aston, A., "Newlyn," Birches Barn Road, Wolverhampton.
L.	1911.	Aston, W. H., 46, Eagle Wharf Road, London, N.
B.	1921.	Athey, J. W. (Major), Fordath Eng. Co., Ltd., Hamblet Works, West Bromwich.
Lncs.	1930	Auckland, W., 130, Markland Hill Lane, Bolton.
Lncs.	1928.	Bacon, J. R., Spring Bank, Bulay Road, Springdale, Huddersfield.
L.	1925.	Bagshawe, A. W. G., Dunstable Works, Dunstable.
Sc.	1929.	Baird, H. A., Loaningdale, Biggar, Scotland.
B.	1920.	Ball, F. A., c/o Ball Bros., Stratford-on-Avon.
B.	1929.	Bamford, W. H., 44, Norfolk Road, Erdington, Birmingham.
M.	1926.	Barbour, A. R., Bon Lea House, Thornaby-on-Tees.

B'nch.	Year of Election.	MEMBERS.
L.	1923.	Bargellesi, G., Foundry Consulting Engineer, Via Tantardini 13, Milano 123, Italy.
L.	1911.	Bartlett, A. R., 1, Lower Park Road, Belvedere, Kent.
L.	1923.	Bartram, J., 369, Grove Green Road, Leytonstone, E.1.
M.	1926.	Bashford, T. E., "Hillingdon," South Road, Norton-on-Tees.
E.M.	1921.	Bates, W. R., United Steel Companies, Limited, Irthlingboro' Iron Works, Wellingboro'.
W.R. of Y.	1930.	Battye, H., Mercer Lea, Deepcar, near Sheffield.
Lncs.	1929.	Baxendale, Rd., 8, Windsor Road, Chorley.
Gen.	1926.	Baxter, J. P., Morro Velho, E.F.C., Raposos Minas, Brazil, S. America.
W. & M.	1922.	Bayley, J. P., "Ty-gwyn," 4, Westfield Road, Clytha Park, Newport, Mon.
Lncs.	1928.	Bayne, James, "Hineawa," Warrington Road, Whiston, near Prescot.
L.	1920.	Beech, A. S., 13-15, Wilson Street, London, E.C.2.
Sc.	1917.	Bell, J., 60, St. Enoch Square, Glasgow.
Sc.	1910.	Bell, W., 14, North Street, Maryport, Cumberland.
Gen.	1922.	Bell, Wm. Dixon, 72, Walpole Road, Itchen, Southampton.
L.	1926.	Belling, C. R., 10, Glebe Avenue, Enfield, Middlesex.
L.	1926.	Bennett, F. H., "Holyrood," 12, Kilmarton Road, Goodmayes, Essex.
W. & M.	1929.	Bennett, J., Elbey, near Stroud, Gloucestershire.
S.	1920.	Benson, E. C., 303, Fulwood Road, Sheffield.
W.R. of Y.	1922.	Bentley, J. N., 2, Grimston Terrace, Hull Road, York.
W.R. of Y.	1922.	Bentley, L. A., Wood End, Bromley Cross, Bolton.
Lncs.	1925.	Best, J. (junr.), "Netherleigh," Manchester Road, Over Hulton, Bolton.

B'nch.	Year of Election.	MEMBERS.
B.	1924.	Bethell, R. P., 51, Sutton Road, Walsall, Staffs.
B.	1925.	Bettinson, C. L., New Bond Street Ironworks, Bordesley, Birmingham.
E.M.	1915.	Bigg, C. W., Someries, Darley Lane, Allestree, near Derby.
S.	1918.	Biggin, Frank, Rye Lodge, Ashland Road, Sheffield.
L.	1929.	Birchall, J. S., c/o 7, Bramhall Street, Rochdale.
N.	1929.	Bird, Major T. G., 5, Manor Terrace, Tynemouth, Northumberland.
N.	1921.	Birtley Iron Company, Ltd. (Subscribing Firm), Birtley, Co. Durham.
W. & M.	1927.	Biss, H. H., "Westcroft," Fields Park Avenue, Newport, Mon.
B.	1922.	Blackburn, W. A., "Wynsill," Lichfield Road, Rushall, Staffs.
L.	1927.	Blackwell, F. O., 29, Westbourne Road, Luton. Beds.
Gen.	1919.	Blair, A., 7, Derryvolgie Avenue, Belfast.
W.R. of Y.	1926.	Blair, J. W., 32, Fifth Avenue, Heworth, York.
W. & M.	1928.	Bloodworth, C. J., 16, Newerne Street, Lydney Junction, Gloucestershire.
L.	1928.	Bone, K. T. J., "Braemar," Hightown Road, Luton.
B.	1912.	Boote, E. M., 11, Lydgate Road, Coventry.
L.	1912.	Booth, C. C., Mildmay Works, Burnham-on-Crouch.
E.M.	1919.	Booth, J. H., Fletton Spring House, Peterborough.
L.	1920.	Booth, P. M., 615, Finchley Road, N.W.3.
Gen.	1929.	Branson, S. A., Zakl. Mech. Ursus, p. Wlochy k/Warszawy, Poland.
N.	1922.	Brailsford, A., 18, Elswick Row, Newcastle-upon-Tyne.
L.	1926.	Brendle, T. F., Hospital Road, Insein, Lower Burma.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1914.	Bridge, W., 199, Drake Street, Rochdale, Lancs.
B.	1928.	Briggs, E. R., "The Mound," Lawford Road, Rugby.
S.	1922.	Brightside Foundry & Engineering Co., Ltd. (Subscribing Firm), Newhall Ironworks, Sheffield.
M.	1926.	British Chilled Roll & Engineering Co., Ltd. (Subscribing Firm), Empire Works, Haverton Hill, Middlesbrough.
Lncs.	1919.	Broad, W., 230, Dumers Lane, Radcliffe, Lancs.
S.	1922.	Brown, E. J., 11, Newlyn Place, Woodseats, Sheffield.
W.R. of Y.	1917.	Brown, P., Park Works, Lockwood, Huddersfield.
S.	1919.	Brown, P. B., Carsick Grange, Sheffield.
Lncs.	1924.	Bruce, A., "Rose Bank," Swanpool Lane, Aughton, Ormskirk, Lancs.
B.	1926.	Buchanan, G., Niagara Foundry Co., Ltd., Bradley, near Bilston.
S.	1928.	Buckley, G. R., Churchfield House, Eckington, near Sheffield.
Gen.	1922.	Bull, R. A., 541, Diversey Parkway, Chicago, Ill., U.S.A.
L.	1924.	Bullers, W. J., Waterloo Foundry, Willow Walk, Bermondsey, S.E.1.
B.	1929.	Bullock, F., 67, Dudley Road, Tipton, Staffs.
Lncs.	1924.	Bullock, T. W., "Shirley," Warrington Road, Rainhill, Liverpool.
E.M.	1910.	Bunting, H., 82, Otter Street, Derby.
E.M.	1905.	Burder, K. M., "Clavering," Ashby Road, Loughboro'.
B.	1922.	Burn, A. J. H., 34, Old Road, Llanelly, S. Wales.
W.R. of Y.	1922.	Burnley, H., Water Lane Foundry, Bradford, Yorks.
S.	1923.	Butler, J., 63, Deepdale Road, Rotherham.
Lncs.	1926.	Button, L. J., 294, Nantwich Road, Crewe.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1929.	Cadman, A. E., 69, Manchester Road, Fairfield, Manchester.
Lncs.	1926.	Cadman, E., 69, Manchester Road, Fairfield, Manchester.
L.	1927.	Calder, N. G., 68, Conyers Road, Streatham, London, S.W.16.
Lncs.	1930.	Calderbank, A., " Strathallan," Urmston Lane, Stretford, Manchester.
Sc.	1917.	Cameron, J. (Cameron & Roberton, Limited), Kirkintilloch.
Sc.	1919.	Cameron, T. P. (Cameron & Roberton, Ltd.), Kirkintilloch.
Sc.	1927.	Campbell, H. D., Shaw (Glasgow) Ltd., Maryhill Iron Works, Glasgow.
Sc.	1911.	Campion, A. (Honorary Life), 8, Thorn Road West, Bearsden, Glasgow.
S.	1923.	Cantrill, W. H., 249, Chatsworth Road, Chesterfield.
N.	1912.	Carmichael, J. D. (Life), Sydenham Terrace, South Shields.
N.	1912.	Carmichael, J. D., Jun., O.B.E. (Life), " Redlea," Grasmere Gardens, Harton, South Shields.
L.	1919.	Carpenter, H. C. H., Prof. (Hon.), 30, Murray Road, Wimbledon, S.W.19.
L.	1929.	Carr, A., Thames Road, Silvertown, London, E.16.
L.	1927.	Cassidy, G. L., c/o The Morgan Crucible Co., Battersea Works, Church Road, Battersea.
S.	1921.	Castle, Geo. Cyril, Beecroft & Partners, Ltd., Mappin Street, Sheffield.
S.	1927.	Cawood, G. R., & Co., Ltd., 1, Cavendish Road, Leeds (Subscribing Firm).
Lncs.	1905.	Chadwick, J. (Life), School Hill Iron Works, 12, Nuttall Terrace, Bolton.
Lncs.	1919.	Chadwick, J. N. (Life Member), School Hill Iron Works, 12, Nuttall Terrace, Bolton.

B'nch.	Year of Election.	MEMBERS.
L.	1919.	Cheesewright, W. F. (Col.), D.S.O., "Padgham," Dallington, Sussex.
L.	1925.	Chell, E., A.M.I.Mech.E., 68, Ferndene Road, London, S.E.24.
L.	1928.	Christopher, H., "Almira," Hillfield Road, Hemel Hempstead, Herts.
Gen.	1923.	Clamer, G. H., 129, So. Berkeley Square, Atlantic City, N.Y.
L.	1925.	Clapp, H. B., 141, Lincoln Road, Peterborough, Northamptonshire.
L.	1928.	Clark, F. H., Theydon Road, Southwold Road, Clapton, London, E.
S.	1922.	Clark, G., 61, Westbourne Road, Sheffield.
L.	1928.	Clark, H. A., Theydon Road, Southwold Road, Clapton, London, E.
L.	1915.	Clark, H. S., 17, Filey Avenue, Stoke Newington, London, N.16.
E.M.	1919.	Clarke, A. S., "Lyndesfarn," Leicester Road, Loughborough.
L.	1928.	Clayton, G. C., 9, Lawn Road, Hampstead, N.W.3.
L.	1917.	Cleaver, C., 10, Ringcroft Street, Holloway, N.1.
W. & M.	1917.	Clement, W. E., Morfa Foundry, New Dock, Llanelly.
L.	1913.	Coan, R., Aluminium Foundry, 219, Goswell Road, E.C.1.
L.	1926.	Coggon, H. F., 10, Rhodesia Avenue, Halifax.
L.	1927.	Coleman, C. W., 1, Lancaster Place, Waterloo Bridge, Strand, London, W.C.2.
L.	1922.	Coll, J., Fundicion de San Antonio S.A., Seville, Spain.
B.	1927.	Collier, J. V., 45, Sheep Street, Northampton.
N.	1912.	Collin, J. J., 55, Cleveland Road, Sunderland.
N.	1916.	Collin, T. S., 4, Argyle Square, Sunderland.
N.	1926.	Colls, F. C., Clarendon House, Clayton Street, Newcastle.

B'nch.	Year of Election.	MEMBERS.
N.	1922.	Consett Iron Co., Ltd. (Subscribing Firm), Consett, Co. Durham.
B.	1904.	Cook, F. J., M.I.Mech.E., 31, Poplar Avenue, Edgbaston, Birmingham.
S.	1929.	Cook, G. N., 34, Rutland Park, Sheffield.
Lncs.	1911.	Cooper, C. D., Dolphin Foundry, Chapel Street, Ancoats, Manchester.
N.	1921.	Cooper, J. H., 69, Stanhope Road, Darlington.
L.	1925.	Cooper, M. J., 5, Mildmay Road, Burnham-on-Crouch, Essex.
L.	1928.	Corbin, F. D., 4, Gloucester Street, London, S.W.1.
L.	1928.	Corrie, J. B., Co., Ltd., 15, Victoria Street, Westminster, S.W.1 (Subscribing Firm).
L.	1926.	Coupe, J., 9, Delhi Road, Edmonton, London, N.9.
Sc.	1928.	Cowan, H., B.Sc., Foundry Technical Institute, Meeks Road, Falkirk.
Lncs.	1924.	Cowlishaw, S. D., 7, Temple Street, Basford, Stoke-on-Trent.
L.	1925.	Cowper, L., "Dellwood," Leichhardt Street, Gleve Point, Sydney, N.S.W., Australia.
E.M.	1914.	Cox, J. E. (The Rutland Foundry Company, Limited), Ilkeston.
L.	1927.	Cox, S., 39, Gerrard Street, Shaftesbury Avenue, London, W.1.
B.	1922.	Cramb, F. M., 5, Triangle Villas, Oldfield Park, Bath.
L.	1929.	Crawshaw, H., 275, Rue Victor Ranter, Auderlecht, Brussels.
L.	1910.	Cree, F. J., 22, Prospect Avenue, Strood, Kent.
L.	1911.	Creighton, T. R., The Foundry, Stepney Causeway, E.
Lncs.	1927.	Crewdson, Capt. R. B., 16, Norfolk Crescent, Hyde Park, London, W.
W.R. of Y.	1922.	Croft, Frank, Crofts, Ltd., Bradford.
M.	1926.	Crosthwaite, C., Thornaby Hall, Thornaby-on-Tees.

B'nch.	Year of Election	MEMBERS.
M.	1926.	Crosthwaite, Ltd., R. W. (Subscribing Firm), Union Foundry, Thornaby-on-Tees.
Sc.	1929.	Cumming, W., & Co., Ltd., Kelvinvale Mills, Maryhill, Glasgow (Subscribing Firm).
L.	1923.	Curtis, A. L., 39, London Road, Chatteris, Cambs.
W. & M.	1929.	Curtis, J., Church Road, Charlestown, St. Austell, Cornwall.
Lncs.	1925.	Daniels, W., 74, Smethurst Lane, Bolton.
N.	1925.	Darlington Railway Plant & Foundry Co., Ltd. (Subscribing Firm), Bank Top, Darlington.
Gen.	1926.	Darnis, I. S., Ingenerio Industrial, Altos Hornos de Vizcaya, Apartado 116, Bilbao, Spain.
Lncs.	1926.	Davenport, J., Myrtle Bank, Grimsargh, Preston.
W. & M.	1928.	Davies, John, 12, Windsor Road, Treforest, S. Wales.
Gen.	1919.	Davies, P. N., 29, Brunswick Road, Brunswick, Melbourne, Victoria, Australia.
L.	1927.	Davis, J. K., Davis Gas Stove Co., Luton, Beds.
B.	1928.	Dawkins, W. A., Lansdowne Avenue, Codsall, Wolverhampton.
Lncs.	1924.	Dawson, S. E., 8, Lynton Park Road, Cheadle, Hulme, Cheshire.
Lncs.	1924.	Deakin, F., 14, Belfield Road, Reddish, Stockport.
B.	1918.	Deakin, W., "Thornlea," Sandy Hill, Shirley, Birmingham.
Gen.	1925.	Dean, J. P., 9, Stalmine Road, Walton, Liverpool.
Sc.	1927.	Deas, John, c/o John Deas & Co., Ironfounders, Market Street, Glasgow, E.
M.	1919.	Deas, P., 4, Blenheim Terrace, Coatham, Redcar.
L.	1925.	Delport, V. (Capt.), 2-3, Caxton House, S.W.1.

B'nch.	Year of Election.	MEMBERS.
B.	1924.	Denham, H., "Birchwood," Walsall Road, Aldridge, Staffs.
S.	1917.	Desch, Professor, C. H., D.Sc., Ph.D., F.R.S., F.I.C., The University, Sheffield.
L.	1927.	Deschamps, J., "The Coppice," Garth Road, Letchworth.
L.	1930.	Dewrance & Co., 165, Great Dover Street, London, S.E.1 (Subscribing Firm).
L.	1926.	Dews, H. C. (Dewrance & Co.), 165, Great Dover Street, S.E.1.
B.	1921.	Dicken, Charles H., "New Vale," Station Road, Balsall Common, Coventry.
S.	1924.	Didden, Capt., F. G. J. M.I.Mech.E., Broad Elms Lane, Ecclesall, Sheffield.
B.	1928.	Dobson, F. E., "Oaksey," Lichfield Road, Four Oaks, Warwickshire.
L.	1914.	Dobson, W. E., "Newlyn," Grand Drive, Raynes Park, S.W.
B.	1926.	Dodd, W., 68, Allport Road, Cannock, Staffs.
Lncs.	1928.	Dodds, J. W., Kensington House, Ashfield Road, Chorley, Lancs.
Lncs.	1928.	Doodson, T. E., "Glenroyd," Hesketh Drive, Southport.
Sc.	1911.	Doulton, B. (Life), Home Court Hotel, 137, Maple Road, Surbiton, Surrey.
M.	1927.	Downing, A. G., 2, Oxford Street, Stockton-on-Tees.
Lncs.	1927.	Drake, T., South Bank, Stockport Road, Timperley, Cheshire.
E.M.	1929.	Driver, J. F., M.I.Mech.E., 65, Middleton Place, Loughborough.
S.	1921.	Duckenfield, W., 47, Dunkeld Road, Ecclesall, Sheffield.
L.	1928.	Duguid, Islor, 119, High Holborn, W.C. 1.
L.	1925.	Durnan, F., Camelon Iron Works, Falkirk.
Lncs.	1926.	Durrans, J., The Croft, Penistone.

B'nch.	Year of Election.	MEMBERS.
L.	1929.	Dykmans, L., Negler & Cie, Fonderie de Fer, 82-86, Rue Everaerts, Antwerp, Belgium.
S.	1921.	Edginton, G., Silverdale, St. Margaret's Drive, Chesterfield.
B.	1922.	Edwards, A.," Dunbar," Old Bath Road, Cheltenham.
M.	1927.	Edwards, A., 17, Jesmond Avenue, Linthorpe, Middlesbrough.
N.	1921.	Eldred, E. J., 8, Ford Street, Gateshead-on-Tyne.
L.	1904.	Ellis, J., 51, Riddings Lane, Wednesbury.
S.	1918.	Elliss, J. A., 217, Middlewood Road, Sheffield.
S.	1913.	Else, L. H., 79, Osborne Road, Sheffield.
Sc.	1925.	English, J., c/o Younger, 32, Stevenston Drive, Shawlands, Glasgow.
S.	1922.	English Steel Corporation, Ltd., Vickers Works, Sheffield.
L.	1926.	Evans, S., 22-23, Laurence Pountney Lane, Cannon Street, London, E.C.4.
E.M.	1918.	Evans, W. T., Mount Pleasant, Sunny Hill, Normanton, Derby.
S.	1920.	Fairholme, F. C., Norfolk Works, Sheffield.
Lncs.	1926.	Farrington Steel Foundry of Leyland Motors, Ltd. (Subscribing Firm), Leyland, Lancs.
L.	1908.	Faulkner, V. C , 49, Wellington Street, Strand, London, W.C.2.
S.	1910.	Feasey, J., 192, West Parade, Lincoln.
B.	1914.	Field, H., "Glenora," Richmond Avenue, Wolverhampton.
B.	1904.	Finch, F. W. (Hon. Life), 52, Denmark Road, Gloucester.
S.	1914.	Firth, A., 29, Ivy Park Road, Sheffield.
S.	1914.	Firth, F. W., " Storth Oaks," Ranmoor, Sheffield.
Gen.	1907.	Flagg, S. G. (Honorary), 1407, Morris Buildings, Philadelphia, Penn., U.S.A.
B.	1923.	Flavel, P., Buchbury Lodge, Leamington.

B'nch.	Year of Election.	MEMBERS.
B.	1922.	Fletcher, J. E., M.I.Mech.E., 8, St. James Road, Dudley, Staffs.
Lncs.	1923.	Flower, E., 7, Marlborough Street, Higher Openshaw, Manchester.
W. & M.	1907.	Fontaine, C., Dock Foundry, Newport, Mon.
Sc.	1917.	Forbes, J. T., 176, West George Street, Glasgow.
B.	1926.	Fordath Engineering Co., Ltd. (Subscribing Firm), Hamblet Works, West Bromwich.
W.R. of Y.	1922.	Forrest, H., 43, Beaumont Road, Manningham, Bradford.
N.	1919.	Fortune, T. C., 76, Falmouth Road, Heaton, Newcastle-upon-Tyne.
B.	1919.	Fosseprez, G., 3, Rue de Grand Jour, Mons, Belgium.
—	1926.	Fox, F. S., 5532, Webb Avenue, Detroit, Michigan, U.S.A.
W.R. of Y.	1925.	Frame, J. Y., 19, Sherburn Street, Hull.
L.	1926.	France, G. E., "Lowther," Exley Lane, Elland, Yorks.
Sc.	1920.	Fraser, A. R., High Craigton, near Milngavie.
N.	1914.	Frier, J. W., 5, Northumberland Villas, Wallsend-on-Tyne.
L.	1919.	Furmston, A. C., Hope Cottage, 211, Neville Road, Letchworth.
L.	1929.	Galbraith, P. P., 57, Belmont Road, Bushey, Herts.
W. & M.	1924.	Galletly, J. P., Ben Clench, Pencisely Road, Cardiff.
B.	1928.	Gameson, T. H., 47, Somerset Road, Handsworth Wood, Birmingham.
L.	1922.	Gardom, J. W., 39, St. Peters Road, Dunstable, Beds.
B.	1928.	Garman, B. A., Yew Tree House, Great Barr, Birmingham.
Lncs.	1922.	Garner & Sons, Limited (Subscribing Firm), Victoria Street, Openshaw, Manchester.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1919.	Gartside, F., 18, George Street, Chadderton, Lancs.
Gen.	1927.	Geilenkirchen, T., Düsseldorf, Faunastr. 37, Germany.
L.	1926.	George, H., " Southdene," High Street, Dunstable.
Sc.	1919.	Gibb, J.,Blairmore, Newmains, Scotland.
L.	1922.	Gibbs, A. F., 55, Gordon Road, Wanstead, Essex.
L.	1930.	Gilbert, T. F., 52, Granville Park, Lewisham, S.E. 13.
S.	1925.	Gill, C. S., 60, Riverdale Road, Sheffield.
Sc.	1920.	Gillespie, P., " Glenora," Falkirk Road, Bonnybridge.
Sc.	1925.	Gillespie, W. J. S.
E.M.	1915.	Gimson, H., " Rhoscolyn," Toller Road, Leicester.
E.M.	1906.	Gimson, S. A., 20, Glebe Street, Leicester.
E.M.	1928.	Glover, W., 42, Elm Tree Avenue, Victory Road, Normanton, Derby.
S.	1929.	Goddard, A. V., " Brentwood," King Egbert Road, Totley, Sheffield.
S.	1905.	Goodwin, J. T., M.B.E., M.I.Mech.E., " Glen Craig," Avenue Road, Whittington Moor, Chesterfield.
L.	1930.	Gossell, K. (Capt.), 110, Cannon Street, London, E.C. 4.
W. & M.	1917.	Gould, P. L., Vulcan Foundry, East Moors, Cardiff.
Sc.	1921.	Graham, J., 68, Sherbrooke Avenue, Maxwell Park, Glasgow.
L.	1926.	Grange, R., 2, Renters Avenue, Hendon, London, N.W. 4.
Lncs.	1920.	Grant, G. C., English Steel Corporation, Ltd., Ashton Old Road, Openshaw, Manchester.
N.	1921.	Gray, C. R., 14, Latimer Street, Tynemouth.
L.	1926.	Gray, T. H., 119, High Holborn, W.C.1.
L.	1927.	Greaves, Dr. R. H., 6, Clifton Terrace, Southend-on-Sea.
E.M.	1930.	Green, C. S., Willow Croft, Little Eaton, Derby.

B'nch.	Year of Election.	MEMBERS.
B.	1925.	Greensill, G. B., "Lynn," Jockey Road, Sutton Coldfield.
N.	1912.	Greensitt, R. H., 24, Stuart Terrace, Felling-on-Tyne.
E.M.	1920.	Greenwood, R., Craven Bros., Ltd., Reddish, near Manchester.
N.	1917.	Gresty, C., 101, Queen's Road, Monkseaton.
W. & M.	1927.	Griffin, E. H., 196, Henleage Road, Henleage, Bristol.
W. & M.	1906.	Griffiths, H., 70, Partridge Road, Cardiff.
Lncs.	1927.	Grundy, H., 20, Thoresway Road. Longsight, Manchester.
W. & M.	1928.	Gundry, P., Polbathic, Cornwall.
S.	1929.	Gutteridge, C., Effingham House, Tile Hill, near Coventry.
S.	1910.	Hadfield, Sir R. A. (Hon.), Hadfields, Limited, Hecla Works, Sheffield.
E.M.	1927.	Hadfield, S., White Lodge, Keyham, near Leicester.
Lncs.	1906.	Haigh, J., Swindon Bank Farm, Pannal, near Harrogate.
W. & M.	1924.	Haines, A. D., Penybryn, Tynypwll Road, Whitchurch, Glam.
W.R. of Y.	1919.	Haley, G. H., Nab Wood House, 6, Tower Road, Shipley, Yorks.
W.R. of Y.	1929.	Hall, R. P., Moorland Avenue, Barnsley.
L.	1926.	Hall, S., 440, Fifth Street, Shawinigan P.O., Canada.
Lncs.	1927.	Hall, T. W., "Ansdel," 7, Greenleach Lane, Worsley, Lancs.
Lncs.	1923.	Hammond, R., 37, Church Road, Smithills, Bolton.
E.M.	1914.	Hammond, Wm., Samson Foundry, Syston, Leicester.
E.M.	1928.	Hammond. Wm., & Co., Ltd., Syston, near Leicester (Subscribing Firm).
S.	1926.	Hampton, C. W., 5, Chorley Drive, Fulwood, Sheffield.

B'nch.	Year of Election.	MEMBERS.
B.	1929.	Hanson, Prof. D., D.Sc., The University, Birmingham.
B.	1910.	Harley, A., Ashlea, Stoke Park, Coventry.
B.	1925.	Harper, W. E., Dudley Foundry Co., Ltd., Moor Lane, Brierley Hill, Staffs.
L.	1918.	Harris, A. J. A. (Capt.), "Grovallia," Laburnum Road, Doncaster.
Lncs.	1922.	Harris, F., 18, Holland Street, Padiham.
S.	1928.	Harrison, J., 29, Troughbrook Road, Hollingwood, near Chesterfield.
M.	1926.	Harrod, H., 18, Egglestone Terrace, Stockton-on-Tees.
Gen.	1922.	Harvey, André, 118, Spring Road, Kempston, Bedford.
B.	1929.	Hashimoto, S., Mitsui Bussan Zosenbu, Tama, Okayamaken, Japan.
S.	1909.	Hatfield, W. H., D.Met., The Brown Firth Research Laboratory, Princess Street, Sheffield.
N.	1921.	Hawthorn, Leslie & Company, R. & W. (Subscribing Firm), St. Peter's Works, Newcastle-upon-Tyne.
Sc.	1928.	Hay, J., 24, Buchanan Drive, Rutherglen.
L.	1926.	Hearn, J. E.. Craig-y-don, West Hill, Luton.
S.	1928.	Hearnshaw, L., "Gleneagles," Manor Road, Brimington, near Chesterfield.
Lncs.	1925.	Heatley, J., 146, Redlam, Blackburn.
L.	1928.	Heeley, W. H., Southern Foundries (1926), Ltd., Purley Way, Croydon, Surrey.
Lncs.	1918.	Helm, R. W., c/o Francis Helm, Ltd., Victoria Foundry, Padiham, Lancs.
B.	1929.	Hemming, F. J., 78, Highgate, Walsall.
Gen.	1926.	Henderson, P.C., M.P., The Right Hon. Arthur (Honorary), 33, Eccleston Square, London, S.W.1.
L.	1928.	Hendra, W., 16, Muncaster Road, West Side, Clapham Common, S.W.11.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1923.	Hensman, A. R., 121, Plymouth Grove, Charlton-on-Medlock, Manchester.
N.	1913.	Herbst, M. B., 23, Saltwell View, Gateshead-on-Tyne.
Lncs.	1926.	Hesketh, F., Yarrow Cottage, Broad Lane, Rochdale.
Lncs.	1925.	Hesketh, F. W., 68, Shaw Road, Thornham, Rochdale.
Lncs.	1926.	Hetherington & Sons, Ltd., John (Subscribing Firm), Vulcan Works, Pollard Street, Manchester.
L.	1927.	Hickman, G. E., Greensteps, Park, Chase, Guildford.
B.	1926.	Hieatt, H. J., Austin Bungalow, Stone Lane, Kinver, Staffs.
L.	1926.	Hider, G. E., Upton Foundry, Torquay.
B.	1928.	Hill, S. A., "Hillfields," Bewdley, Gloucester.
S.	1929.	Hinckley, G. P., "Ferndene," Beauchief, Sheffield.
W. & M.	1912.	Hird, B., "Woodcot," Upper Cwmbran, near Newport, Mon.
L.	1923.	Hobbs, F. W. G., Standard Brass Foundry, P.O. Box 229, Benoni, Transvaal, S.A.
L.	1929.	Hobkirk, W. B., 26, Bunyan Road, Kempston, Beds.
Sc.	1919.	Hodgart, H. M., Vulcan Works, Paisley.
Lncs.	1923.	Hodgkinson, A., Ford Lane Works, Pendleton, Manchester.
Lncs.	1914.	Hodgson, A., 14, Park Range, Victoria Park, Manchester.
Lncs.	1912.	Hogg, J., 321, Manchester Road, Burnley, Lancs.
B.	1927.	Hole, S. B., "Bourne House," Franchise Street, Wednesbury.
L.	1928.	Holmes, W. E., 1, Coronation Road, Plaistow, London, E.13.
B.	1924.	Homer, W. A., 87, Frederick Street, Walsall, Staffs.

B'nch.	Year of Election.	MEMBERS.
Sc.	1914.	Hood, John McLay (Life), 54, Maxwell Drive, Pollokshields, Glasgow.
L.	1930.	Hooper, Barrington, C.B.E., 49, Wellington Street, Strand, London, W.C.2.
L.	1927.	Horsman, S. B., 1, Greenhill, Sutton, Surrey.
L.	1927.	Horsman, W. B., 1, Greenhill, Sutton, Surrey.
L.	1920.	Housby, I., 345, Norwich Road, Ipswich.
Lncs.	1922.	Howard & Bullough, Ltd. (Subscribing Firm), Accrington, Lancs.
B.	1923.	Hudson, F., c/o Fordath Engineering Co., Ltd., West Bromwich.
L.	1924.	Hunt, N. H., c/o Gas Accumulator Co., Ltd. (India); c/o Viartans, 6, Olive Street, Calcutta.
L.	1920.	Hunt, R. J., "Greenhills," Earls Colne, Essex.
N.	1920.	Hunter, Hy., High Cottage, King's Road, Wallsend.
Lncs.	1917.	Hunter, H. E., Barton Hall Engine Works, Patricroft, Manchester.
N.	1929.	Hunter, S., junr., Kenton Hall, Kenton, Newcastle-upon-Tyne.
B.	1907.	Hurren, F. H., Coventry Malleable, Ltd., Lincoln Street, Coventry.
S.	1920.	Hurst, F. A., Woofindin Avenue, Ranmoor, Sheffield.
Sc.	1927.	Hurst, H., 40, Colinslee Avenue, Lockfield, Paisley.
S.	1914.	Hurst, J. E., 56, Housely, Chapeltown, Nr. Sheffield.
L.	1925.	Hutton, R. S., D.Sc., The Greenway, High Wycombe, Bucks.
S.	1911.	Hyde, J. R., A.M.I.Mech.E., "Hillcrest," Clayton Road, Newcastle, Staffs.
S.	1922.	Hyde, Robert, & Son, Ltd. (Subscribing Firm), North Stafford Steel Works, Stoke-on-Trent.

B'nch.	Year of Election.	MEMBERS.
M.	1929.	Ingall, D. H., D.Sc., " Thornlea," Roman Road, Middlesbrough.
B.	1929.	Ireland, S. L., 875, Pershore Road, Selly Park, Birmingham.
Lncs.	1925.	Jadoul, J. E., 325, Moss Lane East, Manchester.
L.	1925.	James, A. W., 1, Broomhill Road, Ipswich.
L.	1926.	James J. A., 101, Stoke Road, Slough, Bucks.
L.	1911.	Jarmy, J. R., " Ajaccio," Abbey Road, Leiston, Suffolk.
Sc.	1929.	Jefferson, J., A.R.S.M., Glenmavis, By Airdrie, Scotland.
W. & M.	1928.	Jeffries, J. J., & Sons, Ltd., Holwells Foundry, Hodwell Road, Bristol.
Gen.	1927.	Jenkins, A., 29, Invicta Road, Sheerness, Kent.
S.	1917.	Jenkinson, S. D., Cromwell House, Wincobank, Sheffield.
L.	1904.	Jewson, H., Norwich Road, East Dereham, Norfolk.
L.	1921.	Jewson, K. S., 3, Elvin Road, Dereham, Norfolk.
E.M.	1909.	Jobson, V., Qualcast, Ltd., Derby.
Lncs.	1928.	Johnson, H., Sudan Government Railways, Atbara, Sudan.
Lncs.	1920.	Jolley, W., " Beechcroft," The Avenue, Ashton-on-Mersey, Cheshire.
W. & M.	1928.	Jones, C. E., 65, Cathedral Road, Cardiff.
Lncs.	1922.	Jones, G. A., 54, Fox Street, Edgeley, Stockport.
E.M.	1928.	Jones, J. J., " Southover," Beacon Road, Loughborough.
B.	1925.	Jones, O. P., 25, Rathbone Road, Bearwood, Birmingham.
Lncs.	1927.	Jones, R. A., 95, Moorfield Road, Pendleton, Manchester.
Lncs.	1930.	Jones, W. H., Thorncliffe, Ross Avenue, Whitefield, Manchester.
N.	1929.	Jopling, T. W., " Ash Lea," Thornhill Park, Sunderland.

B'nch.	Year of Election.	MEMBERS.
L.	1927.	Kain, C. H., Lake & Elliott, Ltd., Braintree, Essex.
S.	1921.	Kayser, J. F., 30, Oakhill Road, Nether Edge, Sheffield.
Lncs.	1925.	Kelly, A. T., 31, Windbourne Road, St. Michaels, Liverpool, S.
L.	1917.	Kelly, Jas., 74, Rotherfield Street, N.1.
Lncs.	1922.	Kent, C. W., 9, Dalston Drive, Didsbury.
Lncs.	1919.	Kenyon, H. M., "Sunny Bank," Whalley Road, Accrington.
Lncs.	1910.	Kenyon, M. S., Waterloo, Whalley Road, Accrington.
Lncs.	1904.	Kenyon, R. W., Entwistle & Kenyon, Limited, Accrington.
Lncs.	1907.	Key, A. L., 229, Stockport Road, Cheadle, Cheshire.
Sc.	1927.	Kidston, R., Springbank, Falkirk.
B.	1928.	King, A., 14, Alexandra Road, King's Hill, Wednesbury.
Sc.	1914.	King, D., Keppoch Ironworks, Possil Park, Glasgow.
L.	1927.	King, E. G., The Louis Cassier Co., Ltd., 22, Henrietta Street, Covent Garden, London, W.C.2.
Sc.	1904.	King, J., 100, Wellington Street, Glasgow.
Sc.	1919.	Kinnaird, George, 21, St. Ann's Drive, Giffnock, Glasgow.
W. & M.	1924.	Kinsman, W. S., 116, Miskin Street, Cardiff.
L.	1929.	Kitching, W. J., 52A, The Promenade, Palmer's Green, N.13.
S.	1925.	Kitching, W. T., c/o John Fowler, Don Foundry, Sheffield.
L.	1922.	Lake W. B., Lake & Elliot, Ltd., Braintree.
L.	1921.	Lambert, Wesley, "Whitefriars," 41, Bromley Road, S.E.6.
Sc.	1907.	Landale, D. (Life), 36, Great King Street, Edinburgh.
Gen.	1922.	Lane, H. M., 333, State Street, Detroit, Michigan, U.S.A.

B'nch.	Year of Election.	MEMBERS.
Sc.	1928.	Lang, J., Calderside, Jerviston Street, Motherwell.
Gen.	1927.	Langenohl, M., Gelsenkirchen, Bulmkerstr. 83, Germany.
L.	1927.	Larke, W. J., Sir, K.B.E., "Eastburn," St. John's Road, Sidcup, Kent.
B.	1927.	Lathe, A., "Westlands," Compton Road, Wolverhampton.
L.	1930.	Laverton, W. T., Jesmondene, George Road, Braintree, Essex.
L.	1921.	Lawrence, Geo. D., 5, Clare Road, Leytonstone, E.11.
Sc.	1907.	Lawrie, A., 20, McKinlay Place, Kilmarnock, Scotland.
B.	1927.	Lee, C. P., The Municipal Engineering Dept., Municipality, Singapore.
B.	1926.	Lench, T. C., "The Beeches," Blackheath, Birmingham.
G.	1922.	Leonard, J. (Hon.), 41, Quai du Canal, Herstal, Belgium.
E.M.	1928.	Leys Malleable Castings Co., Ltd., Derby (Subscribing Firm).
W.R. of Y.	1922.	Liardet, A. A., Leyland Motors, Ltd., Leyland, Lancs.
N.	1920.	Lillie, G., "Bloomfield," Strathmore Road, Rowlands Gill, Co. Durham.
B.	1930.	Lister, F. H., "The Actrees," Berkeley, Glos.
S.	1913.	Little, J., 20, St. Ann's Square, Manchester.
L.	1922.	Littleton, W. H., 29A, Worbeck Road, Anerley, S.E.20.
B.	1927.	Lloyd, D. C., Stockwell End, Tettenhall, near Wolverhampton.
W. & M.	1930.	Lloyd, R. A., 1, Inverness Place, Roath Park, Cardiff.
B.	1926.	Lloyd, W., 285, Arthur Street, Small Heath, Birmingham.
N.	1918.	Logan, A. (R. & W. Hawthorn, Leslie & Company, Ltd.), St. Peter's Works, Newcastle.

B'nch.	Year of Election.	MEMBERS.
S.	1927.	Lomas, A., Red Ridges, Rivelin, near Sheffield.
E.M.	1928.	London Midland & Scottish Railway Co., Euston Station, N.W.1 (Subscribing Firm).
Lncs.	1921.	Longden, Ed., 158, Manley Road, Whalley Range, Manchester.
Sc.	1922.	Longden, J., 11, Drumry Road, Clydebank.
S.	1904.	Longmuir, P., D.Met., 2, Queen's Road, Sheffield.
Lncs.	1913.	Longworth, T. P., Moorside, Horrocks Fold, Bolton.
W.R. of Y.	1913.	Loxton, H., Hill Bros., Nevin Foundry, Leeds.
E.M.	1913.	Lucas, J., "Sherwood," Forest Road, Loughborough.
L.	1921.	Lum, Harry, "Booth-Royd," Wayville Road, Dartford, Kent.
B.	1928.	Lunt, G. T., Briardene, Newbridge Avenue, Wolverhampton.
Sc.	1925.	McArthur, J., "Hawthorn," Shields Road, Motherwell.
Sc.	1929.	M'Cance, A., D.Sc., Westview, Uddington, Scotland.
W. & M.	1922.	McClelland, J. J., "Druslyn," 81, Bishops Road, Whitchurch, Glam.
Lncs.	1930.	MacColl, H. A., B.Sc. "Westburne," Liverpool Road, Ainsdale, Southport.
Sc.	1928.	McFarlane, P., Leicester Avenue, Kelvinside, Glasgow.
Sc.	1919.	McFedries, T., 17, Kirktonholm Street, Kilmarnock.
S.	1916.	McGrah, F. E., 19, Lonsdale Road, Wolverhampton.
L.	1919.	McIntosh, 1, Ecclesbourne Avenue, Duffield, Derby.
Lncs.	1924.	MacKay, M., 109, Edmund Street, Rochdale.
Sc.	1914.	MacKenzie, Alex. D., B.Sc., 35, Braid Road, Edinburgh.
Sc.	1910.	Mackenzie, L. P., 5, Polwarth Terrace, Balcarres Street, Edinburgh.

B'nch.	Year of Election.	MEMBERS.
Sc.	1922.	McKinnon. Gavin, 1477, Dumbarton Road, Scotstoun, Glasgow.
Lncs.	1921.	McLachlan, Jas., 2, Broadoaks Road, Washway Road, Sale, near Manchester.
Gen.	1922.	McLain, D. (Hon.), 710, Goldsmith's Buildings, Milwaukee, Wis., U.S.A.
Lncs.	1923.	McLean, C. G., 14, Jemmett Street, Preston.
Sc.	1929.	McLellan, W. Turner, C.B.E., Clutham House, 10, Princes Street, London, S.W.1.
N.	1928.	Mackay, J. S., 5, Wolverleigh Terrace, Gosforth, near Newcastle-upon-Tyne.
L.	1929.	McManus, F. P., Major, Robinson & Co., 385, City Road, Manchester.
Sc.	1930.	McManus, N., M.B.E., Nyasa, Eglinton Drive, Giffnock, Scotland.
Lncs.	1928.	McMinn, G. M., "Bonnyrigg," Westfield Road, Cheadle Hulme, Manchester.
Sc.	1928.	McPhail, D., 33, Burlington Avenue, Kelvindale, Glasgow.
N.	1918.	McPherson, T., M.B.E., 53, Percy Park Road, Tynemouth.
B.	1910.	McQueen, D., 6, Anchorage Road, Erdington, Birmingham.
Sc.	1918.	McTurk, J. B., Dorrator Iron Company, Falkirk.
B.	1925.	Maddock, D. W., 21, Waterloo Road, Wellington, Shropshire.
Lncs.	1917.	Makemson, T., 21, Beresford Road, Stretford, Manchester.
S.	1921.	Mander, T. G., Norris Deakin Buildings, King Street, Sheffield.
Lncs.	1919.	Markland, T. W., 327, Tonge Moor Road, Bolton.
L.	1927.	Marley, C., "Harewood," Park Hill Road, Chingford, E.4.
N.	1918.	Marr, J. H., North Biddick Hall, Washington, Co. Durham.
Lncs.	1929.	Marsden, F., "Marshdene," Cecil Road, Hale, Cheshire.

B'nch.	Year of Election.	MEMBERS.
S.	1922.	Marshall, J., "The Willows," Barrow Hill, Chesterfield.
S.	1928.	Mason, C. L., "Sandygate Towers," Sheffield.
L.	1928.	Mason, J., 123, Waddon Park Avenue, Croydon.
B.	1929.	Mason, N., Alexandra Lodge, The Wood, Streetly, Birmingham.
L.	1924.	Mason, W. C., Richardson & Cruddas, Byculla Iron Works, Bombay, India.
B.	1927.	Mason, W. H., The Poplars, 84, Hall Green Street, Bradley, Bilston.
Lncs.	1917.	Masters, J., "The Hollins," Vane Road, Longden Road, Shrewsbury.
L.	1911.	Mather, D. G. (Mather & Smith), Ashford Foundry, Godinton Road, Ashford.
S.	1915.	Mather, T., South View, Carholme Road, Lincoln.
L.	1926.	Matthieson, R., 37, Closeside, Enfield, Middlesex.
Sc.	1930.	May, R. L. McL., Kushtia, E.B.Ry., Bengal, India.
L.	1921.	Mayhew, C. M., 60, Ewesley Road, Sunderland.
Lncs.	1917.	Meadowcroft, Wm. H., 10, Hambledon View, Habergham, Burnley.
Lncs.	1919.	Medcalf, W., 265, Manchester Road, Burnley, Lancs.
B.	1927.	Mees, J. H., 129, King William Street, Stourbridge.
L.	1929.	Mellerup, A. E., "Woodfield," Dursley, Gloucestershire.
S.	1922.	Melmoth, F. A., "Lyndhurst," Aughton Road, Swallownest, Sheffield.
M.	1926.	Mercer, J. E., "Sunnydene," Harlsey Road, Hartburn, Stockton-on-Tees.
Lncs.	1912.	Milburn, J., Hawkshead Engineering Works, Workington.
Gen.	1919.	Miles, F. W.
S.	1921.	Miles, R. (Major), Chapeltown, nr. Sheffield.
Lncs.	1916.	Miles, R. A., 46, Dean Lane, Newton Heath, Manchester.

B'nch.	Year of Election.	MEMBERS.
Sc.	1928.	Millar, A. C., 24, Hillhead Avenue, Jerviston, Motherwell.
Sc.	1927.	Miller, J., 7, Eildon Villas, Mount Florida, Glasgow.
Sc.	1930.	Milligan, W., Kizil Mansion, Clydebank.
Lncs.	1918.	Mills, Hilton, 9, Stocks, Alkrington, Middleton, Lancs.
Gen.	1924.	Mills, R. C., 90, Kelsey Street, Waterbury, Conn., U.S.A.
Gen.	1923.	Mitchell, A. M.
Sc.	1930.	Mitchell, J., " Rhubeg," Busby, Lanarkshire.
Sc.	1920.	Mitchell, W. W., Darroch, Falkirk.
Gen.	1910.	Moldenke, Dr. R. (Hon. Member), Watchung, New York.
L.	1919.	Molineux, W. J., Glencairn, Manor Street, Braintree, Essex.
L.	1927.	Mond Nickel Co., Ltd., Imperial Chemical House, Millbank, London, S.W.1 (Subscribing Firm).
L.	1925.	Moore, A. H., Standard Brass Foundry, Benoni, S. Africa.
E.M.	1914.	Moore, H. H., Holmwood, Leicester Road, Loughborough.
B.	1927.	Moran, G., 18, Bridge Street, West Bromwich.
S.	1926.	Moorwood, H. S., Onslow House, Sheffield.
W. & M.	1928.	Morgan, A. J., 48, New King Street, Bath.
W. & M.	1928.	Morgan, C. F., 1, Cynthia Villas, Cynthia Road, Bath.
N.	1912.	Morris, A., Pallion Foundry, Sunderland.
L.	1930.	Morris, Miss C., Coleman Foundry Equipment Co., Ltd., 1, Lancaster Place, Strand, London, W.C. 2.
B.	1930.	Mould, H. W., Wynnstay, Jesson Road, Walsall.
L.	1925.	Mundey, A. H., Fry's Metal Foundry, 42, Holland Street, S.E.1.
B.	1926.	Murray, J. V., 80, Manor House Road, Wednesbury.

B'nch.	Year of Election.	MEMBERS.
L.	1929.	Negler, A., Fonderie de Fer, 82-86, Rue Everaerts, Antwerp, Belgium.
S.	1918.	Newell, Ernest, M.I.Mech.E., The Thorne, Misterton, *via* Doncaster.
B.	1927.	Newsum, A. H., "Enderby," Hadzor Road, Warley Woods, Birmingham.
N.	1912.	Newton, J. W., Flora House, Cobden Street, Darlington.
Lncs.	1920.	Newton, Sam, Linotype & Machinery Ltd., Altrincham, Cheshire.
N.	1927.	Nicholson, F. W., 30, Addison Road, Heaton, Newcastle-upon-Tyne.
L.	1924.	Nikaido, Y. (Lieut.-Com.), Kiro Naval Works, Kure, Japan.
B.	1927.	Norbury, A. L., D.Sc., 24, St. Paul's Square, Birmingham.
L.	1927.	Norman, G. L., Basinghurst, Nightingale Road, Guildford.
S.	1923.	North, The Hon. J. M. W., "Elmwood," Old Whittington, Chesterfield.
N.	1921.	North-Eastern Marine Engineering Company, Ltd. (Subscribing Firm), Wallsend-on-Tyne.
L.	1917.	O'Keefe, Wm., 62, Stanhope Street, Birmingham.
N.	1920.	Oliver, R., 35, Edith Street, Jarrow-on-Tyne.
Lncs.	1921.	Ormerod, J., 24, Barrett Street, Bury.
S.	1913.	Osborn, S., Clyde Steel Works, Sheffield.
L.	1906.	Oswald, J., Sleaford Foundry, Nine Elms Lane, S.W.8.
L.	1919.	Otto, C. A., 22, Owenite Street, Abbey Wood, S.E.2.
B.	1918.	Oubridge, W. A., M.I.M.E. (British Piston Ring Company, Limited), Holbrook Lane, Foleshill, Coventry.
S.	1921.	Oxley, G. H., Vulcan Foundry, Attercliffe, Sheffield.
S.	1915.	Oxley, G. L., Vulcan Foundry, Attercliffe, Sheffield.

B'nch.	Year of Election.	MEMBERS.
S.	1910.	Oxley, W., Vulcan Foundry, Attercliffe, Sheffield.
B.	1930.	Paige, J. F., 49, Wheeley's Road, Edgbaston, Birmingham.
N.	1921.	Palmers Shipbuilding & Iron Company Ltd. (Subscribing Firm), Hebburn-on-Tyne.
W.R. of Y.	1922.	Parker, W., "Ashdene," Tabor Road, Halifax.
E.M.	1905.	Parker, W. B., 3, Murray Road, Rugby.
W.R. of Y.	1907.	Parkinson, J., Shipley, Yorks.
S.	1924.	Parramore, A., Caledonian Foundry, Chapeltown, Sheffield.
N.	1915.	Parsons, Hy. F., "Avondale," Heaton Park View, Heaton, Newcastle.
L.	1927.	Pateman, W. J., 18, Gloucester Road, Luton.
N.	1912.	Patterson, R. O., Thorneyholme, Wylam-on-Tyne.
Sc.	1929.	Paul, J., Meadow View Cottage, Bridgend, Bathgate, West Lothian.
N.	1912.	Paulin, W. J., 1, Stannington Grove, Heaton, Newcastle.
E.M.	1924.	Peace, A. E., Claremont, Littleover Hollow, nr. Derby.
B.	1924.	Pearce, J. G., M.Sc., Director, British Cast Iron Research Assn., 24, St. Paul's Square, Birmingham.
E.M.	1913.	Pearson, N. G. (Lieut.-Col.), Beeston Foundry Company, Ltd., Beeston, Notts.
Lncs.	1909.	Pell, J., 17, Mersey Street, Rosegrove, Burnley, Lancs.
Lncs.	1922.	Pellatt, D. L., "Whitethorn," Lostock, Bolton.
M.	1926.	Pennington, D. G., Lea Close, Middleton St. George, Co. Durham.
Lncs.	1927.	Penrose, J., 190, Horsedge Street, Oldham.
S.	1929.	Perkins, C. B., 4, Wilton Place, Collegiate Crescent, Sheffield.

B'nch	Year of Election.	MEMBERS.
L.	1918.	Perkins, J. E. S., "Hilmorton," The Park, Peterborough.
B.	1920.	Perks, C., Phœnix Castings, Ltd., Coventry.
L.	1926.	Petters, Ltd. (Subscribing Firm), Westland Works, Yeovil.
Gen.	1927.	Phillips, E. A., Laceby, near Grimsby.
L.	1926.	Pisek, Dr. Mont. Fr., Technical High School, Brno, Czecho-Slovakia.
B.	1929.	Pitt, D., 53, Solihull Lane, Hall Green, Birmingham.
E.M.	1922.	Pochin, R. E., 246, Fosse Road, South Leicester.
Lncs.	1922.	Pollard, J. T., 7, Powell Street, Burnley.
Lncs.	1926.	Poole, J., "Clevelands," Bury New Road, Whitefield Manor.
W.R. of Y.	1922.	Poole, W. H., King's Grove, Villa Road, Bingley, Bradford.
S.	1923.	Porter, H. W., 78, Ringinglow Road, Sheffield.
L.	1919.	Pott, L. C., Quipcast Co., 119, Moorgate, London, E.C.2.
E.M.	1924.	Potter, W. C., "Kenwalyn," Sykefield Avenue, Leicester.
S.	1926.	Presswood, C., B.A., "Crowgate," South Anston, near Sheffield.
Sc.	1930.	Preston, T. B., 31, Leven Street, Falkirk.
S.	1908.	Prestwich, W. C., "The Hallowes," Dronfield, Sheffield.
L.	1912.	Primrose, H. S., 17, Victoria Street, London.
Sc.	1920.	Primrose, James M., Mansion House Road, Falkirk.
Lncs.	1912.	Primrose, J. S. G., 17, Salisbury Road, Chorlton-cum-Hardy, Manchester.
B.	1929.	Prince, A. E., 23, Halburton Street, Birmingham.
L.	1926.	Prior, W. H., 62, Andalus Road, London, S.W.9.
B.	1924.	Pritchard, P., "Eastcote," St. Agnes Road, Moseley, Birmingham.
E.M.	1904.	Pulsford, F. C., "Kenmore," Sandown Road, Leicester.

B'nch.	Year of Election.	MEMBERS.
L.	1928.	Quicke, J. H., c/o Leacock & Co., Funchal, Madeira (The Madeira Supply Co., Ltd., Oficinas, Mecanicas, S.E. Fundicao, Rue de Ponte de S. Lazara, N.4).
Gen.	1922.	Ramas, E. (Honorary), 2, Rue de Constantinople, Place de l'Europe, Paris.
B.	1926.	Randle, L. A., 45, Nicholls Street, Coventry.
N.	1912.	Rang, H. A. J., 2, St. Nicholas Buildings, Newcastle-upon-Tyne.
L.	1928.	Rao, Krishna, Mysore Ironworks, Bhadravati, India.
Sc.	1923.	Rattray, W. J., c/o Burns & Co., Ltd., Howrah, Bengal, India.
S.	1921.	Rawlings, Geo., 67, Huntley Road, Sheffield.
M.	1928.	Reay Brass Foundry Co., Ltd., Eagle Works, Skinner Street, Stockton-on-Tees (Subscribing Firm).
W. & M.	1927.	Rees, Ivor, 27, Allington Road, Southville, Bristol.
Sc.	1920.	Rennie, A., " Kilnside," Falkirk.
Sc.	1927.	Rennie, W., " Ardenlea," Cumbernauld, Dumbartonshire.
Lncs.	1919.	Rhead, E. L., Prof. College of Technology, Manchester (Honorary).
Gen.	1923.	Rhydderch, A., Lenton Sands, Robertson Place, Vaucluse, Sydney, Australia.
W. & M.	1925.	Richards, C. E., 53, Merches Gardens, Grange, Cardiff.
E.M.	1930.	Richards, Wm., Strathern, 1, Springfield Road, Leicester.
Lncs.	1919.	Richardson, W. B., Hope Foundry, Farnworth, nr. Bolton.
W. & M.	1924.	Richardson, R. J., " Rosemary," Lan Park, Pontypridd.
Sc.	1911.	Riddell, M., Dungoyne, 35, Aytoun Road, Pollokshields, Glasgow.
M.	1926.	Ridsdale, N. D., 3, Wilson Street, Middlesbrough.

B'nch.	Year of Election.	MEMBERS.
M.	1926.	Ritchie, R. J. H., Cambridge House, Linthorpe, Middlesbrough.
B.	1923.	Roberts, E., 117, Radford Road, Leamington.
B.	1919.	Roberts, G. E., "Rosedale," Earlsdon Avenue, Coventry.
Lncs.	1921.	Roberts, G. P., 153, Brandlesholme Road, Bury, Lancs.
Sc.	1922.	Robertson, Donald M., "Kinfauns," High Station Road, Falkirk.
Sc.	1930.	Robertson, W., 147, Garnoch Road, Kelvinside, Glasgow, N.
W.R. of Y.	1908.	Robinson, J. G., 17, Gibraltar Road, Halifax.
Sc.	1929.	Rodger, J. M., & Son, Kyle Foundry, Ayr, Scotland (Subscribing Firm).
Lncs.	1912.	Roe, S., 23, Grantham Street, Oldham.
S.	1930.	Roebuck, A., 35, Montgomery Road, Sheffield.
Gen.	1909.	Ronceray, E. (Hon.), 3, Rue Paul Carle, Choisy-le-Roi, Seine, Paris, France.
W.R. of Y.	1928.	Roper, E. A., Thorn Cottage, Bogthorn, Oakworth Road, Keighley.
Gen.	1925.	Ropsy, P. A., 27, Rue Dodoens, Antwerp, Belgium.
L.	1929.	Ross, H. J., 28, Prince Rupert Road, Eltham, S.E.9.
B.	1923.	Roxburgh, W., 271, Clifton Road, Rugby.
S.	1918.	Russell, F., c/o General Refractories Company, Limited, Wicker Arches, Sheffield.
E.M.	1924.	Russell, P. A., 88, Dulverton Road, Leicester.
E.M.	1906.	Russell, S. H., Bath Lane, Leicester.
N.	1915.	Sanderson, F., 1, Ellwood Gardens, Gateshead-on-Tyne.
S.	1921.	Sandford, J., 46, Clifford Road, Sheffield.
W.R. of Y.	1922.	Sayers, H., 53, Acre Road, Middleton, Leeds.
B.	1921.	Scampton, Chas., South Avenue, Stoke Park, Coventry.

B'nch.	Year of Election.	MEMBERS.
M.	1927.	Scholes, A., Alma House, Junction Road, Norton-on-Tees.
N.	1929.	Scott, W., 8, Wilson Street, Dunston-on-Tyne.
Lncs.	1927.	Seddon. W. E., 14, Samuel Street, Rochdale.
B.	1910.	Sexton, A. Humbolt (Hon. Life), 6, Clarendon Road, St. Helier, Jersey, C.I.
Sc.	1929.	Shanks, Thos., Beechfield, Denny.
Sc.	1920.	Sharpe, Daniel, 100, Wellington St., Glasgow.
Lncs.	1927.	Shaw. A., 52, King Street, Oldham.
N.	1929.	Shaw, G., 4, Elm Grove, Forest Hall, Newcastle-upon-Tyne.
L.	1906.	Shaw, J., "Cartref," Parkstone Avenue, Southsea.
M.	1929.	Shaw, G., M.A., 53, Southfield Road, Middlesbrough.
N.	1907.	Shaw, R. J. (Life), 26, Queen's Road, Monkseaton. Northumberland.
M.	1922.	Shaw. W. (Subscribing Firm), Wellington Cast Steel Foundry, Middlesbrough.
M.	1929.	Shaw, W. G., B.A., Red Croft, Nunthorpe, Middlesbrough.
S.	1908.	Sheepbridge C. & I. Company, Limited (Subscribing Firm), Sheepbridge Works, Chesterfield.
B.	1930.	Shenton, B.P., 99, Beeches Road, West Bromwich.
L.	1927.	Shepherd, H. H., c/o Crane Bennett, Ltd., Nacton Works, Ipswich, Suffolk.
Lncs.	1907.	Sherburn, H. (Life), "Ellesmere," Padgate, Warrington.
Lncs.	1905.	Sherburn. W. H. (Life), Rotherwood, Stockton Heath, Warrington.
L.	1912.	Shillitoe, H., "Westwood," Potters Bar, London, N.
N.	1920.	Shipley, H. J., East Cottage, Delacour Road, Blaydon-on-Tyne.
S.	1927.	Shirt, F. A., 317, Psalter Lane, Sheffield.

B'nch	Year of Election.	MEMBERS.
Lncs.	1907.	Simkiss, J., Abington House, Hyde Road, Gorton, Manchester.
N.	1913.	Simm, J. N., 61, Marine Avenue, Monkseaton.
L.	1927.	Simpson, H. L., "Brockenhurst," 4, Emlyns Street, Stamford, Lincs.
S.	1926.	Singleton, T., 21, Peveril Road, Sheffield.
Sc.	1926.	Skinner, F. J., Lochend House, Maryhill, Glasgow.
W.R. of Y.	1921.	Slingsby, W., Highfield Villa, Keighley.
L.	1925.	Small, F. G., "Meliden," Burden Lane, Cheam, Surrey.
N.	1921.	Smalley, O., Miramer Hotel, Brooklyn, New York, U.S.A.
Sc.	1927.	Smart, G., Rowallan, Stepps, Glasgow.
L.	1928.	Smeeton, J., 15, Victoria Street, S.W.1.
B.	1928.	Smith, A. B., "Bramber," Histone Hill, Bodsall, Staffs.
B.	1925.	Smith, B. W., Hawkswell Farm, Coleshill, near Birmingham.
Lncs.	1928.	Smith, C. G., "Craigside," Well Lane, Hr. Bebbington, Cheshire.
B.	1919.	Smith, C. R. (Messrs. C. & B. Smith), Stewart Street, Wolverhampton.
L.	1929.	Smith, C. W., "Wirtridge," Kingshill Road, Dursley.
S.	1921.	Smith, Fredk., Devonshire Villas, Barrow Hill, near Chesterfield.
E.M.	1921.	Smith, George, Cavendish Place, Beeston, Notts.
N.	1905.	Smith, J., "Harton Lea," Harton, South Shields.
M.	1926.	Smith, J. D., 19, Shaftesbury Street, Stockton-on-Tees.
N.	1917.	Smith, J. E., 7, Lily Avenue, Jesmond, Newcastle.
M.	1926.	Smith, J. L., "Holmesdale," Billingham, near Stockton-on-Tees.
N.	1913.	Smith, R. H., 16, Whitburn Road East, Cleadon, near Sunderland.

B'nch.	Year of Election.	MEMBERS.
B.	1928.	Smith, W. H., "Exford," Lenwade Road, Warley Woods, Birmingham.
B.	1925.	Smith, W. S., 15, Broadfields Road, Erdington, Birmingham.
L.	1923.	Snook, S. W. G., 30, Lawrence Road, Tottenham, N.15.
L.	1914.	Sommerfield, H. G., Charterhouse Chambers, Charterhouse Square, London, E.C.1.
Lncs.	1926.	Southerst, R., 8, Raven Street, Bury.
S.	1925.	Spafford, Arnold V., Imperial Works, Brown Street, Sheffield.
Lncs.	1927.	Spedding, O. L., Holly Grove, Dobcross, R.S.O., Yorks.
E.M.	1914.	Spiers, T. A., "Delamere," Uppingham Road, Leicester.
E.M.	1928.	Stanton Ironworks Co., Ltd., Stanton, near Nottingham (Subscribing Firm).
Lncs.	1927.	Stanworth, J., "The Woodlands," Rimington, Clitheroe.
Lncs.	1922.	Staveley Coal & Iron Company (Subscribing Firm), Staveley Works, near Chesterfield.
S.	1927.	Steele, F. E., 66, Hatfield House Lane, Firth Park, Sheffield.
Sc.	1930.	Steele, J. S., 4, Minerva Cottages, John Knox Street, Clydebank, Scotland.
Sc.	1920.	Steven, A. W., Lauriston Ironworks, Falkirk.
E.M.	1914.	Stevenson, E., "Charnwood," Sunnydale Road, Carlton, Notts.
E.M.	1928.	Stobart, W., 20, Kenilworth Avenue, Normanton, Derby.
N.	1912.	Stobie, V., Oakfield, Ryton-on-Tyne.
L.	1915.	Stone, E. G., 20, Cantley Avenue, Clapham Common, S.W.4.
L.	1912.	Stone, J., 106, Harlaxton Road, Grantham.
Gen.	1922.	Stones, J., 2, Marshall Road, Agarpara, Kamarhatti P.O., Calcutta, India.

B'nch.	Year of Election.	MEMBERS.
N.	1921.	Stothard, A., 32, Grainger Street West, Newcastle.
E.M.	1916.	Street, W., 20, Burleigh Road, Loughborough.
Lncs.	1921.	Stubbs, Limited, Jos. (Subscribing Firm), Mill Street Works, Ancoats, Manchester.
Lncs.	1912.	Stubbs, Oliver (Hon. Life) (J. Stubbs, Limited), Openshaw, Manchester.
Lncs.	1919.	Stubbs, R. W., 209, Dickenson Road, Longsight, Manchester.
Lncs.	1928.	Studley, G. C., 28, Meadow Bank, Chorltonville, Manchester.
M.	1927.	Styles, W. E., Eskdale House, Cambridge Road, Thornaby-on-Tees.
W.R. of Y.	1922.	Summerscales, W. H. G., Rockfield, Keighley.
W.R. of Y.	1919.	Summersgill, H., Stanacre Foundry, Wapping Road, Bradford.
L.	1927.	Sutton, E. W., 48, Halesworth Road, Lewisham.
Gen.	1926.	Swaine, G., c/o Marshall, Sons & Co., India, Ltd., Argarpara Works, Karnarhatty, P.O. 24, Parganas, Bengal, India.
S.	1908.	Swinden, T., D.Met., 26, Oakhill Road, Nether Edge, Sheffield.
N.	1928.	Swinney, T., Castle View, Morpeth.
W.R. of Y.	1912.	Sykes, J. W., Birdacre House, Gomersall, Leeds.
Lncs.	1927.	Tait, W., Mere, Repetition Castings (M/c), Ltd., Holland Street, Miles Platting, Manchester.
E.M.	1928.	Taite, G., The Old Manor House, Lutterworth.
N.	1927.	Tate, C. B., 32, Grosvenor Drive, Whitley Bay.
Lncs.	1924.	Taylor, A., 84, Hornby Road, Blackpool.
E.M.	1929.	Taylor Bros. (Sandiacre), Ltd. (Subscribing Firm), Sandiacre, nr. Nottingham.
E.M.	1929.	Taylor, H., Yorresdene, Sandiacre.

B'nch.	Year of Election.	MEMBERS.
N.	1922.	Taylor & Son, Limited, C. W. (Subscribing Firm), North Eastern Foundries, South Shields.
Lncs.	1911.	Taylor, R. (Asa Lees & Company, Limited), Oldham.
N.	1925.	Taylor, T., Point Pleasant Hall, Wallsend-on-Tyne.
Lncs.	1920.	Thompson, H., 6, Dobson Road, Bolton.
W.R. of Y.	1922.	Thornton, W. G., 1081, Grangefield Avenue, Thornbury, Bradford.
L.	1924.	Thornycroft & Co., Ltd., John I. (Subscribing Firm), Iron Foundry, Woolston Works, Southampton.
M.	1926.	Thorpe, S. P., 11, Devonshire Road, Middlesbrough.
L.	1925.	Tibbenham, L. J., The Limes, Stowmarket.
W. & M.	1928.	Timmins, D., "Bungalow," Brooks Road, Fishponds, Bristol.
M.	1926.	Todd, H., 50, Derby Grove, Lenton Sands, Notts.
L.	1927.	Tompkins, S. J., Sefton, Birmingham Road, Wylde Green, Birmingham.
S.	1927.	Tonge, J., Bovey Court, Vereeniging, S. Africa.
Gen.	1922.	Touceda, E. (Hon.), 943, Broadway, Albany, N.Y., U.S.A.
S.	1929.	Townsend, C. W. D., Wrawby, Briggs, Lincs.
Lncs.	1928.	Toy, H., 4, Westmorland Road, Urmston, Manchester.
M.	1924.	Toy, S. V., Tudor Court, Nunthorpe, S.O., Yorks.
N.	1927.	Travers, D. Le M., 29, Clayton Road, Newcastle.
L.	1922.	Tremayne, Chas., 26, Eversley Road, Charlton, S.E.7.
Sc.	1922.	Tullis, D. R., Aillig, Campbell Drive, Bearsden, Glasgow.
L.	1926.	Turner, A. C., 144, Turney Road, Dulwich, S.E.24.
B.	1927.	Turner, H. L., 23, Mellish Road, Walsall.
B.	1910.	Turner, Prof. T. (Hon. Life), Netheridge Elm Drive, Leatherhead, Surrey.

B'nch.	Year of Election.	MEMBERS.
B.	1927.	Turner, T. H., M.Sc., 17, Acacia Road, Bournville, Birmingham.
Sc.	1923.	Tutchings, A., 152, Greenhead Drive, South Govan, Glasgow.
Lncs.	1909.	Tweedales & Smalley, Limited, Globe Works, Castleton, Lancs.
L.	1928.	Twigg, W. R., The Laurels, Harpenden, Herts.
B.	1918.	Tyson, E. H., 269, Gillott Road, Edgbaston, Birmingham.
S.	1916.	Underwood, G. H. " Kulti," Cutthorpe, near Chesterfield.
Sc.	1913.	Ure, G. A. (Smith & Wellstood, Ltd.), Bonnybridge, Scotland.
Gen.	1927.	Vanzetti, Comm. Ing. Carlo, C.B.E., Fonderia Milanese di Acciaio Vanzetti, Milan, Italy.
Gen.	1922.	Varlet, J. (Hon.), Esperance Longdoz Works, Liege, Belgium.
Lncs.	1922.	Vickers, Limited (Subscribing Firm), Barrow-in-Furness.
Sc.	1911.	Waddell, R. C., 2, Percy Street, Ibrox, Glasgow.
S.	1907.	Walker, E., Effingham Mills, Rotherham.
S.	1918.	Walker, T. R., B.A., 26, Castlewood Road, Fulwood, Sheffield.
E.M.	1929.	Wallis, J., 5, Matlock Road, Ambergate, Derbyshire.
N.	1921.	Wallsend Slipway & Engineering Co., Ltd. (Subscribing Firm), Wallsend-on-Tyne.
Gen.	1922.	Walters, A. F. (H. I. Dixon & Company, Limited), The Omiar Founding and Eng. Company, Limited, Lov Lane, Mazagon, Bombay, India.
N.	1927.	Walton, S. H., 73, Highbury, Jesmond, Newcastle-upon-Tyne.
S.	1908.	Ward, A. J. (T. W. Ward, Limited), Albion Works, Saville Street, Sheffield.
L.	1919.	Wares, F. J., 216, Cromwell Road, Peterborough.

B'nch.	Year of Election.	MEMBERS.
N.	1919.	Watson, J. H., Benwell Grange Avenue, Newcastle-upon-Tyne.
W.R. of Y.	1922.	Watson, Jos. J., "Gwynfa," College Street East, Crosland Moor, Huddersfield.
B.	1914.	Watson, R., 49, York Street, Rugby.
B.	1917.	Webb, B., 531, Stourbridge Road, Scott Green, Dudley.
L.	1925.	Webster, F. K., Deptford Star Foundry, Rolt Road, Deptford, London, S.E.8.
B.	1928.	Webster, G. R., 8, Marlborough Road, Bearwood, Birmingham.
Sc.	1920.	Weir, Rt. Hon. Lord, The, P.C., D.L., LL.D. (Life Member), G. & J. Weir, Limited, Cathcart, Glasgow.
N.	1912.	Weir, J. M., 7, Stanhope Road, South Shields.
W.R. of Y.	1908.	Welford, R. D., 1, Hilton Road, Frizinghall, Bradford.
S.	1910.	Wells, G. E. (Edgar Allen & Co., Limited), Imperial Steel Works, Sheffield.
S.	1914.	Wells, J. A. E., "Thrift House," Ringinglow Road, Sheffield.
Gen.	1927.	Werner, Dr. Ing. S. G., Lindemannstr. 18, Düsseldorf, Germany.
Lncs.	1926.	West, Walter, Farrington Steel Works, of Leyland Motors, Leyland, Lancs.
S.	1921.	Wharton, E., Rosemont, Station Road, Brimington, Chesterfield.
N.	1913.	Wharton, J., Phœnix Foundry, Maryport, Cumberland.
B.	1928.	White, A. O., 9, Longcroft Avenue, Wednesbury.
W.R. of Y.	1928.	White, H. H., "Rydalhurst," Church Lane, Crosscrates, Leeds.
L.	1929.	Whitehead, J. E., "Carlton Lawn," Clifton Drive, Lytham, Lancs.
B.	1925.	Whitehouse, E. J., "The Knoll," Penn, Wolverhampton.
B.	1929.	Whitehouse, L., 79, Hales Road, Wednesbury, Staffs.
S.	1916.	Whiteley, A., 7, Glen Road, Nether Edge, Sheffield.

B'nch.	Year of Election.	MEMBERS.
Lncs.	1910.	Whittaker, C., & Company, Limited, Dowry Street Ironworks, Accrington.
W.R. of Y.	1928.	Whittaker, F., Greyholme, Horsforth, Yorks.
B.	1919.	Wild, M., 29, Beauchamp Avenue, Leamington.
B.	1921.	Wilkinson, D., 1114, Bristol Road South, Northfield, Birmingham.
W.R. of Y.	1919.	Wilkinson, G. (E. & W. Haley, Ltd.), Thornton Road, Bradford.
Lncs.	1917.	Wilkinson, R., "Lyndhurst," Wargrave Road, Newton-le-Willows, Lancs.
B.	1928.	Wilks, L. P., Rydal Mount, Fowler Street, Wolverhampton.
W. & M.	1930.	Williams, C. E., "Coniston," Cefn-Coed Road, Penylan, Cardiff.
W. & M.	1924.	Williams, R. G., "Rossmore," Calcot Road, Barry.
W. & M.	1916.	Williams, W., Alexandra Brass Foundry, East Dock, Cardiff.
L.	1927.	Williams, W. L., Watch House, Felstead, Chelmsford.
L.	1930.	Williamson, G. C., Hildegarde, Wells Road, Beckley, Kent.
M.	1912.	Wilson, F. P., "Parkhurst," Middlesbrough.
E.M.	1928.	Wilson, P. H., Ivy Mount, Nottingham.
L.	1927.	Windsor, W. T., "Pax," Coggershall Road, Braintree, Essex.
Sc.	1906.	Winterton, H., "Moorlands," Milngavie, Dumbartonshire.
S.	1924.	Winterton, H. T., "The Beild," Newlands Road, Chesterfield.
W.R. of Y.	1912.	Wise, S. W., 110, Pullan Avenue, Eccleshill, Bradford.
B.	1925.	Wiseman, Alfred, Ltd. (Subscribing Firm), Glover Street, Birmingham.
L.	1927.	Withers, E. C. (Com.), 731, Warwick Road, Earl's Court, S.W.5.
S.	1929.	Wood, C., 61, Blair Atholl Road, Sheffield.

B'nch.	Year of Election.	MEMBERS.
B.	1919.	Wood, D. Howard (Capt.), "Kingswood," Park Road, Moseley, Birmingham.
B.	1909.	Wood, E. J. (Patent Axlebox & Foundry Company, Limited), Wednesfield Foundry, Wolverhampton.
Lncs.	1926.	Woodcock, A., 163, Hartington Street, Moss Side, Manchester.
W.R. of Y.	1914.	Worcester, A. S., Toria House, 162, Victoria Street, Lockwood, Huddersfield.
B.	1930.	Wragg, T. J., "Derwent," Queslett Road, Great Barr, Birmingham.
L.	1928.	Wrey, C. R. B., 37A, Thurloe Place, London, S.W.7.
B.	1914.	Wright, E. N. (Life), Oxford Lodge, Penn Fields, Wolverhampton.
E.M.	1928.	Wright, W. H., 190, London Road, Leicester.
E.M.	1927.	Wyborn, S., 35, Hartington Road, Sherwood, Notts.
Lncs.	1928.	Yarwood, W. J., & Co., Ltd., The Dock, Northwich, Cheshire (Subscribing Firm).
L.	1914.	Young, H. J., 3, Central Buildings, Westminster, S.W.1.

ASSOCIATE MEMBERS.

W.R. of Y.	1928.	Ablard, A., 231, Folkstone Street, Bradford Moor, Bradford.
W.R. of Y.	1927.	Ackeroyd, H., 40, Devonshire Street, Keighley.
M.	1926.	Adcock, F. H., 7, Beech Grove, Middlesbrough.
Sc.	1919.	Affleck, J., B.Sc., 21, Overdale Avenue, Langside, Glasgow.
L.	1929.	Ainsworth, E., 22, Whittingstall Road, Fulham, S.W.6.
B.	1915.	Aldridge, S., 91, Dale Street, Walsall.
S.	1927.	Alford, A. L., 408, Windmill Lane, Shiregreen, Sheffield.
B.	1928.	Allen, A. E., 7, The Drive, Gravelly Hill, Birmingham.

B'nch	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1929.	Alston, J.
M.	1928.	Anderson, D., "Nutana," Victoria Avenue, Redcar, Yorks.
Sc.	1926.	Anderson, J. Y., 35, Alice Street, Paisley.
L.	1925.	Armishaw, W. J., 44, Common View, Letchworth, Herts.
E.M.	1928.	Armitage, R., 24, St. Paul's Road, Derby.
M.	1926.	Armstrong, G., 23, Chipchase Street, Middlesbrough.
L.	1925.	Armstrong, L. R., 56, Parliament Hill Mansions, N.W.5.
Sc.	1926.	Arnott, James, 114, Broomhall Road, Newlands, Glasgow.
Lncs.	1916.	Ashton, F., 24, Isherwood Street, Heywood, Lancs.
Lncs.	1927.	Ashton, N. C., 591, Chorley New Road, Horwich, near Bolton.
Lncs.	1923.	Astall, D., c/o Messrs. Chas. Jones, Ninian Foundry, East Moors Road, Cardiff.
L.	1905.	Aston, D. A., 36, Bastwick Street, Goswell Road, London, E.C.1.
Lncs.	1922.	Atkinson, Albert, 11, Guy Street, Padiham, Lancs.
N.	1925.	Atkinson, G., 10, Queen's Drive, Whitley Bay.
S.	1920.	Avill, Wm., Lyndon House, Mumsbro' Lane, Greasborough, Rotherham.
S.	1912.	Ayres, J. A., "Aldbourne," Ecclesfield, Sheffield.
S.	1924.	Bacon, P., 86, Bridge Street, Swinton, near Rotherham.
S.	1909.	Bailey, P. T., 17, Hallowes Lane, Dronfield, near Sheffield.
Sc.	1916.	Bain, W., Ardmore, Bonnybridge, Scotland.
Sc.	1928.	Baird, T. C., 87, Main Street, Barrhead.
B.	1918.	Baker, W., "Kara Gwent," Coalway Road, Penn Fields, Wolverhampton.
W.R. of Y.	1927.	Balme, H., 3, Shaw Terrace, Marsden, near Huddersfield.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1927.	Barber, C., 43, Birch Street, West Gorton, Manchester.
M.	1926.	Barclay, D., 45, Edward Street, Stockton-on-Tees.
S.	1922.	Barker, A. G., 26, Victoria Road, Balby, Doncaster.
B.	1930.	Barker, E. C., 48, George Eliot Road, Coventry.
B.	1919.	Barker, S. B., 34, Darby Road, Coalbrookdale, Salop.
S.	1924.	Barker, W., 136, Nidd Road, Attercliffe, Sheffield.
S.	1913.	Barnaby, N. F. (John Brown & Company, Limited), Scunthorpe.
Lncs.	1910.	Barnes, G., 16, Tremellen Street, Accrington.
Lncs.	1930.	Barnes, W., 22, Lisbon Street, Burnley.
Lncs.	1915.	Baron, E., 24, Grimshaw Lane, Newton Heath, Manchester.
L.	1914.	Barrett, H. G., Letchworth Castings Co., Letchworth, Herts.
Lncs.	1924.	Barrett, S., 150, Chorley New Road Horwich, nr. Bolton.
L.	1911.	Batch, J., 60, Robertson Street, Queen Street, Battersea, S.W.11.
B.	1927.	Bate, F., 48, Sweetpool Lane, West Hagley, Stourbridge.
S.	1920.	Batty, F., 52, Hampton Road, Pitsmoor, Sheffield.
E.M.	1926.	Baxter, J., 108, Stone Hill Road, Derby.
Sc.	1929.	Baxter, M., Whittinghame Place, Bridgend. Bathgate, Scotland.
L.	1921.	Baxter, Percy L., 131, Ampthill Avenue, Benoni, Transvaal, S. Africa.
W.R. of Y.	1924.	Bean, E., c/o Anglo-Persian Oil Co. Abadan, Persia.
L.	1925.	Beardshaw, A., 50, Jackmans Place, Letchworth, Herts.
E.M.	1919.	Beck, H. J., Barton House, Rosamond's Ride, Littleover Lane, Derby.
L.	1925.	Becker, M. L., Ph.D., National Physical Laboratory, Teddington.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1927.	Beech, T. L., 86, Cyprus Street, Stretford, Manchester.
W.R. of Y.	1927.	Beilby, A. R., 233, Melrose Gate, Tang Hall, York.
N.	1925.	Bell, J., 65, Park Avenue, Whitley Bay, Northumberland.
Sc.	1910.	Bell, T., 2, Bellfield Street, Barrhead, Glasgow.
S.	1918.	Bennett, A. M., 12, Brandon Grove, Newton Park, Leeds.
W. & M.	1928.	Bennett, S. L., 2, Lily Street, Roath Park, Cardiff.
W.R. of Y.	1912.	Berry, F., 125, Watkinson Road, Illingworth, Halifax.
Lncs.	1917.	Berry, R. I., 31, Bury Road, Bamford, Rochdale.
B.	1926.	Bettinson, J. S., Woodbourne Lodge, Edgbaston, Birmingham.
S.	1928.	Betts, F., 69, Tapton Bank, Crosspool, Sheffield.
Lncs.	1926.	Bevins, J., 1, Little Union Street, Ulverston.
Sc.	1920.	Binnie, Alex., 15, Cochrane Buildings, Pleasance Square, Falkirk.
B.	1916.	Birch, H., Inglewood, Chester Road, Streetly, Birmingham.
B.	1922.	Bird, J. B., "Corallyn," Hardwick Road, Streetly, near Birmingham.
Sc.	1919.	Black, A., 27, Dixon Road, Crosshill, Glasgow.
Sc.	1928.	Black, J., 20, Watling Street, Camelon, Falkirk.
Sc.	1928.	Blackadder, T., 5, Orchard Street, Falkirk, Scotland.
Sc.	1928.	Blackadder, W., Linton Vale, Meeks Road, Falkirk.
E.M.	1920.	Blackwell, Wm., 36, Arthur Street, Loughborough.
Sc.	1910.	Blackwood, R., "Kenilworth," Johnstone, Glasgow.
E.M.	1919.	Blades, C., The Vines, Wanlip Road, Syston, Leicester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1928.	Blair, W. W., Station House, Grahamston, Falkirk.
E.M.	1924.	Bloor, F. A., "Inglemere," Stenson Road, Derby.
N.	1919.	Blythe, J. D., 81, Northumberland Terrace, Willington-Quay-on-Tyne.
Sc.	1927.	Blythe, N. C., 11, Danes Drive, Scotstoun, Glasgow.
W.R. of Y.	1922.	Booth, G. E., 80, Institute Road, Eccleshill, Bradford, Yorks.
S.	1928.	Booth, J. T., Ringwood Road, Brimington, Chesterfield.
S.	1928.	Booth, W. A., 46, John Street, Brampton, Chesterfield.
N.	1915.	Borthwick, T., Crookhall House, Consett, Co. Durham.
Lncs.	1928.	Bose, R. N., 24, Church Street, Stretford, Manchester.
S.	1927.	Boulton, D. C., 4, Littlemoor Crescent, Newbold, Chesterfield.
M.	1920.	Bound, W. H., Wh. Ex. A.M.I.Mech.E., 12, Dufton Road, Linthorpe, Middlesbrough.
L.	1906.	Bowman, A., 48, Lathom Road, East Ham, E.6.
W. &	1926.	Boxall, H. A.
W.R. of Y.	1929.	Bradbury, H., 33, Perseverence Street, Primrose Hill, Huddersfield.
S.	1916.	Bradley, H., "Cotswold," Bocking Lane, Woodseats, Sheffield.
B.	1925.	Bradshaw, J. H. D., 4, Foley Street, Wednesbury, Staffs.
L.	1928.	Brand, J. P., 2, Ruth St., Stratford, E.15.
N.	1921.	Brass, A., 44, Haydn Terrace, Gateshead-on-Tyne.
Sc.	1928.	Breckenridge, J. M., 7, Orchard Street, Kilmarnock.
Lncs.	1923.	Brereton, C. F., 25, Manchester Road, Chorlton-cum-Hardy, Manchester.
Lncs.	1917.	Brierley, A., 76, Ash Road, Denton, Manchester.
Lncs.	1923.	Brockbank, A. H., 3, Hawkens Street, Old Trafford, Manchester.

B'nch	Year of Election.	ASSOCIATE MEMBERS.
M.	1929.	Brodie, B., 9, Redmire Road, Stockton-on-Tees.
W.R. of Y.	1926.	Brook, J., 10, Elford Terrace, Roundhay Road, Leeds.
Lncs.	1925.	Broughton, H., 1, Chip Hill Road, Deane, Bolton.
N.	1917.	Brown, C. Hy., 57, Whitehall Road, Gateshead-on-Tyne.
Lncs.	1923.	Brown, G. H., 17, Derbyshire Avenue, Stretford, Manchester.
Lncs.	1917.	Brown, J., 227, Milnrow Road, Rochdale.
Sc.	1929.	Brownlee, J., 2, Atholl Terrace, Bathgate, Scotland.
Sc.	1914.	Bruce, A., 6, Lockharton Avenue, Torpichen Street, Edinburgh.
L.	1928.	Bruce, W., 38, Watson Street, Falkirk.
Sc.	1926.	Bruce, W. T., 6, Lockharton Avenue, Edinburgh.
M.	1929.	Brunt, Wm., 11, Rydal Street, West Hartlepool.
S.	1928.	Bryan, J., 30, St. Helens Street, Chesterfield.
Sc.	1927.	Bryden, Walter Myreton, Bonnybridge, Stirlingshire.
Lncs.	1926.	Buck. A., 9, St. Paul's Road, North Shore, Blackpool.
N.	1920.	Buckham, G. H., "Harewood," Grange Road, Newcastle-upon-Tyne.
L.	1926.	Buckingham, F. A. T., 114, Richmond Road, Gillingham, Kent.
E.M.	1928.	Buckland, R. H., 20, Dairyhouse Road, Derby.
L.	1928.	Bullock, D. C., 29, Clarendon Road, Harrow, Middlesex.
B.	1925.	Bullows, W. D., c/o Castings, Ltd., Selbourne Street, Walsall, Staffs.
E.M.	1928.	Bulmer, G. N. B., 11, Station Road, Challaston, Derby.
Lncs.	1930.	Burgess, A., 8, Mellor Street, Stockport.
E.M.	1929.	Burgess, A. E., 21, Foundry Cottages, Syston, Leicestershire.

B'nch.	Year of Election.	
E.M.	1928.	Burgess, F., 21, Foundry Cottages, Syston, near Leicester.
E.M.	1929.	Burgess, S. H., 137, North Street, Barrow on Sour, near Loughborough.
S.	1924.	Burkinshaw, J. W., 13, Laverack Street, Handsworth, Sheffield.
Sc.	1917.	Burns, J. K., 77, Sandy Road, Renfrew.
N.	1925.	Burrell, J., 2, Bede Crescent, Willington-Quay-on-Tyne.
W.R. of Y.	1921.	Butterfield, P., 10, Eastfield Place, Sutton-in-Craven, Keighley, Yorks.
E.M.	1927.	Butters, F. G., 1, Albany Street, Ilkeston.
Sc.	1928.	Butters, F. H. R., 145, Hillend Road, Lambhill, Glasgow.
Lncs.	1919.	Butterworth, J., 40, Clement Royds Street, Rochdale.
W.R. of Y.	1921.	Butterworth, John, 79, Bracewell Drive, Wheatley Road, Halifax.
Lncs.	1929.	Buttriss, J. O., 27, Niobe Street, Walney Island, Barrow-in-Furness.
Lncs.	1926.	Cairns, F., 59, Brodwell Street, Seedley, Manchester.
B.	1924.	Callaghan, G. M., 6, Foxgrove, Acocks Green, Birmingham.
E.M.	1929.	Callis, B., 57, Clarence Street, Loughborough.
S.	1920.	Cameron, N.
Lncs.	1926.	Campbell, A. B., 125, Stamford Road, Audenshaw, Manchester.
Sc.	1912.	Campbell, D. McGregor, Torwood Foundry, Larbert.
L.	1914.	Campbell, J., 9, Western Gardens, Ealing, W.
Lncs.	1918.	Campbell, W., 12, Denbeigh Street, Stockport.
S.	1927.	Carlisle, E. A., 3, Silver Hill Road, Ecclesall, Sheffield.
L.	1921.	Carrell, Hy. Alfred, 6J, Peabody Buildings, Farringdon Road, E.C.1.
Sc.	1930.	Carrol, R., c/o Mrs. Nicol, 46, Melville Street, Pollokshields, Glasgow.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1929.	Carter, J., "South Lawn," St. Paul's Street, Stamford, Lincs.
W.R. of Y.	1927.	Carter, S., Cowley Lane, Lepton, near Huddersfield.
W. & M.	1930.	Ceriez, A. J., 5, May Street, Cathays, Cardiff.
Sc.	1928.	Chambers, H., c/o Macpherson, 20, Douglas Street, Paisley.
L.	1925.	Chambers, J. F., 92, Alma Road, Windsor.
Sc.	1930.	Chapman, W. C., Kushtia, E.B.R., Bengal, India.
W.R. of Y.	1922.	Chappelow, Thos., 181, Taylor Street, Batley, Yorks.
Lncs.	1925.	Cheetham, E., 5, Eldon Road, Edgeley, Stockport.
W. & M.	1928.	Chilvers, W., High Street, Crowmarth, near Wallingford.
Lncs.	1927.	Clark, J. J., 39, Dicconson Street, Ormskirk, Lancs.
N.	1920.	Clark, J. W., 133, St. Thomas' Terrace, Blaydon-on-Tyne.
Sc.	1928.	Clark, R. F., 127, Graham's Road, Falkirk, Scotland.
L.	1923.	Clark, W., 9, Jubilee Road, Basingstoke.
E.M.	1929.	Clark, W., 256, Cossington Road, Sileby, Leicester.
N.	1912.	Clarke, J., Albert Street, Tayport, Fife.
L.	1925.	Clarke, J. W., 17, Major Walk, Peterborough.
Sc.	1928.	Clarkson, A., Liddles Buildings, Stenhousemuir, Scotland.
Sc.	1922.	Cleverley, A. M., B.Sc., 24, York Street, Falkirk, Scotland.
Lncs.	1928.	Cliffe, J., 43, Manley Road, Oldham.
Lncs.	1921.	Coleman, J. I., West Dene, Brooklyn Road, Wilpshire, Blackburn.
B.	1929.	Coleman, F. P., 66, Victoria Avenue, New Bilton, Rugby.
W. & M.	1926.	Coles, F. L., 15, Moon Street, Cardiff.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1920.	Coles, W. H., 2, Gordon Avenue, Woodseats, Sheffield.
S.	1916.	Collins, B. L., P.O. Box 290, Benoni, Johannesburg, South Africa.
W.R. of Y.	1926.	Collinson, K. H., 11, Grandmerc Place, Halifax.
S.	1907.	Cook, A. H., W. Cook & Sons, Ltd., Washford Road, Sheffield.
Sc.	1929.	Cook, T., 28, James Street. Ladywell, Motherwell, Scotland.
S.	1914.	Cook, W. G., Washford Road, Sheffield.
Lncs.	1927.	Cooke, J. E., 116, Derbyshire Avenue, Stretford.
Lncs.	1926.	Cooke, T., 15, Finchley Road, Hale, Cheshire.
M.	1926.	Cooper, A., 50, Upper Oxford Street, South Bank.
E.M.	1929.	Cooper, A., 23, Lees Hill Street, Nottingham.
N.	1919.	Corbett, W. A., " Dinguardi," Bungalow 19, High Farm Estate, Wallsend-on-Tyne.
Lncs.	1926.	Coupe, Wm., junr., 36, Kittlingborne, High Walton, near Preston.
Lncs.	1929.	Crabtree, J. E., 23, Buxton Street, Accrington.
Sc.	1919.	Cree, A., 160, Mount Amnan Drive, King's Park, Cathcart, Glasgow.
E.M.	1926.	Creese, H. J., 112, Mere Road. Leicester.
Lncs.	1910.	Critchley, F., 631, St. Helens Road, Bolton.
L.	1928.	Cropley, H. J., 28, Beach Road, Gorleston-on-Sea, Great Yarmouth.
Lncs.	1928.	Cross, J., 80, Elmfield Street, Church.
Lncs.	1929.	Cryer. F., 6, Moreton Avenue, Stretford, Manchester.
Lncs.	1927.	Cullinmore, G., 15, Lincoln Square, Farnworth, Widnes.
B.	1906.	Curnow. M. H., 41. Heath Lane, West Bromwich.
Sc.	1926.	Currie, J., 1, Sutherland Crescent, Bathgate.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1907.	Dalrymple, D., 20, Beeches Road, West Bromwich.
S.	1920.	Darby, A., 5, Dobbin Hill, Greystones, Sheffield.
Lncs.	1927.	Dathathraya, D., 219, Residency Bazaar, Hyderabad, Deccan, India.
Sc.	1922.	Davidson, W. B. (Jas. Keith & Blackman Co., Ltd.), Arbroath.
W. & M.	1924.	Davies, E. H., 224, Cardiff Road, Aberaman.
W. & M.	1929.	Davies, J. F., 53, Hawthorne Avenue, Newport, Monmouth.
Sc.	1926.	Davis, Thos., 633, Dumbarton Road, Partick, Glasgow.
L.	1914.	Davis, W. H., 8, Pye Street, Portsmouth.
W. & M.	1928.	Dawson, J. A., 1, Greenhill Place, Thrupp, near Stroud, Gloucestershire.
S.	1922.	Day, A. B., 19, Scarsdale Road, Dronfield, near Sheffield.
Lncs.	1924.	Deeley, F., 52, Bewsey Street, Warrington.
Lncs.	1918.	Demaine, F. C., 9, Rising Sun Lane, Garden Suburb, Oldham.
Lncs.	1922.	Demaine F. C., (jun.), 56, Bolton Street, Oldham.
M.	1926.	Denwood, W., 7, Pearl Street, Haverton Hill, Middlesbrough.
W.R. of Y.	1922.	Derrington, H., 101, Norfolk Mount, Halifax.
L.	1909.	Derry, L. B., 3, Preston Road, Yeovil, Somerset.
W. & M.	1930.	Dewfall, J. L., Ton Road, Cwmbran, Mon.
B.	1925.	Dexter, B. J., 80, New Rowley Street, Walsall.
E.M.	1929.	Dexter, G., 10, Barrow Road, Sileby, Leicester.
Sc.	1928.	Dickie, W., 19, Glasgow Road, Paisley, Scotland.
N.	1916.	Dickinson, S., 39, Givens Street, Roker, Sunderland.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1920.	Dicks, G. E., 110, Richmond Hill, Langley, near Birmingham.
S.	1914.	Dixon, A. F., 9, Bristol Road, Sheffield,
L.	1916.	Dobson, J., 3, Bond Isle Terrace, Stanhope, Co. Durham.
N.	1924.	Dodds, J., 64, Scotswood Road, South Benwell, Newcastle-upon-Tyne.
M.	1930.	Dodsworth, R. P., 2, Roscoe Street, Middlesbrough.
Lncs.	1921.	Dolphin, J. H., 9, Chip Hill Road, Deane, Bolton.
W. & M.	1924.	Domville, S., St. Marie, New Main Road, Rumney, Monmouth.
Sc.	1919.	Donaldson, J. W., D.Sc., Scott's Shipbuilding & Engineering Company, Limited, Greenock.
L.	1928.	Donnon, W., Light Alloys Ltd., Willesden Junction, London, N.W. 10.
Sc.	1919.	Dorsie, J. C., Maplewood, Kirkintilloch.
B.	1920.	Dubberley, F., 44, Great Arthur Street, Smethwick, Staffs.
Lncs.	1925.	Duckworth, J. A., 42A, Ormerod Street, Accrington.
Lncs.	1924.	Dudley, Wm., 11, Barlow Street, Lower Openshaw, Manchester.
Lncs.	1929.	Dunkerley, W., 42, Balfour Street, Oldham.
Lncs.	1929.	Dunleavy, F., 457, Bury Road, Bolton.
E.M.	1929.	Dunn, E., 59, Swan Street, Sileby, Leicester.
L.	1920.	Dunn, J. W., 50, Marlow Road, East Ham, E.7.
W.R. of Y.	1930.	Durrans, P. H., The Croft, Penistone, near Sheffield.
W. & M.	1928.	Durrant, G. A., 11, West Park Road, Newport.
Lncs.	1913.	Eastwood, J. H., 83, Princess Street, Castleton, near Manchester.
S.	1929.	Eaton, A., 2, Shady Side, Hexthorpe, Doncaster.
L.	1912.	Eccott, A. E., The Elms, 68, Smithies Road, Plumstead, S.E.18.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1925.	Edginton, J., 3, Coupe Road, Burngreave, Sheffield.
Sc.	1911.	Edmiston. M., Rose Vale, Windsor Road, Renfrew.
B.	1922.	Edwards. F. C., 32, Queen's Head Road, Handsworth, Birmingham.
W. & M.	1929.	Edy, H., 59, Llewellyn Avenue, Ely, Cardiff.
Sc.	1927.	Elder, P., 10, Napier Crescent, Bainsford, Falkirk.
E.M.	1928.	Ellis, E. D., 195/7, Berridge Road, Nottingham.
L.	1922.	Ellis, J. P., 20, Lambourn Road, Clapham, S.W.4.
E.M.	1909.	Ellson, J., 19, Derby Road, Ripley, Derby.
S.	1924.	Emmott, J., 33, Bowood Road, Sheffield.
Sc.	1930.	Erskine, J., 2, Battlefield Avenue, Langside, Glasgow.
Sc.	1920.	Erskine, N. A. W., Morton Cottage, Camelon.
L.	1929.	Etheredge, R. W. E., 21, Hillside, Harlesden, N.W.10.
Lncs.	1924.	Evans, H., 93, Second Avenue, Trafford Park, Manchester.
Lncs.	1929.	Evans, T., 1A, Evans Street, Prescot, Lancs.
L.	1927.	Everest, A. B., B.Sc., Ph.D., The Mond Nickel Co., Ltd., Imperial Chemical House, Millbank, London, S.W.1.
Sc.	1928.	Ewing, W., 25, Clifford Street, Bellahouston, Glasgow.
W.R. of Y.	1922.	Farrar, Levi, 22, Springswood Ave., Shipley, Yorks.
Lncs.	1919.	Farrow, C., 84, Louisa Street, Openshaw, Manchester.
Lncs.	1922.	Faulkner, Thos., 95, Bank Street, Clayton, Manchester.
Lncs.	1924.	Fellingham, T. R., 81, Henshaw Street, Stretford, Manchester.
L.	1930.	Fellows, F., 5, Merebank Lane, Stafford Road, Waddon, Croydon.

B'nch	Year of Election.	ASSOCIATE MEMBERS.
N.	1918.	Fender, B., 15, Kenilworth Road, Monkseaton, Northumberland.
L.	1924.	Fenn, J. H., 25, Francemary Street, Brockley, S.E.4.
Sc.	1929.	Ferguson, T., 81, Commercial Road, Barrhead, Scotland.
Sc.	1912.	Ferlie, T., Steel and Iron Founder, Auchtermuchty, Fifeshire.
S.	1927.	Firth, T. C., Storth Oaks, Ranmoor, Sheffield.
L.	1926.	Fish, F. W., 30, The Crescent, Letchworth, Herts.
M.	1926.	Fisher, F. E. 2, Albert Terrace, Haverton Hill, Middlesbrough.
E.M.	1930.	Fisher, G. E., 27, Judges Street, Loughborough.
Lncs.	1922.	Fist, Thomas, 127, Hughes Street, Hallewell, Bolton.
N.	1922.	Flack, E. W., 3, Falshaw Street, Washington Station, Co. Durham.
B.	1927.	Flavel, S. W. B., 11, Avenue Road, Warwick Street, Leamington Spa.
B.	1918.	Flavell, W. J., Carter's Green Passage, West Bromwich.
Lncs.	1919.	Flitcroft, E., School Hill Ironworks, Bolton.
E.M.	1925.	Food, F. H., Brighton Villa, Melbourne Street, Leicester.
W.R of Y.	1924.	Foster, H., 10, Highfield Place, Bramley, Leeds.
L.	1912.	Fowler, T. E., 72, Station Road, New Southgate, N.11.
W.R. of Y.	1928.	Fowler, S., 30, Victoria Road, Halifax.
Gen.	1923.	Fox, F. S., 6333, Tuxeda Avenue, Detroit, Michigan, U.S.A.
B.	1928.	Fox, N. J., 225, Birmingham Road, Walsall.
W.R. of Y.	1929.	France, O. N., 14, Granville Street, Heckmondwike, Yorks.
Sc.	1930.	Fraser, G., 140, Glasgow Road, Uddingston, Scotland.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1924.	Frith, W., 8, Buckley Street, Ashton New Road, Clayton, Manchester.
N.	1920.	Futers, R., Wm., 23, Brannen Street, North Shields.
E.M.	1925.	Gale, B., "Oakdene," Greendale Road, Carlton, Notts.
Sc.	1904.	Galt, J., Henry & Galt, Sneddon Foundry, Paisley.
B.	1920.	Gaunt, J. W., 101, Beeches Road, West Bromwich.
W. & M.	1930.	Gay, S., 46, Whiteway Road, St. George, Bristol.
L.	1929.	Gentle, G. S., 111, Caulfield Road, East Ham, London, E.6.
L.	1927.	Gerrard, J. Norbreck, Alexandra Road, Peterborough.
Lncs.	1927.	Gibson, T., 11, Lincoln Street, Blackburn, Lancs.
E.M.	1926.	Gill, F., "Wyverdene," Greendale Road, Carlton, Nottingham.
Sc.	1928.	Gillespie, C., 67, Commercial Road, Barrhead.
Sc.	1927.	Gillespie, H. McK., Dawson Terrace, Falkirk, Scotland.
Lncs.	1923.	Gilpin, W., "Sunnyside," Birch Grove, Rusholme, Manchester.
E.M.	1924.	Gilson, A. J., 12, Hampden Street, Derby.
M.	1926.	Gleave, J., 1, Victoria Street, Haverton Hill, Middlesbrough.
W.R. of Y.	1922.	Gledhill, F., 205, East View, Bradford Road, Brighouse, Yorks.
B.	1917.	Glynn, T. A., Jesmond, Fair View Avenue, Hamstead, Birmingham.
Lncs.	1924.	Goodwin, G. W., "Hillside," Eaton Bank, Duffield, Derby.
E.M.	1919.	Goodwin, T., Brae Side, New Bedford Street, Derby.
B.	1922.	Gospel, W. P., Gutta Percha Co., c/o The Staffordshire Stainless Iron Co., Ltd., Baldwin Street, Bilston, Staffs.
Sc.	1919.	Graham, R., 116, Stratford Street, Maryhill, Glasgow.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1917.	Grant, George, 62, Leicester Road, Quorn, near Loughborough.
Sc.	1912.	Gray, J., 2, Station Road, Dumbarton.
E.M.	1929.	Greasley, A. O., 20, High Street, Barrow-on-Soar, nr. Loughborough.
E.M.	1928.	Greatorex, H., 149, Brook Street, Derby.
S.	1925.	Greaves, H. A., 25, Raven Road, Nether Edge, Sheffield.
S.	1924.	Greaves, J., 29, Sheffield Road, Chesterfield.
S.	1919.	Greaves, J. B., 77, Spooner Road, Broomhill, Sheffield.
S.	1924.	Green, A., 201, Doncaster Road, Rotherham.
Lncs.	1924.	Green, A. E., 66, Wolseley Road, Preston.
S.	1914.	Green, P., 54, Rolleston Road, Firth Park, Sheffield.
Lncs.	1927.	Greenhalgh, A., 20, Orchard Street, Heywood, Lancashire.
Lncs.	1920.	Greenhalgh, W., 86, Crosby Road, Bolton.
B.	1925.	Greenway, J. F., 43, Douglas Road, Handsworth, Birmingham.
M.	1926.	Greenwell, O., 25, Chipchase Road, Linthorpe, Middlesbrough.
Lncs.	1924.	Greenwood, T., 1, Schofield Street, Todmorden.
L.	1926.	Gregory, A. W., 98, Ashton Road, Luton.
L.	1918.	Gregory, E., 16, Mansfield Road, Beech Hill, Luton.
W. & M.	1928.	Griffin, L., 83, Holloway, Bath.
B.	1926.	Griffiths, A. G., 56, Runnymede Road, Hall Green, Birmingham.
E.M.	1924.	Griffiths, S., 94, Stenson Road, Derby.
M.	1926.	Griffiths, W., Valley View, Station Road, Amersham, Bucks.
Lncs.	1919.	Grimwood, E. E. G., 129, Glebelands Road, Ashton-on-Mersey.
Lncs.	1912.	Grundy, H. V., Pentrich, Campbell Road, Brooklands, Cheshire.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1920.	Gurney, S. J., 24, Burns Road, Battersea, S.W.
M.	1926.	Hackwood, J., 52, Byland Street, Middlesbrough.
Sc.	1920.	Haig, T., 8, Cardrook Terrace, Muirhall Road, Larbert, Scotland.
B.	1929.	Haines, A., 46, Claremont Road, Rugby.
S.	1909.	Hall, E. D., 50, Napier Street, Sheffield.
L.	1921.	Hall, Geo., "Glenthorne," Swan Hill, Oxton, Birkenhead.
N.	1914.	Hall, J. J., "Ellesmere," King George's Road, Cullercoats, Northumberland.
E.M.	1925.	Hallamore, J. C., Oak Farm, Burton Road, Littleover, near Derby.
Lncs.	1929.	Halliday, E., 88, Harcourt Street, Preston.
E.M.	1925.	Halloran, J., 152, Brook Street, Derby.
Sc.	1925.	Hamil, W., 50, Woodhead Avenue, Kirkintilloch, Scotland.
W.R. of Y.	1927.	Hammond, D. W., 63, Waverley Road, Great Horton, Bradford.
B.	1924.	Hammond, G. A., 13c, Hill Top, West Bromwich, Staffs.
E.M.	1928.	Hancock, A. J., "Eversley," Western Road, Mickleover, Derby.
E.M.	1925.	Hancock, D., 43, Drewry Lane, Derby.
B.	1927.	Hand, A. F., 18, Holyhead Road, Oakengates, Salop.
L.	1918.	Hand, H. E., 189, Manwood Road, Crofton Park, London, S.E.4.
W. & M.	1927.	Hares, A., Park Crescent, 648, Stapleton Road, Bristol.
L.	1927.	Harford, A. E., 85, Sumatra Road, West Hampstead, N.W.6.
Lncs.	1926.	Hargraves, R. C., 32, Parsonage Street, Stockport.
Lncs.	1919.	Hargraves, R. R. (Grandridge & Mansergh, Ltd.), Wheathill Street, Salford, Manchester.
M.	1927.	Harper, F. A., "The Briars," Bishopton Road, Stockton-on-Tees.
Lncs.	1911.	Harper, H., 28, Alexandra Street, Castleton, near Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
B.	1927.	Harper, J., 113, Mansfield Road, Aston, Birmingham.
L.	1925.	Harrington, W. T., 21, Vernon Road, Stratford, London, E.15.
W. & M.	1929.	Harris, T. R., 41, Roskear Road, Camborne, Cornwall.
Lncs.	1929.	Harrison, A., 54, Cheadle Street, Openshaw, Manchester.
M.	1926.	Harrison, A. G., 127, Norton Avenue, Norton-on-Tees.
W.R. of Y.	1928.	Harrison, H., 7, St. Leonards Road, Girlington, Bradford.
Sc.	1916.	Harrower, J. (Bo'ness Iron Company), Bo'ness, Scotland.
L.	1927.	Hart, W. F., "The Gables," Cressing Road, Braintree, Essex.
Sc.	1914.	Hartley, R. F., London Road Foundry, Edinburgh.
W. & M.	1928.	Hawes, W., "Ben Trovato," Whittecks Road, Hanham, Bristol.
E.M.	1925.	Hawley, T. H., 53, Willow Brook Road, Leicester.
W.R. of Y.	1930.	Hawley, W., "West View," 90, Lightcliffe Road, Brighouse, Yorks.
Sc.	1928.	Hawthorne, S., 10, Clarence Street, Paisley.
Sc.	1910.	Hay, J., 120, Brownside Road, Cambuslang, Glasgow.
B.	1910.	Hayward, G. T., 120, Gillott Road, Edgbaston, Birmingham.
Lncs.	1923.	Hayward, R., 39, Belgrave Road, New Moston, Manchester.
E.M.	1922.	Hayward, Wm., 2, St. Mary's Hill, Stamford, Lincs.
Lncs.	1925.	Heatley, H., "Woodville," Livesey Branch Road, Blackburn.
W.R. of Y.	1925.	Heaton, B., Messrs. Hall & Stell, Dalton Lane, Keighley.
B.	1906.	Heggie, C., 79, Holly Lane, Erdington, Birmingham.
Lncs.	1922.	Henderson, G., 1120, Eleventh Street, Trafford Park, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1928.	Henderson, J., 10, Windsor Place, Newmains, Lanarkshire.
N.	1923.	Henderson, J. W., c/o Singapore Harbour Board, Keppel Harbour, Singapore, Straits Settlements.
Sc.	1911.	Henderson, R., 67, Love Street, Paisley.
Lncs.	1930.	Henery, E., 12, Hobson Street, Gorton Road, Reddish, Stockport.
Sc.	1921.	Henry, John, 75, Alma Street, Grahamston, Falkirk.
Lncs.	1922.	Henshaw, J. E., "Trefechan," Hyde Road, Woodley.
L.	1928.	Herring, A., 30, Heathview Road, Thornton Heath, Surrey.
E.M.	1920.	Hey, James Wm., 43, Howe Street, Derby.
B.	1927.	Hibbert, J. C., 39, Montague Road, Erdington, Birmingham.
L.	1925.	Hickenbottom, W. J., 50, Waterloo Road, Dunstable.
Lncs.	1915.	Hill, A., 114, Middleton Road, Heywood, Lancs.
E.M.	1929.	Hill, G. H., 2, Danewood Gardens, Abington, Northampton.
Lncs.	1925.	Hill, H. G., 495, Stretford Road, Old Trafford, Manchester.
E.M.	1920.	Hillman, C. H., 33, Prospect Hill, Leicester.
E.M.	1917.	Hilton, H. J. S., 29, West Avenue, Derby.
B.	1921.	Hinley, Geo. H., 53, Park Lane East, Tipton, Staffs.
W.R. of Y.	1928.	Hions, T. H., Raw Hill, Rastrick, Brighouse.
W.R. of Y.	1922.	Hird, W., The Corner, Harden, Bingley, Yorks.
N.	1928.	Hodges, A. E., 11, Camperdown Street, Gateshead.
W.R. of Y.	1927.	Holdsworth, H., 62, Wood Lane, Fire Lane Ends, Bradford.
E.M.	1926.	Holland, G., "Newstead," Outwood's Drive, Loughborough.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
S.	1920.	Holland, G. A., Red House, Clay Cross, near Chesterfield.
Lncs.	1922.	Holland, W., 157, Barton Road, Stretford, Manchester.
B.	1930.	Holliday, W., 26, Tame Street, Walsall.
B.	1929.	Holman, E. A., 18, Princes Street, Rugby.
E.M.	1917.	Holmes, A., 87, Albert Promenade, Loughborough.
B.	1924.	Hopkins, O. W., 72, Abbey Road, Bearwood, Birmingham.
Lncs.	1925.	Hopwood, A., Water Lane, Wilmslow, Cheshire.
E.M.	1928.	Horton, S. A., 3, Becher Street, Derby.
L.	1921.	Hotchkis, J. D., 29, Romberg Road, London, S.W.17.
Lncs.	1924.	Howard, E. J. L., 8, Queen's Terrace, Clarence Road, Longsight, Manchester.
W. & M.	1922.	Howe, C. A., G.I.P. Loco. Works, Parcl. Bombay, India.
W. & M.	1929.	Howell, W., 41, Monthemer Road, Cardiff.
L.	1927.	Howell, L. H., Vanbrugh Hill House, 1A, Vanbrugh Hill, Blackheath, London, S.E.3.
W. & M.	1930.	Howells, A. R., 24, Spencer Street, Cathays, Cardiff.
S.	1917.	Hoy, R. E., 33, Brunswick Avenue, Beverley Road, Hull.
Lncs.	1926.	Hudson, R., 39, St. Andrew Avenue, Droylesden, Lancashire.
B.	1924.	Hulse, J. C., 51, Westbourne Street, Walsall.
Lncs.	1928.	Humpage, A. J., 69, Mancot Lane, Mancot Royal, Queen's Ferry, Chester.
S.	1925.	Hunt, A., 18, Hollingwood Common, Barrow Hill, near Chesterfield.
Sc.	1926.	Hunter, J. M., 77, Prestwick Road, Ayr.
L.	1923.	Hunter, R. L., "Kirkmailing," East Cote Road, Ruislip, Middlesex.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1922.	Husselbury, E., Rosemead, Winifred Road, Bedford.
L.	1924.	Hutchings, T. C., 10, Lopen Road, Silver Street, Edmonton, London, N.18.
L.	1927.	Hyde, F. E., 22, Volta Road, Swindon.
B.	1925.	Hyde, Sidney, 25, Inhedge, Upper Gornal, near Dudley.
Lncs.	1928.	Ingham, T., 225, Manchester Road, Denton.
Lncs.	1917.	Inskip, A., 992, Ashton Old Road, Openshaw, Manchester.
Sc.	1920.	Irvine, A., The Point, King Street, Larbert, N.B.
B.	1925.	Jackson, A., c/o Consett Iron Co., Ltd., 3, New Street, Birmingham.
Lncs.	1925.	Jackson, A., 27, Marlboro' Street, Accrington.
W.R. of Y.	1928.	Jackson, C. E., 5, Chaucer Street, Hull Road, York.
Lncs.	1923.	Jacques, T., The Cottage, Hill Top, Romiley, near Stockport.
B.	1914.	James, W., 96, Grove Lane, Handsworth, Birmingham.
L.	1925.	Jarvis, B., 30, Princes Street, Dunstable, Beds.
N.	1919.	Jay, H. C., 32, Bayswater Road, West Jesmond, Newcastle-upon-Tyne.
Sc.	1927.	Jeffrey, R. S. M., Lithgow Avenue, Kirkintilloch.
B.	1929.	Jenkins, E. J. E., 101, Roma Road, Tyseley, Birmingham.
S.	1929.	Jervis, T. A., East Drayton, Retford, Notts.
B.	1919.	Johnson, J. B., 27, Ball Fields, Tipton.
M.	1926.	Johnson, L., 45, Lanehouse Road, Thornaby-on-Tees.
B.	1924.	Johnston, W. L., 49, Gough Road, Coseley, near Bilston, Staffs.
Lncs.	1930.	Jones, G. H., 33, Oswald Street, North Reddish, Stockport.
Lncs.	1916.	Jones, J. H., "Elleray," Temple Drive, Swinton, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W. & M.	1929.	Jones, W. R. D., 2, Sandringham Road, Penylon, Cardiff.
Lncs.	1928.	Jones, W., 112, St. Mark's Road, Saltney, Chester.
W. & M.	1930.	Jones, W., 86, Olive Street, Grangetown, Cardiff.
Lncs.	1919.	Jowett, H., 9, Dacre Street, Morpeth.
Lncs.	1922.	Kay, Wm., 9, Eastbank Street, Bolton, Lancs.
Sc.	1930.	Keith, J. G., 7, Wellside Terrace, Falkirk.
Lncs.	1907.	Kemlo, R. W., "Dunottar," Campbell Road, Brooklands, Cheshire.
Sc.	1912.	Kennedy, J., "Dunard," Howieshill, Cambuslang, Scotland.
M.	1929.	Kennedy, W. D. M., 13, Bon Lea Terrace, Thornaby-on-Tees.
E.M.	1918.	Kerfoot, John, 23, Cumberland Road. Loughborough.
Sc.	1929.	Kerr, H. F., 25, Gideon Street, Bathgate.
Sc.	1914.	Kerr, W., 101, Ardgowan Street, Glasgow.
Lncs.	1925.	Kershaw, J., 5, Dalton Avenue, Thatch Leech Lane, Whitefield, Manchester.
E.M.	1927.	Kershaw, T. F., 15, Sandford Road, Syston, near Leicester.
Lncs.	1927.	Kidd, S. (Junior), 4, St. Stephen's Street, Oldham.
Sc.	1927.	Kilpatrick, A., 69, Foundry Street, Carron Road, Falkirk.
N.	1925.	Kirby, A. D., 6, Falshaw Street, Washington Station, Co. Durham.
W.R. of Y.	1922.	Kirkbride, A. D., 24, Springswood Avenue, Shipley, Bradford, Yorks.
Lncs.	1924.	Kirkham. J., 13, Gt. James Street, W. Gorton, Manchester.
Sc.	1920.	Kirkwood, J., Boyd Street, Govanhill, Glasgow.
B.	1922.	Kitchen, B., 1, Hughes Avenue, Birches Barn Road, Wolverhampton.
Lncs.	1929.	Knagg, W. D., 41, Grosvenor Place, Ashton-on-Ribble.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1927.	Knight, J., 112, Winwick Road, Warrington.
S.	1908.	Knowles, J. (c/o Walkers), Manchester Road, Stocksbridge, Sheffield.
B.	1927.	Lafford, T. W., 8, Pensnett Road. Brierley Hill.
Lncs.	1923.	Laing, J., 59, Victoria Road, Bedford.
L.	1929.	Lake, C. J., Mount Place, Braintree, Essex.
Lncs.	1927.	Lally, W., 60, Clovelly Road, Worsley Road, Swinton.
Sc.	1922.	Lang, Wm., 11, Singer Street, Radnor Park, Clydebank.
L.	1929.	Langley, T. R., 55, Grenville Road, Braintree, Essex.
S.	1928.	Law, H. O., 43, Carlisle Road, Grimsthorpe, Sheffield.
Sc.	1919.	Lawrie, R. D., 16, Mayo Road, Bankfoot, Bradford.
Lncs.	1914.	Leaf, J. W., District Bank House, Castleton, near Rochdale.
Lncs.	1929.	Leah, J. T., 13, Cheetham Street, Openshaw.
N.	1913.	Lee, J., 38, Point Pleasant Terrace, Wallsend-on-Tyne.
Gen.	1921.	Leech, Wm. Creighton (N.S.W. Gov. Railways), Wentworth and Rutledge Street, Eastwood, Sydney, N.S.W.
S.	1925.	Levesley, Wm., 32, Westbourne Road, Broomhill, Sheffield.
B.	1919.	Lewis, D. (John Harper & Company, Limited), Albion Works, Willenhall, Staffs.
B.	1925.	Lewis, E. J., 125, Church Vale, West Bromwich.
B.	1910.	Lewis, G., 37, Copthorne Road, Wolverhampton.
E.M.	1928.	Lewis, S., 917, London Road, Alvaston, Derby.
W.R. of Y.	1926.	Liddemore, A. E.
Sc.	1925.	Liddle, R., 108, King's Heath Avenue, Rutherglen, Glasgow.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1927.	Liley, M., 64, Buxton Crescent, Turf Hill Estate, Rochdale.
E.M.	1923.	Limbert, H., 15B, Factory Street, Loughborough.
E.M.	1930.	Linnett, W. Y., 36, Mansfield Street, Derby.
L.	1919.	Lisby, T., 7, Meanley Road, Manor Park, E.
Sc.	1910.	Littlejohn, A., 39, Rupert Street, Glasgow, N.W.
Lncs.	1928.	Livesey, J., 16, Finchley Street, Moston, Manchester.
N.	1928.	Livingstone, J., 40, Dunstan Road, Dunston-on-Tyne.
Lncs.	1925.	Lockett, E., 38, Jackson Street, Gorton, Manchester.
W.R. of Y.	1922.	Lowe, E., 36, Wheathead Lane, Exley Head, Keighley, Yorks.
E.M.	1927.	Lowe, H., "Rose Cottage," Queenborough, near Leicester.
Lncs.	1927.	Lowe, J., 175A, Dill Hall Lane, Church, near Accrington.
W.R. of Y.	1927.	Loxton, C. R., 26, Elmet Avenue, Roundhay, Leeds.
Sc.	1928.	Lumsden, G., 42, Gavin Street, Motherwell.
Lncs.	1910.	Lupton & Sons, H. E., Scaithcliffe Works, Accrington.
Sc.	1926.	McArthur, J. N., 12, Hamilton Drive, Hillhead, Glasgow, W.2.
Sc.	1926.	McArthur, W., 47, Stark Avenue, Camelon, Falkirk.
N.	1919.	McBride, T. B., 8, Stanwick Street, Tynemouth.
Sc.	1910.	McCall, J. J., 162, Cambridge Drive, N. Kelvinside, Glasgow.
S.	1922.	McCleallan, C. J., 110, Carver Street, Sheffield.
Sc.	1925.	McCulloch, W., Millholm, Netherlee Road, Glasgow.
M.	1927.	McCusker, C. B., 32, Lanehouse Road, Thornaby-on-Tees.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
M.	1927.	McCusker, M. S., 6, Wood Street, Stockton-on-Tees.
Lncs.	1924.	McDermott, J. P., 118, Briersill Avenue, Rochdale.
S.	1913.	Macdonald, W. A., 49, Nether Edge Road, Sheffield.
Sc.	1913.	McDonald, W. F., 5, Hutchinson Place, Cambuslang, Scotland.
Sc.	1917.	MacDougall, Miss E., 22, Clarendon Street, St. George's Cross, Glasgow.
L.	1930.	McDowall, R. A., 33, Nealden Street, London, S.W. 9.
Sc.	1911.	McEachen, J., Regent Street, Kirkintilloch, Scotland.
B.	1904.	McFarlane, T., 50, Dundonald Road, Troon, Ayrshire.
Sc.	1927.	McGhie, D. C., 10, Grantly Gardens, Shawlands, Glasgow.
Sc.	1920.	McGovan, A., 69, Battlefield Avenue, Langside, Glasgow.
Sc.	1930.	McHugh, J. B., 16, Hillfoot Street, Dennistoun, Glasgow.
Sc.	1927.	McIntyre, R., 102, Thistle Street, Camelon, Falkirk.
Sc.	1910.	Mackay, G., Bank House, Largs, Scotland.
Lncs.	1923.	McKenzie, Wm., c/o J. Hodgkinson, Ltd., Ford Lane Works, Pendleton, Manchester.
Sc.	1929.	Mackintosh, J., Union Buildings, Camelon, Falkirk, Scotland.
Sc.	1923.	McKinty, J. (Thompson & Lichtner Co.), 80, Federal Street, Boston, Mass., U.S.A.
Lncs.	1922.	Maclachlan, J. R., 7, Newall Mount, Otley, Yorks.
Sc.	1910.	McLachlan, W., 5, Dawson Terrace, Carron, Falkirk.
Sc.	1928.	McMahon, R., 10, Gilmour Street, Kilmarnock.
Sc.	1915.	McNab, J., Bells Wynd, Falkirk.
Sc.	1924.	McNab, R., 13, Walker Street, Paisley.
Sc.	1910.	McPhie, H., 40, Philip Street, Falkirk.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1927.	McVie, J., 507, Stretford Road, Old Trafford, Manchester.
Sc.	1926.	McWhirter, A., 49, Addison Drive, St. Giles, Lincoln.
B.	1908.	Mace, C., 64, Port Street, Manchester.
Gen.	1925.	Mahindra, J. C., 6 and 7, Clive Street, Calcutta, India.
N.	1928.	Mallan, R., 7, Lowthian Terrace, Washington Station, Co. Durham.
Lncs.	1921.	Mallett, E., 1152, Chorley Old Road, Bolton.
M.	1929.	Mansell, R. B., 12, Westbourne Grove, Redcar.
B.	1909.	Marks, J., Sunbury House, 40, Titford Road, Langley, Birmingham.
Lncs.	1923.	Marlow, E., Brounoak, Western Road, Urmston, near Manchester.
Sc.	1910.	Marshall, G., “Fereneze,” Russell Street, Burnbank, Lanarkshire.
L.	1922.	Marshall, H. C., 29, Westward Road, S. Chingford.
Sc.	1912.	Marshall, W. G., “Kyleakin,” Larkhall, Scotland.
Lncs.	1925.	Marsland, J., 205, Manchester Road, Droylesden, Manchester.
Lncs.	1913.	Marsland, T., 401, Manchester Road, Droylesden, Manchester.
Lncs.	1927.	Martin, W., 34, St. George's Road, Withington, Manchester.
Gen.	1924.	Mason, A., 2, Lindsey Street, Frodingham, Scunthorpe, Lincs.
B.	1922.	Masters, T. J., 12, Glover Street, West Bromwich.
L.	1928.	Mathieson, J., 2, Duke's Road, East Ham, London, E.16.
B.	1921.	Mawby, R. A., Hopstone, Cleverley, near Wolverhampton.
Lncs.	1925.	Meadowcroft, H., 14, Worcester Street. Rochdale.
Sc.	1914.	Mearns, A., Bengal Iron Co., Kulti, E.I.R., India.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1928.	Measures, J. F., 4, Paton Street, Leicester.
E.M.	1929.	Mee, E., "Sunnydale," Sunnydale Road, Carlton Hill, Nottingham.
Sc.	1924.	Meikle, A. S., 207, Kent Road, Glasgow.
L.	1928.	Melling, J., 724, Liverpool Road, Peel Green, Patricroft, Manchester.
Lncs.	1926.	Mellor, W., 166, West Street, Oldham.
Sc.	1928.	Melrose, W. J., 9, Stevenson Terrace, Bathgate.
M.	1926.	Menzies, A., 31, Cambridge Road, Thornaby-on-Tees.
Lncs.	1926.	Merigold, J. J., 67, Swans Lane, Bolton.
S.	1913.	Miller, A., 90, Bawtry Road, Tinsley, Sheffield.
Lncs.	1928.	Milner, H., 1, Abbotsford Road, Chorlton-cum-Hardy, Manchester.
Sc.	1928.	Mirrlees, R., 23, Fleming Street, Kilmarnock.
Sc.	1927.	Mitchell, W. C., 93, Glasgow Road, Paisley.
Sc.	1922.	Mitra, S. B., c/o Bengal Iron Co., Ltd., Kulti, E.I.R., India.
Lncs.	1918.	Moffat, J., 12, Dryden Street, Padiham, Lancs.
W.R. of Y.	1927.	Moffitt, R., 172, Devonshire Street, Keighley, Yorks.
Sc.	1916.	Moir, J. D., Bo'ness Iron Company, Ltd., Bo'ness, Scotland.
Sc.	1926.	Moir, T., 10, Alma Street, Falkirk, Scotland.
B.	1916.	Mole, T., 7, Delville Road, Church Hill, Wednesbury.
E.M.	1921.	Moodie, Colin, 169, Station Road, Beeston, Notts.
B.	1928.	Moore, L. G., 77, Harden Road, Leamore, Walsall.
Lncs.	1926.	Moore, R. C., 61, Fitzwarren Street, Seedley, Manchester.
B.	1916.	Moore, W. H., Devonia, Moat Road, Langley Green, Birmingham.
N.	1920.	Moorhead, H. A., 22, Moorland Crescent, Walker Estate, Newcastle.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1909.	Morehead, J. S., 98, Wilton Street, Kelvinside, Glasgow.
B.	1919.	Morewood, J. L., 23, Ravenshaw Road, Edgbaston, Birmingham.
B.	1926.	Morgan, E. S., Dalkeith, Stechford Lane, Ward End, Birmingham.
W. & M.	1929.	Morgan, G. E., 2, King's Road, E.I.R. Jamulpur, India.
B.	1930.	Morris, J. C., "The Rosary," Prestwood Road, Wednesfield.
B.	1930.	Moss, J. E., 94, Spring Hill, Birmingham.
N.	1924.	Mudie, T., 76, Paignton Avenue, Monkseaton.
Sc.	1927.	Muir, W., 23, Wallace Street, Falkirk, Scotland.
Sc.	1930.	Munro, W., 12, Montford Avenue, Kingspark, Glasgow.
N.	1913.	Murray, J., 5, Elmwood Avenue, Willington Quay-on-Tyne.
Sc.	1927.	Murray, T., 98, Dundonald Road, Kilmarnock.
S.	1914.	Naylor, A., 239, Abbeyfield Road, Pitsmoor, Sheffield.
L.	1915.	Naylor, F., 7, Hume's Avenue, Hanwell, London, W.7.
B.	1926.	Neath, F. K., 24, St. Paul's Square, Birmingham.
Lncs.	1925.	Needham, G. A., 11, Newbridge Lane, Stockport.
W.R. of Y.	1925.	Neild, G., 3, Baden Terrace, Hough End, Bramley, Leeds.
N.	1914.	Nekervis, J., 45, Lyndhurst Street, South Shields.
Gen.	1921.	Newland, J. E., 37, Provost Street, Holbeck, Leeds.
Lncs.	1912.	Nicholls, J., 146, Hulton Street, Trafford Road, Salford, Lancs.
N.	1921.	Nicholson, J. D., 13, Taylor Street, South Shields.
Sc.	1929.	Nicol, A., 57, Carronside Street, Bainsford, Falkirk, Scotland.
Lncs.	1928.	Nield, T. A., 31, Highfield Road, Levenshulme, Manchester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1924.	Noble, J., 88, Reddish Lane, Gorton, Manchester.
Lncs.	1928.	Norton, L., 65, High Street, Dean Lane, Newton Heath, Manchester.
L.	1928.	Nunns, J. R., Vickers-Armstrongs, Ltd., Erith, Kent.
S.	1921.	Offiler, G., 9, Ward Place, Highfields, Sheffield.
Lncs.	1920.	Oldham, R., 191, Dill Hall Lane, Church, Lancs.
Lncs.	1923.	Ollier, A. L., 10, Royston Road, Firswood, Chorlton-cum-Hardy, Manchester.
N.	1910.	Olsen, W., Cogan Street, Hull.
Sc.	1920.	Orman, Wm., 55, Sunnyside Street, Camelon, Falkirk.
E.M.	1927.	Orme, R. F., "Hallworth," Hinchley Road, Forest East, Leicester.
E.M.	1928.	Oswin, H. A., 37, The Banks, Sileby, near Leicester.
B.	1922.	Owen, A. C., 9, Sunnyside Road, Ketley Bank, Oakengates, Salop.
Lncs.	1924.	Owen, W., 33, Granville Road, Gorton, Manchester.
S.	1914.	Oxley, C., 101, Montgomery Road, Sheffield.
B.	1924.	Palmer, A., 14, Marsh Hill, Stockland Green, Birmingham.
Sc.	1928.	Parker, A. P., Williamlea, Morningside, Newmains.
B.	1920.	Parkes, I., 157, Whitehall Road, Greets Green, West Bromwich.
L.	1920.	Parnell, H., "Freda Villa," 25, Queen's Road, Burnham-on-Crouch.
Lncs.	1925.	Parrington, P., 30, Vernon Street, Bury.
B.	1926.	Parsons, D. J., Chawn Hill, Stourbridge.
Sc.	1914.	Patrick, A., 65, Mungalhead Road, Falkirk.
B.	1925.	Patrick, J., 5, St. Margaret's Street, Canterbury, Victoria, Australia.
L.	1925.	Payton, T. G., 5, Victoria Street, Dunstable, Beds.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
L.	1929.	Peacock, F. C., 52, Butt Road, Colchester.
B.	1929.	Pearce, F. C., 111, Earlsdon Avenue, Coventry.
E.M.	1928.	Pearn, C. S., Warnham, Gibson's Lane, Berstall, Leicester.
N.	1925.	Pearson, C. E., 2, Pearl Street, Saltburn-by-the-Sea.
E.M.	1927.	Pedge, F., 23, Foundry Cottages, Syston, near Leicester.
E.M.	1906.	Pemberton, H., 15, Wolfa Street, Derby.
B.	1929.	Pemberton, W. G., 90, Bridge Street, Rugby.
E.M.	1929.	Perkins, F. H.
L.	1927.	Perry, A. E., 122, Tufnell Park Road, London, N.7.
Lncs.	1922.	Phillips, A., 36, Greatstone Road, Stretford, Manchester.
B.	1927.	Phillips, H., "Fairholme," Parkvale Avenue, Wednesbury, Staffs.
Sc.	1929.	Phillips, W., 10, Victoria Place, Pelmont Station, Stirlingshire.
B.	1918.	Pickin, J., Lilac Cottage, Doseley, Dawley, Salop.
L.	1920.	Pierce, G. C., 11, Athelney Street, Bellingham, S.E.6.
L.	1928.	Pierce, W. E., 51, Headcorn Road, Bromley, Kent.
S.	1928.	Pochin, G. D., 118, Hunterhouse Road, Sheffield.
S.	1926.	Pollard, C. D., 392, Firth Park Road, Sheffield.
Lncs.	1930.	Poole, S. B., Clevelands, Whitefield, Manchester.
Lncs.	1918.	Potts, W., 1, Far Lane, Hyde Road, Gorton, Manchester.
N.	1928.	Pratt, W., 23, Dene Street, Pallion, Sunderland.
Lncs.	1928.	Preston, G. W., 46, Edward Street, Higher Openshaw, Manchester.
Lncs.	1929.	Preston, W., 46, Horbury Street, Elton, Bury.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1922.	Priestley, Jos., 258, Waterloo Street, Bolton, Lancs.
Lncs.	1922.	Priestley, Thos., 185, Kay Street, Bolton, Lancs.
Sc.	1928.	Proctor, T. F., 2, Lorne Terrace, Maryhill, Glasgow, N.W.
B.	1909.	Pugh, C. B., Gorway Road, Walsall.
S.	1917.	Pugsley, T. M., "Argyle," Morley Avenue, Rosebery, Sydney, N.S.W.
E.M.	1916.	Radford, H. P., 151, Barclay Street, Leicester.
Sc.	1929.	Rae, A., 14, Burnbank Terrace, Glasgow, N.W.
Gen.	1928.	Ramaseshiah, Mysore Iron Works, Bhadravati, India.
M.	1926.	Ramsey, J. E., 95, Princes Road, Middlesbrough.
M.	1926.	Rand, T., 11, Pearl Street, Saltburn-by-the-Sea.
Sc.	1904.	Rankin, R. L. (Sharp & Company), Lennox Foundry, Alexandria, Scotland.
Gen.	1928.	Rao, J. S. Gangadhar, Mysore Iron Works, Bhadrayati, S. India.
L.	1920.	Rasbridge, W. J., 160, Evelyn Street, Deptford, S.E.
Lncs.	1910.	Rawlinson, W., "Fairhaven," Portland Road, Ellesmere Park, Eccles, Manchester.
W. & M.	1928.	Rea, H., 176, Caerleon Road, Newport.
N.	1928.	Reece, P., 120, Northbourne Street, Gateshead.
Lncs.	1927.	Reynolds, J. A., "Nirvana," Eccleston Park, near Prescot.
Lncs.	1907.	Reynolds, W., 13, Park View Terrace, Oldham.
W. & M.	1928.	Richards, T. D., 23, Keppoch Street, Cardiff.
L.	1925.	Richards, W. S., 68, Beatrice Avenue, Keyham Barton, Devonport.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Lncs.	1929.	Richardson, J., 38, Willows Lane, Accrington.
N.	1912.	Richardson, W., 204, South Frederick Street, South Shields.
L.	1924.	Richman, A. J., "Strathaven," Brooks Hall Road, Ipswich.
Lncs.	1927.	Ridyard, A., 26, Astonwood Road, Higher Tranmere, Birkenhead.
Lncs.	1911.	Riley, J., M.Sc., A.M.I.C.E., A.M.I. Mech.E., M.I. & S.I., 3, Glen Road, off Lees Road, Oldham.
Lncs.	1927.	Rishton, H. A., 78, Fern Bank, Haslingden, Rossendale.
S.	1912.	Roberts, G. E., 149, Sharrow Vale Road, Sheffield.
N.	1921.	Robertson, H., 60, Ryhope Road, Grangetown, Sunderland.
Sc.	1920.	Robinson, C. H., West Dene, Lochairnvoich Road, Kilmacolin, Scotland.
Lncs.	1920.	Robinson, F., 369, Wigan Road, Deane, Bolton.
B.	1929.	Robinson, H. W., 296, Walsall Road, Fallings Heath, Wednesbury.
B.	1925.	Robinson, J., 8, Esplanade East, Calcutta, India.
M.	1917.	Robinson, J. H., 11, Balfour Terrace, Linthorpe, Middlesbrough.
Lncs.	1928.	Robinson, S. E., 39, Hood Street, Accrington.
N.	1919.	Robson, F., 44, Stannington Place, Heaton, Newcastle-upon-Tyne.
L.	1927.	Robson, N. E., 10, Railway Street, Braintree, Essex.
S.	1913.	Rodgers, F., Brightside Foundry & Engineering Co., Ltd., Newhall Iron Works, Sheffield.
S.	1913.	Rodgers, J. R. R., 362, Firth Park Road, Sheffield.
Sc.	1924.	Rodgers, P., Jubilee Place, Bonnybridge.
B.	1917.	Roe, H. J., 29, Park Road, Moseley, Birmingham.
Gen.	1920.	Rogers, C. F., 28, Maycock Road, Coventry.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W. & M.	1928.	Rogers, D., 3, Coronation Road, Llanelly, S. Wales.
Sc.	1926.	Rolland, W., 10, Victoria Drive, Scotstoun, Glasgow.
Sc.	1922.	Ross, E. J., 12, Afton Street, Langside, Glasgow.
Lncs.	1922.	Rowe, F. W., 41, Moorside Avenue, Crosland Moor, Huddersfield.
E.M.	1924.	Rowell, E. L., 30, Russell Street, Nottingham.
W.R. of Y.	1922.	Rowntree, F., 9, St. Mary's Road, Bradford, Yorks.
S.	1927.	Roxburgh, J., 720, Abbeydale Road, Sheffield.
E.M.	1928.	Rushton, D., 93, Violet Street, Derby.
Sc.	1928.	Russell, M., 29, Laurel Street, Partick.
E.M.	1930.	Russell, W. G., 4, Clarefield Road, Leicester.
M.	1926.	Rutherford, C., "Inglefield," Eaglescliffe, near Yarm., S.O.
N.	1925.	Rutledge, W. B., 61, North View, Heaton, Newcastle-upon-Tyne.
Lncs.	1924.	Ryding, F., 52, Barnsley Street, Wigan, Lancs.
W.R. of Y.	1927.	Rymer, A. S., West Bank, Heworth, York.
L.	1930.	Salt, E., 295, Dallow Road, Luton, Beds.
L.	1923.	Sanders, H. H., 21, Etherley Road, Harringay, N.15.
E.M.	1921.	Sanders, Horace L., 61, Rowditch Avenue, Derby.
B.	1905.	Sands, J., 27, Victoria Street, West Bromwich.
M.	1926.	Sault, A., 23, Collin's Avenue, Norton-on-Tees.
L.	1928.	Saunders, R. A. D., 24, St. Paul's Road, Hemel Hempstead, Herts.
Lncs.	1928.	Schofield, H., B.Sc., 37, Birch Hall Lane, Longsight, Manchester.
S.	1927.	Scholes, A., 35, Bromwich Road, Woodseats, Sheffield.
Sc.	1928.	Scott, A., Wallace Street, Falkirk.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1923.	Scott, C., 1426, 8th Street, Apt. of Rockford, Illinois, U.S.A.
N.	1916.	Scott, G. W., 1, Northumberland Villas, Wallsend-on-Tyne.
N.	1918.	Scott, W., 7, Lynwood Avenue, Blaydon-on-Tyne.
S.	1921.	Senior, George, 305, Upperthorpe, Sheffield.
Lncs.	1925.	Service, J., 78, Highfield Road, Seedley, Manchester.
W. & M.	1929.	Seymour, L. W., Bucklebury Alley, Cold Ash, near Newbury, Berks.
W.R. of Y.	1913.	Shackleton, H. R., Upper Pear Tree Farm, Hainsworth Shay, Keighley.
Sc.	1928.	Shaw, J., 91½, Kirk Road, Wishaw.
L.	1924.	Shawyer, G. H., 81, Edward Street, Deptford, S.E.8.
L.	1926.	Shawyer, junr., G. W., 81, Edward Street, Deptford, S.E.8.
B.	1924.	Shearman, F. E., 63, Summerfield Crescent, Edgbaston, Birmingham.
Lncs.	1926.	Shepherd, F. L., 215, Tottington Road, Bury.
S.	1929.	Sheppard, H., 164, Hasland Road, Hasland.
S.	1923.	Sherratt, W., 39, Horndean Road, Pitsmoor, Sheffield.
E.M.	1925.	Sherriff, C., 9, Elms Grove, Loughborough.
B.	1925.	Shore, A. J., "Bradda," Quinton Hill, Birmingham.
B.	1920.	Shorthouse, W. H., Haybridge Iron Works, Wellington, Salop.
B.	1927.	Shwalbe, D., 62, Milverton Road, Erdington, Birmingham.
M.	1929.	Siddle, W., 11, Scarborough Street, Thornaby-on-Tees.
Lncs.	1922.	Simkiss, H., 28, Energy Street, Bradford Road, Manchester.
B.	1914.	Simpson, H., Greenhurst, Doseley, Dawley, Salop.
W.R. of Y.	1925.	Simpson, J. A., 3, Jesmond Place, Hunslet Hall Road, Leeds.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1916.	Sinclair, J., 25, Granville Street, Millfield, Sunderland.
Lncs.	1905.	Skelton, H. S., "Lindsey," Old Lane, Eccleston Park, Prescot, Lancs.
S.	1925.	Skerl, J. G. A., M.Sc., Dept. of Applied Science, St. George's Square, Sheffield.
L.	1925.	Skidmore, B., 2, Jackmans Place, Letchworth, Herts.
B.	1930.	Skinner, J. S., 54, Sheepwash Lane, Horseley Heath, Tipton, Staffs.
E.M.	1925.	Slade, R. H., 254, St. Thomas Road, Derby.
Lncs.	1929.	Slater, A., 13, Rosedale Road, Rushholme, Manchester.
S.	1929.	Slater, E. H., "The Homestead," Shatton, Bamford, near Sheffield.
L.	1911.	Slater, H. O., "Sunny Hill," Lessners Park, Belvedere, Kent.
W.R. of Y.	1928.	Slingsby, T. J. L., Highfield Villa, Keighley, Yorks.
Lncs.	1906.	Smethurst, J. H., Briery Croft, Lodge Lane, Warrington.
L.	1927.	Smith, A. C., 9, Greenway Gardens, London, N.W.3.
E.M.	1928.	Smith, A. E. W., 62, Molineux Street, Derby.
Sc.	1927.	Smith, B. D., 27, Corsewall Street, Coatbridge.
E.M.	1928.	Smith, C. H., 467, Osmaston Park Road, Derby.
Lncs.	1925.	Smith, F., 15, Milnrow Road, Rochdale.
Sc.	1921.	Smith, J., 6, Kennard Street, Falkirk.
B.	1917.	Smith, S., 114, Tetley Road, Hall Green, Birmingham.
Lncs.	1909.	Smith, S. G., 62, Sylvan Avenue, Timperley, Cheshire.
E.M.	1930.	Smith, T. 17, Hawthorn, St., Osmaston, Derby.
Lncs.	1924.	Smith, W., 358, Halifax Road, Todmorden.
Lncs.	1929.	Smith, W., 11, Springs Road, Kitt Green, near Wigan.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
E.M.	1925.	Smith, W. F., 62, Molineux Street, Derby.
B.	1928.	Smith, W. F., 148, Willow Avenue, Edgbaston, Birmingham.
E.M.	1926.	Smith, W. H., Ryton Grange Avenue, Normanton, Derby.
M.	1929.	Smithson, John K., South Avenue, Stillington, near Stockton-on-Tees.
N.	1929.	Snaith, G. T., 78, Nora Street, High Barnes, Sunderland.
Sc.	1924.	Sneddon, F. M., 28, Forest Street, Mile End, Glasgow.
S.	1924.	Somerfield, H., 146, Sandygate Road, Sheffield.
W. & M.	1928.	Southcott, S., Wood View Ynysymaerdy, Briton Ferry, S. Wales.
N.	1929.	Spedding, G. H., 3, Railway Street, Tow Law, Co. Durham.
Lncs.	1926.	Stacey, C. W., 19, Derbyshire Crescent, Stretford, Manchester.
B.	1927.	Stanton, L., 8, Low-wood Road, Erdington, Birmingham.
B.	1917.	Starr, F. G., 128, Selwyn Road, Rotton Park, Birmingham.
Lncs.	1917.	Stead, H., 1st 36, Cheetham Hill Road, Stalybridge.
S.	1914.	Steggles, A. L., 240, Bellhouse Road, Sheffield.
B.	1914.	Stephen, S. W. B., The Woodlands, Hagley Road West, Birmingham.
L.	1921.	Stevens, Wm., "Newland," Church Road, Rodbourne, Cheney, Swindon.
Sc.	1925.	Stirling, E., York Place, Kirkintilloch, Scotland.
N.	1914.	Stobbs, R., 199, Stanhope Road, South Shields.
W. & M.	1929.	Stokes, W., 18, Moira Street, Cardiff.
Lncs.	1920.	Storer, W. H., 255, Settle Street, Great Lever, Bolton.
B.	1930.	Storie, P., c/o Mr. Burns, 55, Prince Albert Street, Birmingham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1928.	Stewart, G. G., Smiths' Buildings, Bridgend, Bathgate, Scotland.
L.	1930.	Stokes, A. J., 49, Valentines Road, Ilford, Essex.
L.	1925.	Stubbs, R. G., 290, Commercial Road, Peckham, S.E.15..
L.	1922.	Summers, H. G., 35, Perry Hill, Catford, S.E.6.
E.M.	1927.	Summersgill, E. (Junior), 47, Station Road, Long Eaton, Notts.
Lncs.	1910.	Sutcliffe, A., 1, Firwood Grove, Tonge Moor, Bolton.
Lncs.	1923.	Swann, H., 31, Alexander Road, Patricroft, Manchester.
Sc.	1927.	Syme, T. R., 307, Murray Place, off Bilsland Drive, Glasgow, N.W.
Lncs.	1922.	Tate, C. M., Brook Royd, Todmorden Road, Burnley.
Gen.	1906.	Taylor, A. (Fielding & Platt, Limited), Atlas Iron Works, Gloucester.
M.	1926.	Taylor, D., 35, Langley Avenue, Thornaby-on-Tees.
B.	1925.	Taylor, E. R., 148, South Road, Handsworth, Birmingham.
W. & M.	1905.	Taylor, F. J., J.P. (Taylor & Sons, Limited), Briton Ferry, South Wales.
B.	1926.	Taylor, F., "The Willows," Gipsy Lane, Willenhall, Staffs.
E.M.	1930.	Taylor, H. 16, Drage Street, Derby.
Lncs.	1921.	Taylor, James, 3, Tremellen Street, Accrington.
W.R. of Y.	1927.	Taylor, W., 77, Dorchester Road, North Shore, Blackpool.
L.	1925.	Teasdale, I., Homeland, Norton Village, Letchworth, Herts.
N.	1921.	Temple, G. T., 35, Grosvenor Drive, Whitley Bay.
B.	1926.	Tennant, A. McA., 115, Wheelwright Road, Erdington, Birmingham.
Lncs.	1922.	Thatcher, E. H., The Newport Foundry Co., Mill Parade, Newport.
N.	1924.	Thom, J., 11, Moorland Crescent, Walker, Newcastle-upon-Tyne.

B'nch.	Year of Election.	ASSOCIATE MEMBERS
M.	1929.	Thomas, J., 15, Arch Street, Central Estate, Hartlepool.
Lncs.	1929.	Thompson, J., 4, Picking Street, Chester Road, Manchester.
L.	1926.	Thompson, J. S., "Arley," Bedonwell Hill, Abbey Wood, S.E.2.
Sc.	1925.	Thomson, D. B., 1, Knowe Terrace, Hillend Road, Lambhill, Glasgow.
S.	1921.	Thomson, T. R.
L.	1927.	Tichelly, L. J., Universal System of Machine Moulding, Ltd., 13/15, Wilson Street, London, E.C.2.
Lncs.	1911.	Timmins. A. E., 133, Roose Road, Barrow-in-Furness.
E.M.	1928.	Tompkin, A., 54, Havelock Street, Leicester.
E.M.	1927.	Tompkin, S. E., 332, East Park Road, Leicester.
Sc.	1925.	Tonagh, Chas., 254, Stevenson Street, Calton, Glasgow.
Lncs.	1914.	Topping, G., 17, Bebbington Street, Clayton, Manchester.
Sc.	1920.	Trapp, P., Kilnside Cottage, Falkirk.
E.M.	1924.	Tunnicliffe, F. J., 9, Augusta Street, Derby.
Sc.	1923.	Turnbull, Alex. W., Primrose Cottage, Bonnybridge.
Sc.	1930.	Turner, D., 20, Victoria Crescent, Clarkston, Glasgow.
Lncs.	1930.	Turner, H., 32, Wood Lane, Ashton-under-Lyne.
W.R. of Y.	1927.	Turner, L., 14, Whitwell Green, Dewsbury Road, Elland.
S.	1918.	Turner, W., 90, Edgedale Road, Sheffield.
B.	1923.	Twigger, T. R., Post Office, Bubbenhall, near Kenilworth.
Sc.	1927.	Tyrie, T., 35, Melville Street, Kilmarnock.
L.	1925.	Underwood, W. G., 5, Farlton Road, Earlsfield, S.W.18.
Sc.	1920.	Ure, R., Stenhouse House, Carron, Falkirk.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
N.	1922.	Van-der-Ben, C. R., 169, Dunsmuir Grove, Gateshead.
E.M.	1928.	Varney, F., 18, Sale Street, Derby.
E.M.	1921.	Vaughan, Benj. H., 25, Holmes Street, Derby.
B.	1917.	Vaughan, G. A., Pen Glen, Tividale Road, Burnt Tree, Tipton.
Lncs.	1921.	Vernon, G. W., 11, Ashfield Road, Burnley.
B.	1830.	Vowles, C. D., Junr., 68, All Saints Street, West Bromwich.
M.	1928.	Waddell, W. 33, Oliver Street, Linthorpe, Middlesbrough.
N.	1914.	Wainford, E. H., 17, Windsor Road, Saltburn-by-the-Sea.
Lncs.	1925.	Walker, A., 117, Robert Street, Newton Heath, Manchester.
Lncs.	1928.	Walker, A., 45, Highfield Road, Levenshulme, Manchester.
B.	1928.	Walker, A., "Coogee," Lower Hillmorton Road, Rugby.
W.R. of Y.	1921.	Walker, Alex. W., 113, Dalton Green Lane, Huddersfield.
Sc.	1920.	Walker, D., 5, New Houses, Anderson Street, Bonnybridge.
Sc.	1920.	Walker, G., 21, Napier Place, Bainsford, Falkirk.
Sc.	1920.	Walker, Wm., 10, Larbert Road, Bonnybridge, Falkirk.
W. & M.	1929.	Wall, A., 6, Denton Road, Canton, Cardiff.
B.	1916.	Wall, J., 15, Flavell Street, Woodsetton, near Dudley.
Sc.	1930.	Wallace, T., 11, Hood Street, Kilmarnock.
S.	1927.	Walmsley, T., 2, Calder Way, Firth Park, Sheffield.
Lncs.	1915.	Wallwork, R., N., Western Road, Wilmslow, Cheshire.
Lncs.	1930.	Ward, Geo., 100, Kenyon Street, Gorton Manchester.
E.M.	1924.	Ward, J. C., "Wilnorith," Collingham Road, Leicester.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
Sc.	1930.	Ward W. 233, Ledard Road, Glasgow, S.2.
E.M.	1925.	Warner, Amos, 252, St. Thomas Road, Derby.
Lncs.	1928.	Warner, H. E. 128 Rosemeath Road, Urmston near Manchester.
S.	1928.	Wass, E., 7, Oakwood Road, Balby, Doncaster.
W.R. of Y.	1926.	Wass, O. H., 244, Barnsby Road. Sheffield.
S.	1911.	Wasteney, J., Vulcan Foundry, Eckington, near Chesterfield.
Sc.	1930.	Watson, J. H., Balgrochan Terrace, Mid Street, Bathgate, Scotland.
Gen.	1914.	Watson, R., Saxilley House, 49, York Street, Rugby.
Sc.	1919.	Watt, R., Etna Iron Works, Falkirk.
L.	1927.	Watts, W., 23, Rolt Street, Deptford, London, S.E.8.
W. & M.	1928.	Wayman, M., 12, Foxcote Road, Bedminster, Bristol.
B.	1923.	Webb, A. W. J., 1, Sidney Street, Gloucester.
B.	1927.	Webb, A. E., 45, Brettell Street, Dudley, Worcester.
E.M.	1921.	Webb, Ernest Alfred, Bettwyscoed, Hinckley Road, Kirby Muxlo, near Leicester.
S.	1909.	Webster, C., 34, Milton Road, Rotherham.
Sc.	1927.	Webster, D. M., 15, Garden Terrace, Falkirk.
Sc.	1928.	Webster, J. F., 4, Carnegie Street, Arbroath, Scotland.
B.	1926.	Webster, W., 74, Horseley Road, Tipton, Staffs.
W. & M.	1928.	West, S. J., 44, Hungerford Road, Weston, Bath.
B.	1911.	Westwood, J. H., 1583, Stratford Road, Hall Green, Birmingham.
Lncs.	1925.	Wharton, L., 4, Ridehalgh Street, Colne, Lancs.

B'nch.	Year of Election	ASSOCIATE MEMBERS.
Lncs.	1928.	Whitaker, G., 3, Ruskin Street, Barden Estate, Burnley.
W.R. of Y.	1928.	Whitaker, G. H., 20, Sandy Wood Street, Keighley.
E.M.	1929.	White, S., 34, Victoria Road, Sandiacre, Notts.
Lncs.	1929.	Whitehouse, F., "Heybury," Bury Old Road, Heywood, Lancs.
G.	1926.	Whitfield, C. S., Bengal Iron Works, Kulti, E.I.R., Bengal, India.
L.	1911.	Whiting, A., Brynhella, Pembroke Road, Erith, Kent.
L.	1924.	Whiting, A. F., East View, Field Lane, Letchworth, Herts.
Lncs.	1929.	Whitton, A., 96, Monk Street, Accrington.
E.M.	1928.	Whysall, J. E., "Mayfair," Empress Avenue, Sneiton Hill, Nottingham.
E.M.	1928.	Whysall, John, 58, Greenwood Road, Nottingham.
S.	1925.	Wild, A. J., Midland Brass Foundry, Attercliffe, Sheffield.
E.M.	1926.	Wild, H., 14, Albert Promenade, Loughborough, Leicestershire.
M.	1926.	Wilkes, R., 39, Pearl Street, Haverton Hill, Middlesbrough.
M.	1910.	Wilkinson, T., Stockton Street, Middlesbrough.
S.	1919.	Williams, A., 31, Burngreave Bank, Sheffield.
L.	1927.	Williams, S. V., 22, Mayfield Avenue, Kenton, Middlesex.
Sc.	1911.	Williamson, H., 3, Nain Street, Dalmuir.
Sc.	1920.	Williamson, J., 111, Stirling Street, Denny, Stirlingshire.
L.	1920.	Willsher, W. H., "Breydon," Oakhill Gardens, Woodford Green, London, E.18.
Lncs.	1919.	Wilson, A. E., 84, Dewhurst Road, Syke, Rochdale.
L.	1925.	Wilson, A. M., Messrs. Parlanti, Beaumont Road, W. Kensington.

ASSOCIATE MEMBERS

B'nch.	Year of Election.	
L.	1927.	Wilson, C. H. V., 31, King's Avenue, Clapham Park, London, S.W.4.
Sc.	1927.	Wilson, J., 30, Polworth Gardens, Edinburgh.
Lncs.	1928.	Wilson, J. E., 15, Kaye Lane, Almondbury, Huddersfield.
Sc.	1928.	Wilson, J., 43, West Thornlie Street, Wishaw.
Sc.	1927.	Wilson, J. R., 2, Linden Place, Anniesland, Glasgow.
W.R. of Y.	1930.	Wilson, T. C., Blakeborough, Ltd., Brighouse, Yorks.
B.	1929.	Wilson, R., 6, Cobden Street, Wednesbury, Staffs.
Sc.	1928.	Wilson, W. M., 105, Arkleston Road, Paisley.
Lncs.	1904.	Wilson, W. R., 15, Sackville Street, Liverpool.
E.M.	1921.	Winfield, F., "Ambleside," Osmaston Park Road, Derby.
W.R. of Y.	1926.	Winter, N. F. S., Green Hayes, Halifax.
E.M.	1928.	Winterton, W. L., 195, Berridge Road, Nottingham.
W.R.	1924.	Wise, S. F., 110, Pullan Avenue, Eccleshill, Bradford.
Lncs.	1912.	Wolstenholme, J., 111, Carlton Terrace, Bury, and Bolton Road, Radcliffe, Manchester.
B.	1922.	Wood, A., 30, Toll End Road, Tipton, Staffs.
B.	1927.	Wood, A., Sunny Bank Hill, Crest Avenue, Brierley Hill.
S.	1926.	Wood, E. A., 30, Dixon Street, Rotherham.
W.R. of Y.	1922.	Wood, John, 6, Hudswell Street, Sandal, Wakefield.
B.	1927.	Woolen, R., 19, Gillott Road, Edgbaston, Birmingham.
M.	1926.	Woolley, R. E., 5, Albion Terrace, Saltburn-by-the-Sea.
B.	1927.	Worley, S. C., "Ashmore," 153, Bearwood Road, Smethwick, Birmingham.

B'nch.	Year of Election.	ASSOCIATE MEMBERS.
W. & M.	1926.	Wren, J., "Westholm," Edward Street, Griffithstown, Mon.
Lncs.	1925.	Wright, H. G., 78, Lloyd Street, Heaton Norris, Stockport.
W.R. of Y.	1923.	Wright, L. L., 168, Oxford Road, Gomersall, near Leeds.
B.	1927.	Wright, R. E., Oxford Lodge, Penn Fields, Wolverhampton.
Sc.	1913.	Wright, W., Burnbank Foundry, Falkirk.
Lncs.	1924.	Wylie, J. F., 206, Stockport Road, Bredbury, Stockport.
Lncs.	1925.	Yates, J., 8, Ivy Road, St. Stephen's Estate, Bury.
Lncs.	1928.	Yates, S., Bagshaw, Chapel-en-le-Frith, Derbyshire.
Lncs.	1926.	Yates, W., 38, Clifford Street, Leigh, Lancashire.
Lncs.	1924.	Yeoman, Robert, 42, Wellington Road North, Stockport.
Lncs.	1926.	Yeoman, S., 42, Wellington Road North, Stockport.
Sc.	1919.	Young, J., 9, Regent Street, Rutherglen, Glasgow.
N.	1921.	Young, James, 72, Carlisle Street, Felling-on-Tyne.
Sc.	1930.	Yuill, W., 26, Ellangowan Road, Shawlands, Glasgow.

ASSOCIATES.

B.	1929.	Acton, F., 91, Regent Road, Handsworth, Birmingham.
N.	1925.	Adams, F., 98, Avondale Road, Byker, Newcastle.
B.	1925.	Andrews, E., 56, Lansdown Road, West Didsbury.
B.	1925.	Bache, T. R., 181, Walsall Street, West Bromwich.
N.	1925.	Badsey, R. C., 5, Lovaine Terrace, North Shields.
N.	1920.	Banks, V. L., St. Cuthbert's Vicarage, Newcastle-upon-Tyne.

B'nch.	Year of Election.	ASSOCIATES.
N.	1929.	Barrett, J. H., 27, Fairless Street, South Shields.
Sc.	1927.	Bell, W. M., 2, Bellfield Street, Barrhead.
N.	1924.	Betham, W. S., 23, Eldon Street, High Shields.
S.	1929.	Biggin, C., 254, Derbyshire Lane, Woodseats, Sheffield.
B.	1930,	Bird, T. J., 52, Hillary Street, Walsall.
N.	1929.	Birks, E., 36, King Edward Street, Gateshead-on-Tyne.
N.	1925.	Blackwell, J., Harrison Road, Willington Quay-on-Tyne.
Sc.	1926.	Blackwood, W. S., 12, Napier Street, Linwood, Scotland.
B.	1922.	Boudry, C., 46, Holly Lane, Smethwick.
N.	1929.	Bowie, S., 1, North Grove, Roker.
N.	1930.	Boyle, L., "Burwood," Dene Road, Tynemouth.
B.	1914.	Boyne, W., 158, Moor End Lane, Erdington, Birmingham.
N.	1928.	Buchan, S., 100, Quadrant, Balkwell, North Shields.
N.	1928.	Buckley B. A., 3, Monk Street, Sunderland.
L.	1928.	Burgess, F. G., 13, Saxon Road, Luton, Beds.
L.	1928.	Challis, R. L., 29, Tower Hamlets Road, Forest Gate, London, E.7.
L.	1924.	Chamberlain, E. E., 70, Albert Street, Slough, Bucks.
Sc.	1926.	Clark, J., 28, King Street, Paisley.
Lncs.	1927.	Connell, C. H., 9, Muriel Street, Great Clowes Street, Lr. Broughton.
N.	1929.	Cook, W., 7, Smith Street, Tow Law, Co. Durham.
N.	1928.	Cosgrove, J., 295, Stanhope Road, South Shields.
N.	1928.	Cox, S., 78, Stanley Street, Rosehill, Willington-on-Tyne.
L.	1926.	Cummings, F. C., 3, Waller Road, New Cross, London, S.E.16.

B'nch.	Year of Election.	ASSOCIATES.
N.	1930.	Cunningham, B. W., 42, Henley Gardens, Consett, Co. Durham.
Gen.	1918.	Currie, E. M., 3, Stockton Road, Coventry.
N.	1924.	Cuthbertson, J., 81, Dunsmuir Grove, Gateshead-on-Tyne.
Lncs.	1927.	Daintith, R., 286, Rishton Lane, Gt. Lever, Bolton.
S.	1927.	Dalton, W. E., 310, Owler Lane, Sheffield.
N.	1924.	Davidson, T. H., 24, Longley Street, Newcastle.
N.	1923.	Davison, R., 79, Second Avenue, Heaton, Newcastle-upon-Tyne.
B.	1928.	Dawkins, B. J., "Rosemary," Lansdowne Avenue, Bakem, Wolverhampton.
N.	1924.	Dickinson, B., 8, Albion Terrace, South Shields.
N.	1924.	Dodd, C., 6, Relton Terrace, Monkseaton.
Sc.	1930.	Douglas, N. F., 41, Stewarton Street, Wishaw, Scotland.
L.	1928.	Doulton, M. D., Windmill House, Clapham Common, London, S.W.4.
B.	1925.	Dubberley, W., 27, Lewisham Road. Smethwick, Birmingham.
N.	1926.	Dunbar, J., 16, Burn Terrace, Willington Quay-on-Tyne.
N.	1918.	Eglen, T., 521, Chillingham Road, High Heaton, Newcastle-upon-Tyne.
N.	1918.	Elsdon, W., 7, Berwick Terrace, Percy Main.
N.	1918.	Errington, R., 12, Fern Dene Road, Gateshead.
B.	1925.	Evans, E. H., 100, Brunswick Road, Handsworth, Birmingham.
Sc.	1927.	Ewen, G., 29, Oakbank Terrace, Glasgow.
N.	1917.	Ferguson, J., "Roselea," King George Road, South Shields.
S.	1922.	Firth, Tom L., 191, Fox Street, Sheffield.
N.	1925.	Fleck, J., 75, Lamb Street, Walker-on-Tyne.

B'nch.	Year of Election.	ASSOCIATES.
N.	1913.	Ford, A., 43, Moore Street, Gateshead.
B.	1929.	Fox, A., "Beechmount," Birmingham Road, Walsall.
B.	1924.	Frost, C., 55, Waverley Road, Small Heath, Birmingham.
N.	1928.	Gibson, A. A., 131, Bewicke Road, Willington Quay-on-Tyne.
N.	1929.	Gibson, C. S., 3, Winifred Gardens, Wallsend-on-Tyne.
N.	1928.	Gibson, E., 13, Potter Street, Willington Quay-on-Tyne.
N.	1929.	Gibson, T. W., 2, Dukes Cottages, Newburn-on-Tyne.
N.	1930.	Gill, J. W., 21, N.E.R. Cottages, Washington Station, Co. Durham.
Sc.	1928.	Graham, W., 94, Waverly Drive, Wishaw.
L.	1924.	Greaves, J. H., 38, Solway Road, Wood Green, N.22.
N.	1925.	Green, S., 25, Campbell Street, Newcastle-upon-Tyne.
B.	1930.	Greenhouse, H. G., 3, Pool Cottage, Kingstanding Road, Birmingham.
N.	1925.	Grigor, R., 38, Grey Street, Wallsend-on-Tyne.
B.	1925.	Hadley, E. T., 207, Horseley Heath, Tipton, Staffs.
N.	1929.	Hall, J. W., 86, Eighth Avenue, Heaton, Newcastle-upon-Tyne.
B.	1909.	Hamilton, G., 13, Anderson Road, Tipton.
N.	1923.	Harle, J. E., 162, South Palmerston Street, South Shields.
M.	1926.	Harvey, E. J., 4, Rydal Road, Stockton-on-Tees.
Sc.	1927.	Harvie, R., 21, Campbell Street, Maryhill, Glasgow.
S.	1921.	Heeley, John Jas., 36, Gertrude Street, Owlerton, Sheffield.
N.	1930.	Henderson, E., 17, Gladstone Street, Consett, Co. Durham.
N.	1930.	Henderson, W., junr., 6, Rosewood Crescent., Walkerville.
Sc.	1920.	Hill, T., 146, Kippen Street, Airdrie

B'nch.	Year of Election.	ASSOCIATES.
Lncs.	1925.	Hindley, W., 13. Charles Street, Farnworth, near Bolton.
B.	1926.	Hird. J., "Fernside." Long Street, Dursley, Gloucestershire.
N.	1925.	Hodgkinson, H. D., 1, Rose Avenue, Whickham. Gateshead.
N.	1930.	Howe, W., 21, Tanfield Street. Sunderland.
N.	1928.	Howse. R., 1. Jersey Street, West Hartlepool.
N.	1927.	Hunter, R. W., 104. Shrewsbury Crescent. Humbledon Hill, Sunderland.
N.	1928.	Jagger. E., 28. Franklin Street, Jarrow.
Sc.	1927.	Jardine, W., 98, Bank Street. Alexandria. Dumbartonshire.
N.	1929.	Jennings, R., 13, Victoria Square, Jesmond, Newcastle-upon-Tyne.
B.	1919.	Johnson, J. B., junr., Slater Street, Great Bridge, Tipton.
W. & M.	1928.	Jones, C. E., 65, Cathedral Road, Cardiff.
N.	1925.	Jones, J., 21. Cooper Street, Sunderland Road, Gateshead-on-Tyne.
N.	1930.	Kirby, A. R. D., junr., 6, Falshaw Street, Washington Station, Co. Durham.
N.	1928.	Kirkland, J., 28. Camden Street, North Shields.
N.	1922.	Kelly, F. J., 1545, Walker Road. Newcastle-upon-Tyne.
L.	1929.	Kent, B. B., Five Pines. Longdon Wood, Keston, Kent.
S.	1928.	Kenyon, P., 72, Queen Street, New Brimington, Chesterfield.
Sc.	1928.	Laird, T., 3A, Buccleuch Terrace, Cambusnethian, Wishaw.
N.	1928.	Lamberton, J., 19, Railway Street, Jarrow-on-Tyne.
N.	1928.	Lowes, E. G., 13, Woodbine Avenue, Wallsend-on-Tyne.
N.	1924.	Lowes, W., 1. Baden Street, Chester-le-Street.
Lncs.	1914.	Lucas, G. W., 36, Langford Street, Leek, Staffs.

B'nch.	Year of Election.	ASSOCIATES.
N.	1929.	McDonald, C. R., The Villa, Willington Quay-on-Tyne.
N.	1925.	McDougal, T. D., 3, Westmoreland Street, Wallsend-on-Tyne.
N.	1929.	McErlane, H., 64, St. James' Square, Gateshead.
N.	1930.	McFarlane, G., 20, St. Mark's Road North, Sunderland.
Sc.	1924.	McGowan, V. M., Atlas Engineering Works, Bhadreswar, near Chandernagore, Bengal, E.I.R. India.
Sc.	1926.	McGurnaghan, M., 206, Gallowgate, Glasgow.
N.	1926.	McQuillan, J., 1, Lodge Terrace, Wallsend-on-Tyne.
Sc.	1927.	Main, J. W., 175, Holm Street, Glasgow, C.2.
N.	1929.	Mark, T., 46, Hedley Street, Gosforth, Newcastle-upon-Tyne.
M.	1926.	Martin, J. H., 29, Marton Grove Road, Middlesbrough.
Lncs.	1923.	Meadowcroft, H., 10, Hambledon View, Habergham, Burnley.
B.	1925.	Meredith, C., 4, Thomas Street, Smethwick, Birmingham.
N.	1929.	Miller, G. S., 5, Victoria Street, Seaham Harbour, Co. Durham.
N.	1928.	Mitchinson, T. S., Bank Top House, Walbottle, Newburn-on-Tyne.
N.	1929.	Moat, A. M., 38, Victoria Avenue, Wallsend-on-Tyne.
B.	1930.	Morris, J. T., "The Rosary," Prestwood Road, Wednesfield, Staffs.
S.	1925.	Nesbit, G. L., 7, Ruskin Avenue, Mexborough.
N.	1925.	Nesbitt, J., 26, Bede Crescent, Holy Cross Estate, Willington Quay-on-Tyne.
N.	1924.	Nichol, J., 131, George Street, Willington Quay-on-Tyne.
N.	1929.	Nixon, E., 56, Wolsley Gardens, Newcastle.
N.	1929.	Noble, E., 135, Ayton Street, Byker, Newcastle.

B'nch.	Year of Election.	ASSOCIATES.
N.	1925.	Nuttall, G., 88, High Street East, Wallsend-on-Tyne.
N.	1925.	Osborne, G. F., 39, Franklin Street, Sunderland.
S.	1929.	Oxley, T. A., Tapton Heights, Tapton Ville Road, Sheffield.
N.	1923.	Peacock, J. E., 40, Bolam Street, Newcastle-upon-Tyne.
N.	1923.	Peacock, S., 12, John Street, South Shields.
N.	1922.	Picken, A. D., 87, Cuthbert Street, Hebburn-on-Tyne.
N.	1928.	Pillow, H. C., 3, Delaval Road, Whitley Bay.
L.	1922.	Pittuck, M. D. (Miss), c/o H. J. Young, 3, Central Buildings, Westminster, S.W.1.
Lncs.	1926.	Pollard, Wm., 104, Rose Hill Road, Burnley, Lancs.
N.	1926.	Pratt, S., 29, Randolph Street, Jarrow-on-Tyne.
N.	1917.	Rang, E. J., M.Sc., 8, Bath Terrace, Tynemouth.
N.	1926.	Reay, T., 27, Percy Street, Wallsend-on-Tyne.
N.	1922.	Redpath, J., 25, Burnley Street, Blaydon-on-Tyne.
N.	1928.	Reece, T. E., 120, Northbourne Street, Gateshead.
Sc.	1927.	Reid, A., 12, Anderson Street, Burnbank, Hamilton.
Sc.	1923.	Reid, J. N. (junr.). Burnhead Road, Larbert.
S.	1929.	Rhodes, W., 80, Skinnerthorpe Road, Firvale, Sheffield.
Sc.	1923.	Riddell, J., 113, Coventry Drive, Glasgow.
N.	1924.	Robson, J., 15, Hawthorne Grove, Wallsend-on-Tyne.
N.	1925.	Robson, J., 20, Frederick Street, Gateshead-on-Tyne.
N.	1928.	Robson, R. W., 6, Nelson Street, Gateshead-on-Tyne.

B'nch.	Year of Election.	ASSOCIATES.
N.	1923.	Rollin, C. N., Stanhope House, Westoe Village, South Shields.
Sc.	1927.	Rose, D., 12, Victoria Street, Alexandria, Dumbartonshire.
Sc.	1927.	Ross, W. junr., 2, Macdonald Street, Rutherglen, Glasgow.
N.	1926.	Rowley, J. S., 51, South Terrace, Wallsend-on-Tyne.
N.	1925.	Ruff, J., 88, Richardson Street, Wallsend-on-Tyne.
M.	1926.	Saunders, A., 34, Queen's Street, North Ormesby, Middlesbrough.
N.	1925.	Scott, R. J., 32, North Terrace, Wallsend.
L.	1926.	Sherman, W. T., "Woodlands," Avery Hill Road, New Eltham.
N.	1929.	Slassor, J. B., 243, Sunderland Road, Gateshead.
N.	1930.	Smith, M., 137, Chirton West View, North Shields.
B.	1925.	Smith, W. H., 21, Horseley Road, Tipton, Staffs.
N.	1925.	Soulsby, W. A., 14, Armstrong Terrace, Gosforth.
S.	1929.	South, G. E., 13, Struan Road, Carterknowle, Sheffield.
N.	1912.	Spence, W. D., 124, Heaton Park Road, Newcastle-upon-Tyne.
N.	1922.	Spencer, F. C., 20, Leazes Terrace, Newcastle-upon-Tyne.
B.	1910.	Spiers, F., 4, Angel Street, Worcester.
N.	1925.	Spowart, D., 31, Houghton Avenue, Cullercoats.
N.	1926.	Stafford, J., 143, Harriet Street, Byker, Newcastle-upon-Tyne.
Lncs.	1927.	Stanworth, S., The Woodlands, Rimington, Clitheroe.
N.	1928.	Steele, D., 4, Boundary Street, Willington Quay-on-Tyne.
N.	1924.	Stoddart, J., 7, Ferndale Avenue, Wallsend-on-Tyne.
N.	1925.	Strong, Leslie, 59, Marine Avenue, Monkseaton, Northumberland.
E.M.	1915.	Styles, W. T., 52, Roe Street, Derby

B'nch.	Year of Election.	ASSOCIATES.
B.	1910.	Sutton, W. H., 147, Anthony Road Saltley, Birmingham.
Lncs.	1926.	Tate, W. G., Brook Royd, Todmorden Road, Burnley.
N.	1926.	Thompson, J. T., 42, Monk Street, Gateshead-on-Tyne.
N.	1929.	Townsend, W., 24, Victoria Avenue, Sunderland.
B.	1930.	Trayherne, T. W., 23, Sycamore Road, Aston, Birmingham.
Sc.	1924.	Turnbull, J., Primrose Cottage, Bonnybridge.
M.	1926.	Vause, W., 33, Hannah Street, Thornaby-on-Tees.
L.	1927.	Ward, E., 56, Park Street, Stoke Newington, London, N.16.
L.	1911.	Wells, G. E., 89, Larcom Street, Walworth, S.E.
B.	1926.	Whitehouse, T., 4, Carlton Road, Smethwick, Staffs.
N.	1927.	Wood, N., 100, Rodsey Avenue, Gateshead-on-Tyne.
B.	1928.	Woodall, F., 43, Beach Road, Sparkhill, Birmingham.
Sc.	1927.	Wright, J., 198, James Road, Townhead, Glasgow.
Sc.	1928.	Wright, S., "Fernlea," Portland Park, Hamilton.
Sc.	1926.	Young, H., c/o G. Hudson, Wesley Place, North Arlington, New Jersey, U.S.A.
Sc.	1930.	Young, J. P., 40, Well Street, Paisley.

Members changing their addresses are requested to notify the General Secretary or the Branch Secretary IMMEDIATELY.

Members should notify the General Secretary or the Branch Secretary of any errors in the Membership List.

NAME INDEX.

SUBJECT INDEX.